A pro-poor approach to upgrade agri-food value chains in Tanintharyi region of Myanmar

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Following decades of isolation, Myanmar's continuing transition to democracy, peace-building, and economic liberalisation has resulted in sustained economic growth and subsequent reductions in poverty. Although Myanmar's economy is underpinned by its agricultural sector, agricultural productivity and profitability are among the lowest in Asia, leading to higher rates of poverty in rural areas. With almost 70% of Myanmar's population engaged in agriculture, small-scale farms are critical leverage points for improving the livelihoods of farm and non-farm households.

In 2017, the New Zealand government approved a five-year project to upgrade agri-food value chains to strengthen rural livelihoods in the Tanintharyi Region of Myanmar. Embedded within this livelihoods project, this research incorporated action research methods to select upgrading interventions that target small-scale farmers in the pork value chain. Small-scale farmers in the project's target villages face multiple production, processing, and marketing constraints and system shocks that result in poor quality products that are not viable for higher value markets. Traditional pro-poor upgrading approaches primarily rely on qualitative and descriptive data collected through a one-time "snapshot" of the value chain. However, the search for interventions to upgrade smallholder agri-food value chains needs tools that consider the dynamic and complex nature of the chain while allowing for trade-off analysis to strengthen pro-poor decision-making.

This research used participatory spatial group model building tools to engage a diverse group of stakeholders to identify and describe the dynamic processes in the pork value chain system. A quantitative system dynamics model of the pork value chain was constructed to account for critical feedback loops, structures, and relationships in the system. The model integrated modules of animal production, marketing, investment, finance, knowledge, credit, and collective action. The latter two modules represent new innovations in agri-food systems modeling. Once validated, the model was used to conduct a comprehensive *ex-ante* impact evaluation of potential pro-poor upgrading interventions, including trade-off analysis across diverse performance indicators, value chain actors, and temporal horizons.

Results showed that technical upgrading activities implemented along with novel producer group arrangements brought sustained financial benefits to target communities and outperformed the short-term gains generated by these activities in the absence of collective action. A distinct rank order of individual technical interventions emerged: (1) establishing animal health workers, (2) microcredit, (3) technical training, and (4) artificial insemination. The model showed that a well-sequenced, multipronged approach with these technical activities enabled a larger number of poor households to benefit from pig livelihoods while also reducing risks from environmental and economic shocks. The model's results determined the upgrading strategy of the project: establishing producer groups whose members are empowered to produce hybrid pig breeds for the burgeoning domestic premium pork market. The institutional arrangements underpinning the producer groups must be investor-friendly to encourage investment in value-adding assets and continued patronage by members.

The study demonstrated how a systems dynamics model can engage the complexity within agri-food value chains using spatial group model building tools to identify critical problems and relationships in the system. Moreover, it demonstrated the merit of integrating such models into rural development projects that require *ex-ante* information about value chain interventions that best sustain growth in smallholder incomes.

Keywords: agricultural value chains, inclusive, pro-poor, Myanmar, system dynamics, spatial group model building, poverty alleviation

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List of Acronyms

A1 - Activity one: US$150,000 in microcredit is made available to pig producers

A2 - Activity two: Technical training is provided to pig producers

A3 - Activity three: Animal health workers trained and equipped

A4 - Activity four: Artificial insemination unit established for hybrid sows

A5 - Activity five: Combination of activities one, two, three, and four

AHW - Animal Health Worker

ASEAN - Association of Southeast Asian Nations

ASF - African Swine Fever

CLD - Casual Loop Diagram

FAO - Food and Agricultural Organisation of the United Nations

FF - Farrow-to-Fatten

FGD - Focus Group Discussion

GAHP - Good Animal Husbandry Practices

GIS - Geographical Information Systems

GMB - Group Model Building

GVC - Global Value Chain

ILRI - International Livestock Research Institute

INGO - International Non-Governmental Organisation

KII - Key Informant Interviews

LBVD - Livestock Breeding and Veterinary Department

MADB - Myanmar Agricultural Development Bank

MBT - Model Building Team

MoALI - Ministry of Agriculture, Livestock, and Irrigation

MFAT - Ministry of Foreign Affairs and Trade

MIMU - Myanmar Information Management Unit

MMK - Myanmar Kyats

WV - World Vision

PAC - Project Advisory Committee

PG - Producer Group

PO - Producer Organisation

TRRILD - Tanintharyi Region Rural Income and Livelihood Development

UNDP - United Nations Development Programme

RG - Reference Group

SD - System Dynamics

S1 - Scenario One: Project interventions are implemented across all pig producers

S2 - Scenario Two: Project establishes 32 producer groups with 20 members

S3 - Scenario Three: Project encourages producer groups to graduate to producer organisations after three years

SA - Sensitivity Analysis

SGMB - Spatial Group Model Building

US$ - United States Dollar

VC - Value Chain

WF - Wean-to-Fatten

Chapter 1
Introduction

Chapter one provides context to this thesis by outlining the challenges facing small-scale farmers in Myanmar and the development project and theoretical frameworks that inform this research. It then identifies the research problem and objectives, concluding with an outline of the relevance of the research and the structure of the thesis.

1.1 Background

A country of rich political and cultural history, Myanmar is attempting a triple transition: nation building, from 60 years of civil conflict to sustainable peace; state building, from an authoritarian military system to democratic governance;[1] and economic liberalisation, from a closed centrally-planned economy to an open, integrated, and transparent market-based economic system (United Nations Development Programme [UNDP], 2016). Since the installation of a quasi-civilian government signalled the start of this transition in 2011, Myanmar's economy has made rapid progress. The country's GDP has more than doubled since 2008 and economic growth rates remain strong, reaching over 6% per year from 2017 to 2019 (Asian Development Bank [ADB], 2021). Myanmar's poverty rate also declined by one-third over the last decade (World Bank, 2017). While headlining as one of the fastest growing economies in the Association of Southeast Asian Nations (ASEAN), Myanmar, remains one of the poorest nations in the region (World Bank, 2014). Myanmar's poverty rate is 32.1% and a further one-third of the population falls within 50% of the poverty line (World Bank, 2017). Poverty is much higher in Myanmar's farms and rural villages, sitting at 38.8% (13.8 million poor), compared with 14.5% in towns and cities (1.7 million poor) (World Bank, 2017). With almost 70% of Myanmar households (HHs) engaged in agriculture, poverty is strongly associated with small-scale farming and correlated with low agricultural incomes and lack of access to productive assets (Boughton et al., 2018; World Bank, 2017).

Taking advantage of Myanmar's highly favourable climatic conditions for diverse agricultural production, approximately two-thirds of the population engage in agriculture, forestry, and fisheries for their livelihoods (Ministry of Agriculture, Livestock, and Irrigation [MoALI], 2018; Zorya, 2016). As a result, the agricultural sector underpins Myanmar's economy, accounting for nearly 30% of GDP, 25% of export earnings, and 56% of employment, as well as ensuring food security for the rural poor

[1] The work contained in this thesis was completed prior to the military coup that took place in Myanmar on February 1, 2021 and, therefore, does not take into consideration the changes in circumstances that resulted.

(MoALI, 2018). While there is rich agricultural potential in Myanmar (Raitzer et al., 2015), agricultural productivity across all sectors and performance measurements is among the lowest in Asia (World Bank, 2016). Low agricultural productivity and profitability are caused by multiple factors including insecure land tenure; lack of access to quality seeds, fertiliser, and pesticides; low technology usage; poor access to technical extension services; and limited access to affordable credit (MoALI, 2018; World Bank, 2018). Commercialisation in the agricultural sector is further inhibited by limited knowledge and skills in value addition that meets market demand, crude post-harvest processing and storage facilities, and poor access to modern value-adding equipment (MoALI, 2018; World Bank, 2016). The government has historically underinvested in the sector, leading to weak rural and export infrastructure, and poor-quality research and extension services (MoALI, 2018). As a result, small-scale farms are labour intensive, largely devoid of productive assets, and struggle to profitably engage with quality differentiated local, domestic, and international agri-food value chains (VCs) (HARP-F & MIMU [Myanmar Information Management Unit], 2018; World Bank, 2016).

Given that 87% of Myanmar's poor live in rural areas, small-scale farms are critical development leverage points as they are a highly important source of rural incomes for both farm and non-farm households (Boughton et al., 2018). Empirical studies have shown that a rise in agricultural productivity and commercialisation in developing economies leads to investments and growth in non-agricultural sectors and off-farm employment, which in turn diversifies and grows the entire economy (International Fund for Agricultural Development [IFAD], 2016; Southgate et al., 2011). Recognizing the vital importance of upgrading small-scale farmers, the Government of Myanmar's Agriculture Development Strategy 2018-2023 has prioritized "linking associated smallholder farmers to agri-food enterprises within organized value chains" (MoALI, 2018, p.12). Donor agencies in Myanmar have also focused their efforts on supporting small-scale farmers to "step-up" into commercially successful enterprises (Livelihoods and Food Security Fund [LIFT], 2014).

In 2017, the New Zealand Ministry of Foreign Affairs and Trade (MFAT) approved a five-year project to upgrade agri-food VCs to strengthen rural livelihoods in the Tanintharyi Region of Myanmar. The project is implemented through a quadripartite partnership: World Vision (WV), an international non-government organisation (INGO), to implement in-country; VisionFund, a microfinance institution (MFI), to provide financial services; and Lincoln University (LU) and the International Livestock Research Institute (ILRI) to provide research-informed technical assistance. The Tanintharyi Region Rural Income and Livelihood Development (TRRILD) project has three key outputs: (i) Producer groups and organisations are established and equipped to engage in markets; (ii) Producers are introduced to economic and market engagement opportunities through selected VCs; and (iii) Producer groups, organisations, and households are provided access to pro-poor financial services. This PhD research was embedded within Output Two of the TRRILD project in that it employed action-research methods to guide the selection of pro-poor upgrading interventions for targeted agri-food VCs. Another LU PhD student focused on Output One of the TRRILD project, prescribing and implementing novel institutional and governance mechanisms to establish functional producer groups (PGs) and producer organisations (POs) to undertake the transactional and value adding interventions within the selected agri-food VCs. These two pieces of PhD research were designed to be complementary: PGs and POs were to be established in a manner that best enables small-scale farmers to capture value-added in the upgraded chains.

The scope of this research was determined by the TRRILD project's focus on agri-food VCs in Myeik and Palaw Townships of Myanmar's Tanintharyi Region. Tanintharyi is the southern-most region in Myanmar, bordering Thailand to the east and south, and the Andaman sea to the west (Figure 1). Located in the coastal agro-zone, the region's poverty headcount (43.9%) is well above the national average (World Bank, 2017). A participatory VC assessment was undertaken by the TRRILD project from March to October 2018, selecting pork and rice as target VCs for the project. While this PhD research guided the selection of the TRRILD project's pro-poor upgrading interventions for both the pork and rice VCs, this thesis focuses primarily on the pork VC. The research targeted small-scale pig producers from 32 rural villages (home to around 9,000 households [HHs]) in Myeik and Palaw along with associated VC actors (Figure 2). Research relating to the rice VC is drawn upon in the thesis to support findings and insights regarding the methodology used to select pro-poor upgrading interventions.

Figure 1: Map of Myanmar
Source: MIMU (2018)

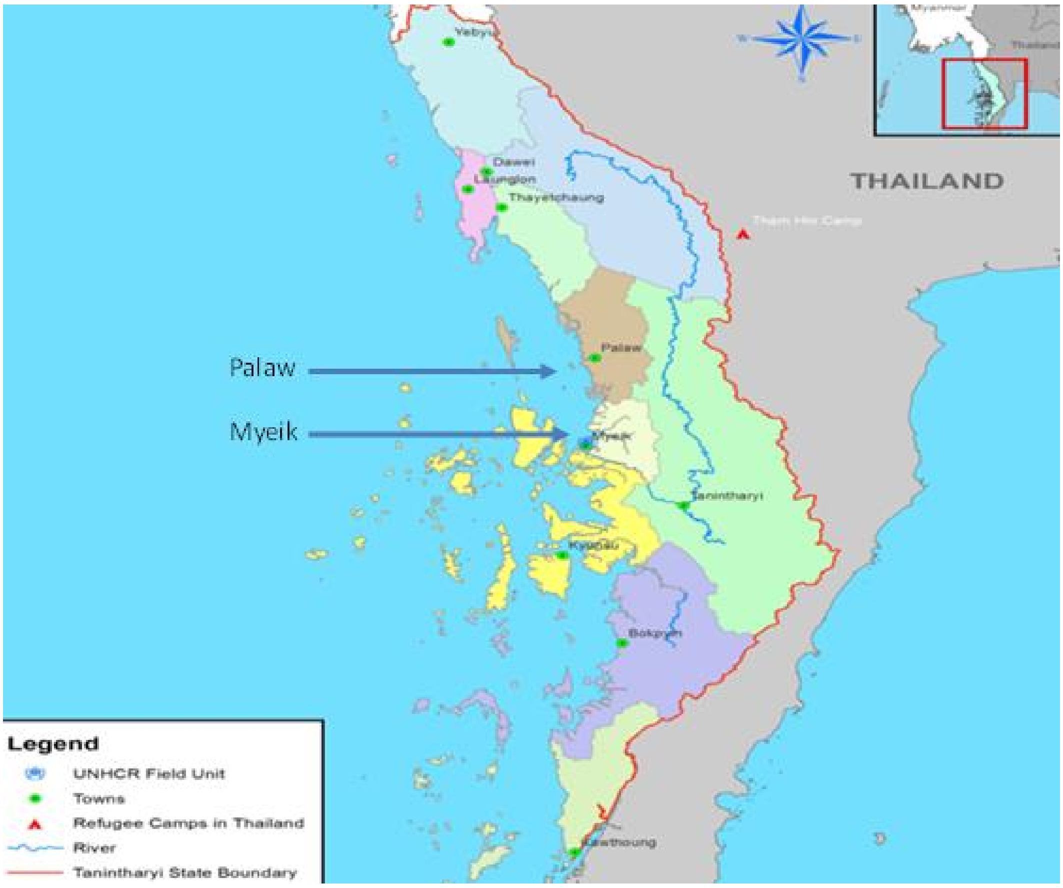

Figure 2: Map of the TRRILD project's target townships in Myanmar's Tanintharyi region
Source: United Nations High Commissioner for Refugees (2014)

The TRRILD project's baseline survey (Lyne & Snoxell, 2018) reveals critical insights into the livelihoods of small-scale farmers in the target location with selected results presented in Table 1. Though livelihoods are diversified, small-scale farming was the primary livelihood strategy for targeted rural HHs. More than half of rural HHs earned most of their cash incomes from small-scale farming. Moreover, for non-farm HHs, one-half of their business enterprises involve processing and trading locally produced food, while 22% depended on small-scale farms for daily wages. The survey also indicates high-levels of poverty in the target villages. On average, HHs were earning less than a dollar a day per person and over 40% of HHs experienced food shortages during the year, with non-farm HHs faring worse than farm HHs.

The research applies a VC framework to strengthen the livelihoods of targeted small-scale farmers in the TRRILD project. A VC describes the full range of activities that bring a product or service through the different nodes of production to delivery to final consumers (Kaplinsky & Morris, 2000). In agri-food terms, the VC covers the journey of a product from "farm to fork". VC approaches were originally developed to determine a firm's competitive advantage (Porter, 1985) and then later applied to understand the uneven economic benefits accruing to developing economies as they integrated into global production networks (Gereffi, 1994). A key theme that emerged was the role of "lead" firms that dictated where value is added among the chain actors (Gereffi et al., 2005). This led to an emphasis on the governance of VCs, driven by transaction costs, in determining how producers in developing economies could capture added value and the resultant economic benefits (Humphrey & Schmitz, 2002). This research applies these VC concepts of nodal segments, governance, transaction costs, and added value to analyse the pork VC in the target region.

Table 1: Results from TRRILD project baseline survey

Characteristics	*All rural HHs*	*Non-farm HHs*	*Farm HHs*
Female-headed HHs (%)	32	33	32
HHs in minority ethnic groups (%)	26	11	39
HH size	5.20	5.23	5.18
HHs earning income from farming activities (%)	54	2	96
HHs earning income from wage work on farms (%)	18	22	15
HHs earning income from non-farm wage work (%)	50	67	36
HHs earning income from own business enterprises (%)	24	30	16
HHs earning income from processing or trading locally produced food (%)	19	15	23
HH income in 2017, excluding petty wages (US$)	1,310	900	1,654

Source: Lyne & Snoxell (2018)

The research adopts a pro-poor approach to upgrade the pork VC in Myeik and Palaw. A pro-poor orientation aims to counteract the exclusion of small-scale farmers from value adding chains and persistent poverty in farm and non-farm HHs (Seville et al., 2011). This approach extends the scope of VC analysis by paying specific attention to the constraints that small-scale farmers face in accessing markets, in deficiencies in their resources, physical infrastructure, and operating environment, and in the institutional voids that characterise many developing economies (Trienekens, 2011). Additionally, a pro-poor approach analyses the distribution of benefits among VC actors to prioritize upgrading activities that increase the share of value added (and income) captured by small-scale farmers (M4P, 2008). A pro-poor approach evaluates these upgrading activities through a wider lens than solely economic impacts. This includes considering poverty, gender, risks, labour, and environmental factors, not only for small-scale farmers but also for non-farm households (Bolwig et al., 2010). A pro-poor approach seeks pragmatic, “win-win” solutions by identifying partnerships that consider the asset and risk profiles of small-scale farmers, power and information asymmetries, and the socio-political climate (Bolwig et al., 2010). Proponents of the pro-poor approach advocate for action-research methodologies, including *ex-ante* impact evaluations to select appropriate pro-poor upgrading strategies, that are then adjusted iteratively based on the monitoring of results (Riisgard, et al., 2010).

1.2 Research problem

Small-scale farmers in Myeik and Palaw face significant constraints to entering into and adding value within agri-food VCs. The TRRILD project baseline survey reveals small-scale farmers have severe restrictions to accessing affordable credit (Lyne & Snoxell, 2018). Combined with irregular cash flows, this creates liquidity problems, meaning farmers are unable to invest in productive assets and apply quality inputs to improve farm productivity. Furthermore, inadequate extension services and traditional farm practices result in poor quality agri-food products which are not viable for higher value markets. These low-quality agri-food products are typically sold at the farm gate or in the nearby village to buyers and traders at cash-market prices. While a common set of farm enterprises (betel nut, paddy, pigs, cashew, and rubber) are practised across the target villages, there is scarce evidence of collective action among farmers. The constraints present in Myeik and Palaw, echo conditions small-scale farmers face across Myanmar and other developing economies and lend themselves to a pro-poor VC approach (Trienekens, 2011). Arising from these constraints is the research's central problem: how can small-scale farmers and surrounding communities in Myeik and Palaw substantively engage in, and meaningfully benefit from, value-adding agri-food value chains?

To address the central research problem and achieve Output Two of the TRRILD project, a methodology is required that accommodates both the dynamic and complex nature of agri-food VCs and the need to understand the socio-economic impacts of upgrading strategies. Agri-food VCs, particularly livestock ones, are characterised by biophysical delays, cyclical behaviours, and dynamic interactions between nodes in the VC (Rich et al., 2011). Traditional pro-poor VC methodologies primarily rely on qualitative and descriptive data, are often collected through a one-time "snapshot" of the VC and tend to cluster information at the macro- or meso-level (Rich et al., 2011). These approaches are therefore limited in their ability to quantify, *ex-ante*, the impacts of upgrading strategies as they do take into consideration the dynamic nature of the VC and the complexity of the connections and interdependencies in the VC system (Rich et al. 2011). Traditional approaches also struggle to consider the wider consequences and trade-offs (intended or unintended) of upgrading activities within or beyond the immediate VC system. This includes understanding how the impacts of upgrading interventions are experienced differently by the full range of small-scale farmers, non-farm households, and other VC actors, along with bringing to light environmental, gender, and social concerns (Stoian et al., 2011). Action research has been suggested as an appropriate methodology for pro-poor VC interventions (Riisgard et al., 2010). Within a research-informed development intervention, tools are required that not only accommodate the dynamic nature of VCs and include trade-off analysis based on the project's finite time, resource, and financial constraints, but also allow for wider stakeholder participation that builds ownership of the project's activities and encourages partnerships. Linked to the central research problem is therefore a second question of process: what tools appropriately support the selection and implementation of upgrading strategies within a pro-poor agri-food VC project?

1.3 Research objectives

The research's primary purpose is to identify and describe interventions to upgrade pro-poor, agri-food VCs in the Tanintharyi Region of Myanmar. Operating in an action research paradigm, the second and related purpose of the research is to recommend pro-poor upgrading interventions for implementation within the TRRILD project.

These dual purposes are accomplished through the following key objectives:

i. Identify and describe the dynamic processes and relationships within selected agri-food value chains in Myanmar's Tanintharyi region.

ii. Analyse the *ex-ante* impacts of pro-poor interventions to upgrade selected agri-food value chains in Myanmar's Tanintharyi region.

iii. Describe the pro-poor upgrading interventions recommended for the TRRILD project, highlighting initial implementation efforts and short-term outcomes.

The thesis focuses on the pork VC in Myeik and Palaw as the principal case study to address these three research objectives. Systems thinking and system dynamics (SD) tools are utilised as the primary analytical framework to achieve Objectives One, Two, and Three. SD principles and tools are uniquely placed to capture the dynamic and complex nature of agri-food VCs, and encourage system learning that leads to behaviour change among VC stakeholders (Rich et al., 2011; Stroh, 2015). The research uses spatial group model building (SGMB) tools to develop richer, spatially contextualised qualitative and quantitative SD models of the pork VC in Myeik and Palaw using SD language to describe the dynamic elements and sub-modules of the pig VC, highlighting key feedback loops, delays, stocks, and parameters (Objective One). The quantitative SD VC model is used to conduct an *ex-ante* impact evaluation of potential pro-poor upgrading interventions, with these interventions determined by stakeholders within the SGMB process and TRRILD project (Objective Two). The *ex-ante* scenario testing quantifies the impacts and costs of upgrading strategies across VC actors, with a focus on small-scale pig producers (Objective Two). The results of scenario testing are then analysed to select a concentrated number of upgrading interventions that have multiplier effects across the chain and are appropriate for the TRRILD project's timeframe, resource limitations, and operating environment (Objectives Two and Three). Findings from the SD VC models also contribute to the TRRILD project's first output as they help identify PGs and the institutional arrangements needed to graduate them to POs that can invest in value-adding assets and joint ventures with strategic partners.

The choice of SGMB tools to select and support the implementation of upgrading strategies within a pro-poor agri-food VC project addresses the second research problem and forms the fourth research objective:

iv. Explore the effectiveness of SGMB tools to engage stakeholders in agri-food value chain analysis and upgrading.

This thesis achieves this final objective by outlining factors that influenced the effectiveness of SGMB tools for engaging TRRILD stakeholders in VC analysis, along with highlighting critical lessons learned. The study also investigates how SGMB participant understandings of the target VCs evolved through the SGMB process. While Objectives One, Two, and Three focus only on the pork VC, Objective Four draws on material from SGMB process undertaken to upgrade both the pork and rice VCs in the TRRILD project.

1.4 Relevance of the research

Primarily, the study provides technical contributions to determine the pro-poor upgrading strategies for implementation within the MFAT-funded TRRILD project. Secondarily, the research contributes an agri-food case study in rural Myanmar to the wider field of pro-poor VC literature. This case study demonstrates the applicability of SGMB tools and quantitative SD models to determine high-impact pro-poor VC upgrading strategies. While quantitative SD models have been previously developed to analyse agri-food VCs, this research contributes a first-time application of a SGMB process to the wider participatory GMB literature. Past examples of SD models of agri-food VCs did not move beyond theoretical policy recommendations. However, this research is embedded in a development initiative and documents the selection of pro-poor upgrading interventions based on the model's findings and the project's operational boundaries. This thesis therefore demonstrates an innovative methodology for agri-food VC projects: the use of participatory SD tools to identify, *ex-ante*, high-impact pro-poor interventions that guide project implementation. Arising from the application of SD tools in this case study are two new VC modules (credit and collective action) that can be applied to future agri-food system models. Further extending the knowledge base, the model's recommendations and the initial results of selected upgrading strategies are explored in this thesis to generate conclusions applicable to VC interventions in Myanmar and other developing economies.

1.5 Structure of the thesis

Chapter 1 introduced the research, covering small-scale farming in Myanmar, the TRRILD project, and the relevant literature that informs the research's problems, overall purpose, and specific objectives. Chapter 2 begins with a review of small-scale farming's role in development and VC theories. It then traces the characteristics of modern agri-food VCs, considers the problems they create for small-scale farmers in developing economies, outlines the pro-poor VC approach, and summarises common pro-poor upgrading entry points, including those uniquely emphasised within the TRRILD project. Chapter 2 ends with a review of system dynamics and its recent application to pro-poor agri-food VCs. Chapter 3 explains the research methodology, building on action research and case study principles and tools. Included in Chapter 3 is an overview of two agri-food SD modules, created as part of this research for contextualisation to the pig VC SD model. Chapter 4 presents a description of the pork VC model, followed by an analysis of the results of the *ex-ante* scenario testing of pro-poor upgrading interventions in Chapter 5. In Chapter 6 the pro-poor upgrading recommendations provided to the TRRILD project are discussed along with the effectiveness of SGMB tools and subsequent learning. The thesis concludes with Chapter 7 which summarises the research's key findings, theoretical and policy contributions, and challenges as well as offering recommendations for future research.

Chapter 2

Literature review

This chapter provides an overview of VC literature, drawing attention to VC theories relevant to small-scale farmers in developing economies. It highlights the characteristics of modern agri-food VCs, considers the barriers they create for small-scale farmers, and outlines the pro-poor VC approach, including the TRRILD project's pro-poor upgrading strategy. The chapter ends with a review of system dynamics and its recent application to agri-food VCs.

2.1 The role of small-scale farms in poverty reduction

On a global-scale, poverty rates are declining. However, over 750 million people still live in extreme poverty, of which two-thirds live in rural areas (Food and Agricultural Organisation of the United Nations [FAO], 2017). Small-scale farms dominate rural livelihoods, generating 80% of the world's food in Africa and Asia and supporting the livelihoods of around 2.6 billion people (FAO, 2017; IFAD, 2016). These small-scale farms provide significant opportunities for rural poverty reduction given their role in both food security and on- and off-farm income generation (FAO, 2017; Hendriks & Lyne, 2003; IFAD, 2016). Empirical evidence shows that investments in agriculture produce three to four times greater poverty reduction outcomes than investments in other sectors (FAO, 2016; IFAD, 2016). In developing economies, investments in agriculture produce long-term structural benefits to the economy through a virtuous cycle: improved agricultural productivity and commercialisation lead to investments and growth in non-agricultural sectors and off-farm employment which diversify the economy and result in savings and export earnings which furthers productivity investments (IFAD, 2016; Southgate et al., 2007). In response to these opportunities, a pro-poor approach is strongly supported by the development community to upgrade small-scale farmers within agri-food VC (Mitchel & Coles, 2011).

2.2 Value chains

A VC describes "the full range of activities which are required to bring a product or service from conception through the different phases of production, to delivery to final consumers and then disposal after its use" (Kaplinsky & Morris, 2000, p.4). Put simply in agri-food terms, the VC documents the journey of products from "farm to fork". There are two main theoretical foundations in the VC literature: (i) Porter's (1985) focus on the VC and value system to improve the competitive advantage of firms; and (ii) the Global VC (GVC) approach used to understand the increasing wealth gaps within and between countries because of trade globalisation (Gereffi, 1994; Kaplinsky & Morris, 2000).

Porter (1985, p. 36) conceptualised an individual firm's VC as the "collection of activities that are performed to design, produce, market and deliver, and support its product". According to Porter (1985), firms should concentrate on understanding the breakdown of its VC activities to determine the firms' sources of competitive advantage. The VC's activities consist of two broad types: primary and secondary. Primary activities are directly related to the creation of products and services and are further divided into five categories: inbound logistics, operations, outbound logistics, marketing and sales, and service. Secondary activities are support services required across the VC, such as human resource management, planning, procurement, and technology. Importantly, Porter (1985) contested that VCs are systems of interdependent activities rather than stand-alone functions. As a result, a change in one activity can have a positive or negative impact on another. Competitive advantage is therefore found not only in improving individual activities, but also through optimising and coordinating linkages between activities in the VC.

In Porter's (1985) framework an individual firm resides in a value system. Porter's (1985) value system is essentially an expanding VC, whereby the firm can link vertically to the VC of suppliers (upstream) and buyers (downstream) that are all part of delivering a final product or service. Competitive advantage, therefore, also arises from optimising and coordinating linkages between individual firms, referred to as "inter-link linkages" (Kaplinsky & Morris, 2000, p.7). Though Porter's terminology was later subsumed (value systems became VCs) and his focus was on strategic decision-making in firms, the concepts of value systems and inter-link optimisation and coordination are foundational to agri-food VC approaches.

Global VC (GVC) analysis came to prominence in the 1990s out of the growing concern that the globalisation of trade was contributing to rising inequalities within and between countries (Kaplinsky & Morris, 2000). Gereffi (1994) noted the rise of powerful transnational firms and the integration of trade as VCs became fragmented across national boundaries. Observing the links to commodity chain approaches, Gereffi (1994) pointed to "lead" firms that controlled and coordinated the VC. Power and information asymmetries across the chain resulted in the lead firms (typically from developed countries) largely determining value addition and its benefits among chain actors. Building on Porter's definitions, GVC analysis focuses on the dynamic inter-linkages across a productive sector (groups of interconnected firms rather than the individual firm) to understand how poor countries are integrated into global markets and to determine how economic rent is distributed among VC actors (Kaplinsky & Morris, 2000). GVC analysis sought to understand which activities are kept within a firm, which are outsourced to other firms, and where the various activities are located (Gereffi et al., 2005, p. 79). This analysis would then help identify leverage points for firms in developing economies to capture increased value from the chain and prevent a race to the bottom as low-value commodity exporters (Kaplinsky & Morris, 2000).

2.2.1 Global value chain upgrading

The upgrading of VCs to enable emerging economies to benefit from integration into the global economy is a key concern within the GVC literature (Gereffi & Kaplinsky, 2001). GVC upgrading refers to the ability of firms to innovate and increase the value added of their products and processes (Giuliani et al., 2005; Humphrey & Schmitz, 2002). Four GVC upgrading strategies are commonly described in the literature (Humphrey & Schmitz, 2002; Kaplinsky & Morris, 2000). In the first strategy, the efficiency of internal processes is improved, both within and between links in the VC. Increases in efficiency can arise from new technologies or the reorganisation of processes. Second is product upgrading, which encompasses the introduction of new products within individual links within the chain or in the inter-chain relationships. The third strategy, functional upgrading, rearranges (or adds to) the mix of activities undertaken by individual firms or moving core functions (manufacturing, marketing, etc.) between different links in the VC. The final strategy is inter-chain upgrading, whereby an entire new product or service is developed across the VC. GVC theories expanded the domestic clustering literature, highlighting the importance of a firm's external linkages across international boundaries, rather than a sole focus on domestic partnerships (Humphrey & Schmitz, 2002).

Industry and contextual forces shape the upgrading strategies available to firms in developing economies (Gereffi & Fernandez-Stark, 2016). There is some evidence that upgrading strategies are hierarchical with sequential progression possible, as shown in the horticultural and garment manufacturing industries (Gereffi, 1999; Gereffi & Fernandez-Stark, 2016). However, Trienekens (2011) noted that product and process upgrading strategies are most pursued in developing countries, with an associated lower accrual of benefits. Accordingly, Gereffi and Fernandez-Stark (2016) asserted that many of the highest value capture activities are in pre- and post-production manufacturing services, such as research, design, marketing, and services, which remain in developed countries. A key issue, therefore, is for developing economies to capture the added benefits of functional upgrading instead of remaining a commodity producer. Evidence shows that the inter-related dimensions of power and information asymmetries, lead firms, and chain governance largely determine which upgrading strategies are adopted by chain actors and the related distributional benefits (Gereffi, 1999; Humphrey & Schmitz, 2002; Kaplinsky & Morris, 2000).

2.2.2 Value chain governance and transaction costs

The governance of VCs underpins upgrading decisions and the distribution of benefits accrued by chain members (Kaplinsky & Morris, 2001). Gereffi (1994, p.97) defined governance as "authority and power relationships that determine how financial, material and human resources are allocated and flow within a chain." VCs are characterised by repeated interaction between nodes, with governance describing the nature of these interactions (Humphrey & Schmitz, 2002). Governance encompasses the coordination of VC nodes related to position, logistics, quality standards, and monitoring. Due to asymmetric power relationships, VCs are often governed by one or more lead firms that play the dominant role in the chain, coordinating and controlling product flows and therefore the accrual of economic rent (Gereffi, 1999). Drawing from case studies, Gereffi (1999) distinguished between buyer-driven and producer-driven chains based on the position of the lead firm. In buyer-driven chains, buyers play the lead governing role and establish production networks that provide goods based on the design and manufacturing specifications of lead firms (Dolan & Humphrey, 2004). In producer-driven chains, large manufacturers play the lead role in coordinating backwards and forward linkages. These chains are characterized by technology- and capital-intensive manufacturing industries.

Building on the work of Sturgeon and Lee (2001) and Humphrey and Schmitz (2002), Gereffi et al. (2005, 2016) conceptualised a typology of governance within GVCs. The five basic VC governance types are outlined below:

i. *Market-based relationships or "spot-markets".* Transactions are simple and require limited exchanges between actors in the chains. Information about the product's attributes is easily understood and the cost of switching to new partners is low for both parties.

ii. *Modular value chains.* Information about the complex transactions is easy to codify. Suppliers are contracted to provide products to specifications and take full ownership of the supply process typically using generic machinery. Switching costs are low due to low asset specificity.

iii. *Relational value chains.* Advantageous when actors rely on each other for complex information that is not easily learned or transmitted. The interactions between buyer and seller are increasingly frequent and complex, involving mutual dependence and higher investment in asset-specific production resources (i.e., machinery, people, technology). A key requirement is trust built through repeated interactions and social and spatial bonds.

iv. *Captive value chains.* Suppliers are dependent on large buyers and face high costs for switching products and buyers because of transaction costs and asset specific investments. As such, suppliers are "captive" to buyers and subject to higher levels of control and monitoring by the lead buyers.

v. *Hierarchy*. Processes are vertically integrated into a single unit and governance takes the form of management control. Products and services are developed within the firm due to complexity or lack of a capable supplier.

Bhattarai et al. (2013) postulate that within agri-food VCs, governance or marketing arrangements will move through this typology from spot markets to hierarchy as transaction costs between the parties involved increase. Transaction costs are defined as the costs of carrying out any exchange (Hobbs, 1996). Within the VC, transaction costs occur through the interactions within and between the various chain nodes. *Ex-ante* costs occur before contracting, are typically fixed, and are associated with searching for information and contract negotiation (Hobbs, 1996). *Ex-post* transaction costs happen after an arrangement is entered into and are incurred through monitoring and enforcement of agreements (Hobbs, 1996). According to transaction cost economics, companies select the governance form or vertical coordination that minimizes transaction costs, under conditions of bounded rationality and opportunism (Trienekens, 2011, p.58).

Transaction costs are determined by uncertainty, asset specificity, frequency, and complexity (Poulton & Lyne, 2009; Williamson, 1979, 1991). Uncertainty refers to unanticipated changes in the circumstances involving a transaction (Bhattarai et al., 2013). Two common categorisations of uncertainty are environmental and behavioural (Jaffee, 1995). Environmental uncertainty is related to elements outside of a firm's control, such as weather and global price volatility. Behavioural uncertainty arises from incomplete, imperfect, or asymmetrical information which can lead to adverse selection and moral hazards (Hobbs, 1996). When elements of the transaction are uncertain, VC actors will seek more control over downstream or upstream firms. For example, in agri-food VCs uncertainty because of price volatility, weather shocks, or a product's credence attributes can shift governance arrangements from spot markets to relational contracts.

Asset specificity occurs when one partner in an exchange makes resource investments which are specific to that exchange and have little or no value in redeployment (Hobbs, 1996, Williamson, 1991). There is an increasing risk of hold-up problems as asset specificity increases (Klein, 1996). For example, when Firm A in an agri-food VC invests in product-specific machinery or technology, its trading partner may opportunistically offer less favourable trade terms knowing that the asset-specific investment has locked Firm A into the exchange. In VCs, as firms increase their asset-specific investments, they seek to strengthen control to offset investments and hold-up risks. These result in higher transaction costs and tighter governance mechanisms as firms seek more information about partners, fuller contractual relationships, and face potential legal costs through contract enforcement.

The complexity of transactions also increases transaction costs and encourages a movement away from spot markets towards vertical integration (Gereffi et al., 2005). Within simple transactions, buyers can easily describe and price the desired product. This makes the costs associated with searching and contracting lower as products and quality markers are typically standardized. Asset-specific investments are also less risky as standard products are manufactured and bought from a variety of firms. However, when products and service requirements become increasingly complex, coordination costs increase due to higher information needs and time sensitivities (Gereffi et al., 2005). Complexity also increases asset specific investment which increases the risk of opportunistic behaviour.

The frequency of transactions also influences transaction costs. Recurring transactions between the same partners can reduce transaction costs as trust is established and partners seek to protect their reputations and opportunity for repeat business (Hobbs, 1996). Meanwhile, the costs of frequently searching for partners and negotiating contracts increase transaction costs and can lead to more hierarchical governance structures (Bhattarai et al., 2013).

2.2.3 Contextual drivers of modern agri-food value chains

Agri-food VCs are shaped by contextual drivers related to inherent biological and environmental conditions, and the more recent rise of globalisation, consolidation of retail power, and quality differentiated competition (Boehlje et al., 2011; Lee et al., 2012). Inherently high volatility in both production and marketing conditions increase the uncertainty of the agri-food industry (Boehlje et al., 2011). Agriculture is directly impacted by local environment and biological conditions, such as pests, diseases, and extreme weather events, which increase the volatility of production and processing. The instability in output and efficiency is further influenced by large swings in agri-food commodity prices. The agri-food industry is also characterised by lengthy seasonal biological production cycles, which result in time delays to changing market and environmental conditions. Additionally, production is often fragmented across different locations and countries, leading to coordination problems, and resulting complexity (Boehlje et al., 2011). This provides challenges for downstream firms that require products that consistently meet quality, safety, and traceability standards.

The effects of globalisation, liberalised trade conditions, foreign direct investment, and technological innovations, have resulted in increasing cross-border trade of agri-food products (Lee at al., 2012). The last three decades have seen a rise in transnational agri-food businesses that assimilate producers in developing economies into their sourcing networks. Global supply chain networks are now able to supply diversified products, year-round, at price points which appeal to mass consumer bases (Trienekens & Zuurbier, 2008). This continual supply, originally focused on processed foods, though increasingly fresh produce is traded domestically and internationally for year-round sale in supermarkets and retail stores (Reardon et al., 2012).

Power in global agri-food VCs has generally shifted towards larger buyers (Boehlje et al., 2011). Increasingly, consumers around the globe purchase processed food and fresh fruit and vegetables from retailers and supermarkets rather than traditional shops or wet-markets (Reardon et al., 2012). Since the 1990s, the rise in supermarket and food retail sales has spread to include Latin America, Central Europe, Central America, Asia, and Russia. As a result, supermarkets and retailers are emerging as the lead firms in domestic and international agri-food VCs (Lee et al., 2012). The change to consumer-purchasing decisions is driven by rising incomes, urbanisation, convenience of one-stop shopping, increasing role of women outside the home, and concerns over food safety standards (Reardon et al., 2012). Meanwhile on the supply side, investments from international and domestic retail firms are further supported by modernised procurement systems and government support (Reardon et al., 2012). With increased share of the consumer market, supermarkets and retailers require supply chains to meet their demands for lower prices, consistent quality, and stringent food quality and safety standards. Larger agri-businesses have proven better able to absorb the costs of these stringent standards while reducing the transaction costs for buyers, often at the expense of small-scale farmers who face significant upgrading constraints (Reardon et al., 2012).

Ever more food retailers are using quality attributes to distinguish their products from competitors (Boehlje et al., 2011). The focus on quality differentiated products results in closer coordination and more vertically integrated VCs (Lee et al., 2012). Buyers have typically moved towards a smaller group of large-scale suppliers that can ensure their products meet the required food safety, quality, and traceability standards. Standards have arisen in response to government regulations, consumer concerns and preferences, technological improvements in measuring contaminants, and the risks involved in elongated transnational supply chains (Boehlje et al., 2011; Narrod et al., 2009; Trienekens & Zuurbier, 2008). Food quality standards cover intrinsic product characteristics and increasingly extrinsic characteristics (i.e., credence attributes) of the production process that cannot be immediately judged by the consumer (e.g., Fairtrade, environmental sustainability, organic). The reliance on credence attributes as a quality differentiator causes transaction costs to rise which leads to even tighter control and integration in the agri-food VC (Lee et al., 2012).

The proliferation and complexity of food standards has mixed benefits for small-scale farmers in developing economies (Boehlje et al., 2011; Vorley et al., 2009). While developing economies have become more integrated into global food markets due to year-round demand for products, stringent standards have increased compliance costs that have excluded many small-scale farmers (Narrod et al., 2009; Trienekens & Zuurbier, 2008). Raised compliance costs for small-scale farmers relate to information (how to produce safe food), reputation (how to be recognised as producing safe food), and cost (how to find cost-effective technologies for compliance and remain competitive with larger producers) (Narrod et al., 2009; Reardon & Berdegué, 2002). Collective action and innovative public-private partnerships have emerged as key pathways for small-scale farmers to comply with standards and enter niche or high-value markets (Narrod et al., 2009).

2.2.4 Constraints for small-scale farmers in developing economies

Small-scale farmers in developing economies face numerous production constraints as well as considerable barriers to engage in higher-value VCs. While a large volume of literature covers this topic, this section briefly outlines the key constraints through the framework of (i) access and orientation to market; (ii) resources and physical infrastructure; and (iii) the institutional environment (Trienkens, 2011).

Within developing economies, three general types of market channels exist: local, national, and international. These market channels increasingly attach greater importance to quality, safety, and traceability attributes through the typology from local to international and, as such, market intelligence becomes increasingly critical (Dolan & Humphrey, 2004; Trienekens, 2011). Small-scale farmers face challenges accessing market intelligence on product standards, volumes, and pricing and lack the social capital to engage with key actors within higher value market channels to overcome information asymmetries. This is further compounded by their difficulty in complying with standards, reputation for poor quality and reliability, and weak bargaining power (London et al., 2010; Trienekens, 2011).

Even once small-scale farmers gain requisite market intelligence, a lack of resources and physical infrastructure limits their ability to deliver agri-food products that meet higher value market standards. Porter's (1990) broad definition of resources (i.e., physical, human, knowledge, technology, and infrastructure) is useful for framing these constraints. The right balance of physical resources is needed to meet agri-food market demands, including, *inter alia*, water access, energy, secure land tenure, suitable agro-ecological conditions, distance from markets, and physical inputs (Poulton, et al., 2006; Poulton & Lyne, 2009). Moreover, meeting quality standards for higher-value markets requires sustained access to affordable, quality inputs (e.g., seeds, fertilisers, pesticides), and efficient pre- and post-harvest services (London et al., 2010; Poulton et al., 2010). A lack of affordable credit and savings facilities further inhibits the ability of small-scale farmers to invest in quality seasonal inputs and fixed and moveable assets while still maintaining enough working capital to offset lumpy investments (London et al., 2010; Milder, 2008). Crop and health insurance, important means of reducing risks, are also typically absent (London et al., 2010). A lack of technical knowledge and skilled labour often limits the production efficiency of small farms and can prohibit the uptake of new, appropriate farm technologies even when they are available at affordable prices (Trienekens, 2011). Infrastructure gaps, common in developing economies, contribute to higher transaction costs for small-scale farmers, hampering the flow of products to markets and upstream flow of market intelligence (Poulton et al., 2010; Trienekens, 2011). These include poor transportation conditions, and unreliable electricity, water, and communication services. Infrastructure deficits are amplified by weak healthcare systems, poor social safety nets, and an unsupportive regulatory environment (Poulton et al., 2010).

The institutional environment of developing economies can further restrict small-scale farmers from VC upgrading (Trienekens, 2011; Vorley et al., 2009). Institutions are essentially "the rules of the game in a society, or more formally, are the human devised constraints that shape human interactions" (North, 1990, p. 3). Developing economies are often typified as having institutional voids, which occur when institutions that support markets are weak, absent, or negatively impact small-scale farmers (Mair & Marti, 2008). Government regulations and policies (regulative institutions) may constrain farmers through limited investment in agri-food research and innovation (Ruttan & Hayami, 1998), application of unfavourable taxes or policies (Poulton et al., 2006), and an inability to enforce contract law (Eaton & Shepherd, 2001). Business institutions can in turn favour existing powerful actors and relationships that prevent small-scale farmers from upgrading within VCs. Cognitive institutions or socio-cultural norms based on ethnic, gender, or religious lines may place limitations of movement, knowledge, innovation transfer, or labour necessary for improvements in farm production (Eaton & Shepherd, 2001; Trienekens, 2011).

2.3 The pro-poor value chain approach

The increasing realisation of the constraints facing small-scale farmers and the mixed results of traditional VC approaches on poverty reduction have given rise to the pro-poor VC approach (Seville et al., 2011; Stoian et al., 2012). Also referred to as "inclusive" VCs, the pro-poor VC approach is defined by the United Nations Industrial Development Organisation (UNIDO) (2011, p. 7) as "a positive or desirable change in a VC to extend or improve productive operations and generate social benefits: poverty reduction, income and employment generation, economic growth, environmental performance, gender equity and other development goals." A pro-poor approach, therefore, places small-scale farmers, and the communities in which they reside, at the centre of change. The emphasis is on "making VCs work better for the poor" through widening the total amount and value of agri-food products that small-scale farmers sell through the chain, while increasing the share of value added (or income) that small-scale farmers capture compared to others in the chain (M4P, 2008). However, it is increasingly acknowledged that "win-win" relationships that strengthen the entire VC are necessary for sustainable impacts (Cooper et al., 2021; Stoian et al., 2012; Vorley et al., 2009). Thus, a pro-poor approach pays attention to both vertical links (i.e., how VCs integrate local livelihood systems of small-scale farmers to upstream and downstream networks) and wider horizontal elements and trade-offs. These horizontal elements and trade-offs include an analysis of the varying impacts of VC integration within local contexts of poverty, assets bases, risk tolerance, gender, labour, and the environment (Bolwig et al., 2010; Stoian et al., 2011). Table 2 provides a summary of key horizontal elements and their applications to agri-food VCs. The pro-poor approach is also multi-chain, considering local, domestic, and export VCs, with entry points determined by the target farmers' asset bases, the resilience of their livelihoods, and the business case for inclusion (Stoian et al., 2012; Vorley et al., 2009).

Table 2: Summary of key horizontal elements and their applications to agri-food value chains

Horizontal elements	*Applications to agri-food value chains*
Participation	- Who is participating in and who is excluded from agri-food VCs? - What other VCs are small-scale farmers participating in and why?
Poverty	- How does integration within a VC and upgrading impact poverty-levels of small-scale farmers and the communities in which they live? - How do small-scale farmers balance livelihood strategies and how does upgrading affect household income, resources, risk, and benefit allocations? - What are the impacts of VC participation on a household's income, non-cash assets, and well-being? - How do upgrading strategies reinforce or reduce access to key productive resources?
Vulnerability and Risk	- How do upgrading strategies increase the vulnerability of small-scale farmers to shocks in the agri-food industry?
Inequality	- What inequalities persist among small-scale farmers and will VC upgrading exacerbate or ameliorate these?
Gender	- What are the gender dimensions within small-scale farmer households and how will upgrading strategies alter gender dynamics?
Labour	- How does VC restructuring alter the employment arrangements (job loss/creation, wage changes, conditions) of community members across the chain?
Environment	- How do VC upgrading strategies affect the environment through emissions and resource utilisation and interaction?

Source: Bolwig et al., 2010; Riisgaard et al., 2010; Stoian et al., 2012.

2.3.1 Common elements in the pro-poor value chain approach

Across the various literature streams (theoretical, action research, case studies, toolkits), a common pro-poor VC approach has emerged, though terminology varies, and processes may be merged or lengthened. First, to ground the pro-poor approach, a contextual understanding of constraints facing small-scale farmers is required (Bolwig et al., 2010; Trienekens, 2011). Along with the general agri-food VC constraints, Bolwig et al. (2010, p.178) argued that a pro-poor approach should seek to understand constraints and opportunities as outlined in Table 2. This stance shifts the framing of small-scale farmers in VCs away from a homogenous production unit to a diverse set of actors that will engage and benefit from VCs in multiple ways. Thus, a pro-poor approach recognises that the VC system is dynamic and interconnected, impacting small-scale farmers, and surrounding communities, in different ways at different times, while also reinforcing broader VC constraints and behaviours (Stoian et al., 2012; Riisgaard et al., 2010). Additionally, Bolwig et al. (2010) stressed the importance of understanding local socio-cultural and political environments, to help identify the powerful actors that influence and control chain participation and the relationships which are key to leverage for upgrading.

The second element of a pro-poor approach entails a value chain analysis (VCA) that investigates and describes the interactions between the different actors in the chain through a four-step process (M4P, 2008; Rich et al., 2011; Trienekens, 2011.). First, a VCA systematically maps out the actors that are involved in the chain, covering production, processers, wholesalers, traders, marketers, and retailers (M4P, 2008). In mapping the chain, a key distinction is made between vertical and horizontal networks (Trienekens, 2011). The vertical dimension describes the flow of goods and services from producer to consumer (i.e., farm to fork), while the horizontal dimension highlights relationships between actors in the same level of the chain, for example farmer associations. The second step in a pro-poor VCA is to draw attention to the role of governance and how it influences the position of small-scale farmers within the different chains. Analysing chain governance helps recognise lead firms and power asymmetries, which determine the location of functions, value addition, and benefits of each node (Trienekens, 2011). The transaction cost perspective also helps to identify governance mechanisms that can increase small-scale farmers' bargaining power and lower transaction costs for purchasers of their goods (Bhattarai et al., 2013). Identifying value addition and the distribution of benefits among chain actors are the third and fourth strands of VC analysis. Value is added throughout the chain based upon quality, costs, innovations, etc., and reflected in the price of goods and product margins of each actor (M4P, 2008). Identifying how value is added across different chain nodes and actors helps determine which market channels and upgrading strategies are within reach of small-scale farmers considering context, governance mechanisms, asset bases, and resources available for upgrading (Bolwig et al., 2010)

The final element of the pro-poor approach is the selection of appropriate VC upgrading strategies based on findings from the detailed VCA that was informed by context and constraints. Building on GVC literature, four broad pro-poor upgrading strategies for small-scale farmers within agri-food VCs are commonly identified (Bolwig et al., 2010; Kilelu et al., 2017; Trienekens, 2011):

i. *Improving process or product.* These strategies cover improvements within the same node by utilising technology or management gains. Process upgrades improve productivity which increases the volume produced and/or decreases production costs. Product upgrades cover shifting to more sophisticated products or improving quality attributes of an existing product that increase unit prices. Product and process upgrades are market-driven and include intrinsic (such as quality, composition, packaging) and extrinsic product attributes (such as food safety, traceability, ethical and environmental considerations).

ii. *Changing and/or adding functions.* Small-scale farmers can take on new functions in the VCs, a process referred to as functional upgrading. The upgrading can take the form of downstream functions, small-scale farmers add value by processing, grading, branding, or marketing their products, or upstream functions, whereby they provide inputs or services to other chain actors.

iii. *Improving value chain coordination.* Improving horizontal coordination often involves establishing collective marketing arrangements among small-scale farmers to reduce costs through bulk orders and to increase revenues and mitigate risks by joint marketing (Poulton et al., 2010; Trienekens, 2011). Collective action among small-scale farmers has been shown as a precondition for other upgrading strategies, as it strengthens bargaining power and reduces transaction costs and risks for upstream actors (Markelova, et al., 2009). Vertical coordination improves relationships between two actors at different nodes. For small-scale farmers this means "getting a better deal through closer and longer-term business ties with buyers" (Bolwig et al., 2011, p.36). Improving coordination involves upgrading governance structures in the VC. Increased vertical coordination can come through contract farming, relational contracts, or strategic partnerships and can bring benefits to small-scale farmers, such as relevant market information, input and service provision, financial services, price guarantees, and price premiums. Downstream actors also benefit through access to reliable supply of products that meet quality and safety requirements (Eaton & Shepherd, 2001).

iv. *Improving the institutional environment.* VCs sit within institutional environments that can help support or exclude small-scale farmers from upgrading (London et al., 2009; Trienekens, 2011). Given the wide-range of institutional voids, a targeted approach needs to consider the political will, resources available, and the time horizons required to bring about change (Bolwig et al., 2010; Kilelu et al., 2017; Mitchell et al., 2009).

2.3.2 Selection of pro-poor upgrading strategies

These four general pro-poor upgrading strategies are mutually reinforcing, and several strategies can be selected to multiply the effects (Trienekens, 2011). Bolwig et al. (2010, p.34) suggested that upgrading strategies should ideally be evaluated considering horizontal elements, and "action points" selected where political pressure or strategic action is feasible in relation to powerful downstream actors in the chain. Rather than operating in isolation, a "whole-of-chain" or "win-win" approach to upgrading is suggested by increasing the stake of powerful chain actors in the integration and upgrading of small-scale farmers (Riisgard et al., 2010; Stoian et al., 2011). The selection of upgrading strategies also depends upon the incentives, resources, capacity, and power of organisations facilitating the upgrading, whether they are buyers, small-scale farmers, traders, non-government organisations (NGOs), donors, or government entities (Bolwig et al., 2010; Vorley et al., 2009).

Ex-ante impact evaluations to help select appropriate pro-poor upgrading strategies and iterative monitoring to change approaches based on learning and contextual changes are recommended (Riisgard et al., 2010). However, there is scarce reference in the pro-poor literature on specific tools and methodologies that best support such a research-led approach. This includes tools and methodologies that can: (i) factor in the dynamic and complex nature of agri-food VC systems, (ii) measure economic and horizontal impacts in the chain, and (iii) build consensus among chain stakeholders around "whole-of-chain" approaches. A number of oft-selected "action points" for upgrading small-scale farmers have emerged that cut across the four broad upgrading strategies outlined above. These are summarised in Table 3. While case-studies on these action points abound, there is limited research using more systematic trade-off analysis to help development agencies select and allocate limited resources to high-impact action points.

Table 3: Summary of common pro-poor upgrading action points

Action point	*Key elements*
Collective action	- Farmer controlled marketing organisations provide an opportunity for small-scale farmers to actively coordinate nodal functions - Allows access to higher value markets through (i) pooling of capital to invest in value-adding assets and technologies; (ii) strengthening of bargaining power; (iii) enlarging economies of scale for inputs (goods and services) and outputs that decrease transaction, production, processing, and marketing costs; (iv) lowering the cost and increasing the sharing of market information and technologies; and (v) coordinating small-scale farmers' production and harvesting to meet buyer demands for quality, timing, and volume. - Common cooperative problems (e.g., free rider, horizon, portfolio, control, and influence problems) are tackled through innovative institutional arrangements (Esnard, et al., 2017; Lyne & Collins, 2008; Markelova et al., 2009; Narrod et al., 2009; Poulton et al., 2010;)
Technology and innovation	- Small-scale farmers access appropriate technologies that improve yield, quality, and decrease production costs. - The appropriateness of technology is determined by the relative price of inputs, i.e., land-saving when labour is abundant and labour-saving when land is abundant. - Improved technology and innovation can flow to small-scale farmers through tighter vertical coordination in the VC to meet market demands - The public sector, NGOs, and private sector have roles in technology dissemination, but the up-take is driven by profit incentives. (Rattan & Hayami, 1998; Trienekens, 2011)

Table 3: Summary of common pro-poor upgrading action points (continued)

Action point	*Key elements*
Rural agribusiness finance	- Provision of credit to small-scale farmers can come from sources internal and external to the VC. - Internal to the VC: Within contractual and relational governance mechanisms, credit is provided to small-scale farmers to purchase quality inputs and productive assets to meet contractual obligations around quality and volume. - External to the VC: Banks, microfinance, and financial institutions provide credit by substituting collateral for business plans, supply contracts, and repayment ability. International banks can encourage local banks to lend to rural farmers through loan guarantee arrangements. - Blended finance models use donor funds as leverage for private capital by decreasing the risk profile of investments. - Term loans provided through graduated or deferred repayments can assist in alleviating cash flow problems associated with investments in productive farm assets. (Finnemore et al., 2004; Milder, 2008; Sutton & Jenkins, 2007)
Contract farming	- Contract farming decreases the investment risks to small-scale farmers and buyers as they undertake VC upgrading strategies. - Contract farming seeks a “win-win” arrangement based on profitability. Buyers “win” through access to agri-food products at the quality, volume, price, and time required by downstream actors. Small-scale farmers “win” through a guaranteed market and price and access to quality inputs and services, new technology and training, and knowledge which can be applied to other farm enterprises. - Small-scale farmers tend to prefer written contracts that allow for variable price options related to quality. (Abebe et al., 2013; Eaton & Shepherd, 2001)
Multi-stakeholder chain initiatives	- Public-private partnerships connect small-scale farmers to inputs, services, and collection centres in “hubs” or “parks” that enable their integration in quality-differentiated retail markets. - Increasing uptake of Inclusive Business Models (IBMs), where multiple stakeholders work together to integrate the poor into agri-food VCs and provide strategic finance and business assets. - Private sector is incentivised by positive image, profit-making ability, and market position. (Narrod et al, 2009; Stoian et al., 2012; Sutton & Jenkins, 2007)
Alternative value chains	- Niche, quality, safety, environmental, and ethical differentiated VCs are developed through improved consumer knowledge on production and processing practices. Examples include Fairtrade, organic, and transnational alternative agri-food networks. - Importance is increasingly placed on credence attributes of safety and ethical elements resulting in relational contractual arrangements between small-scale farmers and downstream actors. - Consumers depend on third-party certification, labelling, reputation, and participatory guarantee systems as an assurance that products meet quality, safety, environmental, and ethical requirements. (Hatanaka, 2009; Nelson et al., 2016; Ruben & Fort., 2012)

2.3.3 TRRILD project’s pro-poor approach

The TRRILD project, which forms the context for this research, was designed to address upgrading constraints faced by small-scale farmers in Myanmar. Two pro-poor upgrading “action points” underpinned the project’s strategy and led to the selection of consortium partners: first, the provision of VC financing, undertaken in large part by the TRRILD project’s partner MFI; and second, the establishment of producer groups (PGs) for small-scale farmers that can readily transition to producer organisations (POs) capable of investing in value-adding assets. This second strategy was supported by LU's other PhD Researcher within Output One of the project. Although briefly covered in Table 3, the literature surrounding these two interventions are reviewed in more detail in this section, providing background to the credit and collective action modules newly created within the research's SD model of the pork VC.

2.3.3.1 Value chain finance

Accessing credit is a significant barrier for small-scale farmers in upgrading their enterprises in developing economies (Miller & Jones, 2010). While farm liquidity can come from multiple sources, the timing of cash incomes from farms and low levels of household savings typically mean small-scale farmers must rely on credit to upgrade their enterprises. Credit allows small-scale farmers to finance seasonal inputs and invest in fixed or moveable assets that improve productivity and profitability (Khandker et al., 2016). This credit typically comes from three main sources: (i) informal lenders such as moneylenders, friends, relatives, and local loan associations; (ii) VC actors who make loans or purchases on credit available to farmers to promote integration; and (iii) formal financial institutions like commercial banks, MFIs, and NGOs (Shakhovskoy et al., 2019).

Unfortunately, access to credit for rural small-scale farmers is tightly constrained in most developing economies (Miller et al., 2018). Globally, there is an estimated US$240 billion demand for smallholder finance, of which only US$70 billion, or 30%, is currently met (Shakhovskoy et al., 2019). The gap of US$170 billion is concentrated in long-term agricultural investment financing, where 98% (US$86 billion) of the demand remains unmet, compared to seasonal agricultural loans in which 67% (US$66 billion) of the demand is unmet. There are several well-documented reasons for these financial gaps. Because small-scale farmers are typically spread across a large geographic area, often with poor infrastructure services, formal providers face information challenges in lending, making the assessment, provision, and monitoring of loans highly costly (Kloeppinger-Todd & Sharma, 2010). Additionally, small-scale farmers may lack loan collateral, such as land titles, furthering the belief that the agricultural sector is high-risk given climate variations and there is insufficient scale to generate sufficient returns when compared with urban ventures (Milder, 2008; Pica-Ciamarra et al., 2010).

Lending from MFIs has rapidly increased since its introduction in the 1970s, now reaching around 140 million clients a year providing a variety of services beyond small loans, such as savings, remittances, and insurance (Convergences, 2019). While initially viewed as a potential development panacea, microfinance has been criticised for delivering modest pro-poor outcomes, potentially causing over-indebtedness, and delivering a mixed performance in the SME sector (Banerjee & Duflo, 2011; Buckley, 1997; Cull, 2015; Morduch, 2000). Moreover, the increasing commercialisation of the sector has lowered the appetite of MFIs towards more risky borrowers, like small-scale farmers, because of the high-transaction costs involved in accessing farmers and targeting loan offerings to different agricultural products (Cull, 2015; Khandker et al., 2016; Milder, 2008; Morduch, 2000). Authors have also brought attention to the unsuitability of many MFI loan products to the agriculture sector, citing short loan terms that do not synchronise well with farm production cycles and regular repayment schedules that preclude borrowers from undertaking investments in lumpy assets (Pellegrina, 2011). This mismatch can lead small-scale farmers to favour higher interest loans from informal sources or commercial banks over MFIs that offer lower interest rates (Pellegrina, 2011).

The finance gap facing rural farmers seeking to commercialise their enterprises has been termed "the missing middle" by Milder (2008). Farmers seeking to upgrade their enterprises frequently require meso loan sizes beyond the amounts of standard MFIs (i.e., greater than US$500) but below the level of capital and collateral that necessitates the interest of commercial banks. Meso loans are required for bulk purchasing inputs, or for making investments in value-adding assets, such as a rice mill or a slaughtering facility. Milder (2008) and Miller and Jones (2010) have documented various options for finance from both within and external to the VC that can address the "missing middle;" these include, *inter alia*, financing from the lead firm, loan guarantees, input supplier credit, warehouse receipts, and leasing. While case studies have retrospectively highlighted the pitfalls and successes of these types of VC finance (Doran et al., 2009; Milder, 2008; Miller & Jones, 2010), an *ex-ante* impact evaluation of the different finance options available to small-scale farmers and producer associations is notably, uncommon. This type of evaluation could bring to light the impacts of different financial products (e.g., term loans, seasonal loans, leasing, etc.) provided to the various VC nodes (i.e., input supplier, individual farmers, cooperatives) allowing for trade-off analysis between the different financial products on offer and other possible pro-poor upgrading options.

Small-scale farmers in Myanmar face severe restrictions in accessing credit. In the last decade, access to formal finance in Myanmar has improved from 10% of the general population in 2011 to 48% in 2018 (Duflos et al., 2013; Jefferies et al., 2018). However, 30% of the general population still cannot access any financial services, while 21% rely solely on informal providers that routinely charge high interest rates. While the state-owned Myanmar Agricultural Development Bank (MADB) provides low-interest loans for seasonal inputs for paddy production, credit facilities for agriculture or VC lending outside of this sector remain extremely low (Jefferies et al., 2018). Moreover, the needs of commercially orientated farmers are not adequately met because of the small loan sizes and shortened loan terms from MADB, commercial banks, and MFIs. As a result of the extremely limited outreach of commercial banks and MFIs in rural Myanmar, small-scale farmers generally turn to informal lenders for VC financing (Hein et al., 2016; Jefferies et al., 2018). Even though their interest rates can range from 5% to 20% per month, there is still a strong demand for informal lending, showcasing the importance of credit for small-scale farmers (Hein et al., 2016).

The TRRILD baseline survey conducted in 2018 showed small-scale farmers in the project's target villages have severe restrictions to accessing affordable credit (Lyne & Snoxell, 2018). Only 12% of farmers borrowed from formal providers, while 48% borrowed from informal moneylenders and family, though demand was much higher for formal lenders. Combined with irregular cash flows, this finance gap creates liquidity problems, meaning farmers in the target region were unable to invest in productive assets and apply quality inputs to improve farm productivity or meet standards demanded by higher value markets (Snoxell & Lyne, 2019). With the slow development of the commercial banking sector, the TRRILD project's MFI partner would remain a key provider of formal credit in the pork and paddy VCs. Decisions about this MFI's level of investment and how to contextualise current product offerings to promote pro-poor upgrading lend themselves to a quantitative analysis that can consider risks and shocks in the system as well as the impacts of providing credit to different VC nodes and small-scale farmers with diverse risk and asset profiles. A quantitative analysis could prove helpful in shifting the TRRILD's partner MFI funding towards the "missing middle," by detailing horizontal and temporal impacts of lending to individuals and groups for value-adding investments, compared with the MFI's existing practices of small, short cycle loans to individuals.

2.3.3.2 Producer groups and producer organisations

As outlined in Table 3, collective marketing, through the formation of PGs and POs, is promoted as a pro-poor form of horizontal coordination that can help small-scale farmers to access higher value markets (Markelova et al., 2009). While often used interchangeably, a clear distinction between PGs and POs is emerging in the literature. PGs are typically less formal with their main function being "transactional," in that they provide training to members, enable bulk purchasing of inputs, and collectively market produce. Mwambi et al. (2020) suggest that PGs are more inclusive because they require less capital and investment from members. In contrast, POs focus on integration within the VC as a means of delivering economic benefits to members (Bijman, 2016). This integration can take place either downstream, through the PO providing value-adding services to allow access to high-value markets, or upstream, where value is captured through the manufacture and supply of inputs. The emphasis on marketing or value-adding strategies means POs require larger capital investments and improved management capabilities than PGs (Bijman, 2016). New Institutional Economic theory has shown that institutional arrangements adopted by POs are critical to incentivise capital investments in value-adding assets while also encouraging member patronage to maintain marketing and supply contracts (Esnard et al., 2017). The TRRILD project aimed to first establish PGs that would later become POs by extending their transactional activities to include value adding strategies. This sequence would entail constituting PGs with institutional arrangements that support this transition and enable POs to source capital for value adding investments.

Traditional cooperatives are susceptible to governance and capital problems when they invest in value-adding strategies that require a consistent supply of quality products from members. The literature identifies these as free rider, horizon, portfolio, control, and influence problems which have led to the evolution of non-traditional and hybrid cooperative structures (Chaddad & Cook, 2004). In traditional cooperatives members are rewarded for their patronage rather than their level of investment. This discourages members from investing in shared assets as benefits accrue to larger patrons who have not necessarily contributed capital in proportion to their patronage (Chaddad & Cook, 2004). A New Generation Cooperative (NGC) seeks to address this free-rider problem by issuing delivery rights to members to ensure that they invest capital in proportion to their patronage. Tradeable delivery rights are a contractual right and obligation of a member to deliver a certain volume of product to the PO at a premium price (Moore & Noel, 1995). In the horizon problem, members are reluctant to make investments in durable assets because they may not realise benefits beyond their membership in the PO. As a result, members give preference to favourable prices rather than leaving profits in the PO for further investment. The issuing of non-redeemable delivery rights that members can trade among themselves can overcome both the free-rider and horizon problems. Tradeable delivery rights can be sold or granted to PO members and traded between them, allowing members to capture appreciation on their capital as well as manage their farm risk. Appreciable delivery rights also encourage contractual compliance (Moore & Noel, 1995). To invest in value-adding assets smallholder POs often require capital beyond the level raised by selling tradeable delivery rights to members. POs can raise further capital by issuing a second class of shares to members and external investors that are both tradeable and appreciable (Chaddad & Cook, 2004).

A recent advancement in the evolution of POs is the emphasis on inclusive business models (IBMs) that involve the use of blended finance (Organisation for Economic Co-operations and Development [OECD], 2017; Sutton & Jenkins, 2007;). An IBM is defined as a business partnership that promotes the integration of small-scale farmers into markets while enabling mutual benefits for both poor farmers and other business partners. Kelly et al. (2015) suggest that including existing VC actors and more committed and capable small-scale farmers increases the effectiveness of these partnerships. Stakeholders in the partnership collaborate with one another to achieve their own objectives, with each bringing unique value into the arrangement. One concern in IBMs is the liquidity constraints that would prevent POs from fully capturing value-add if investments in assets are largely owned and controlled by other partners. To mitigate this risk, POs should adopt institutional arrangements that attract external investment while still enabling POs to have majority or meaningful control. Blended finance can support IBMs by using cheap capital from donors and public agencies to leverage debt and equity capital from private investors by improving the risk-return profiles of investment that enhances pro-poor outcomes (OECD, 2017).

Consequent to these concerns, the TRRILD project made several provisions to incentivise equity-sharing arrangements with strategic partners within an IBM. A large portion of the project's budget was set aside to establish two MFI branches that will service the target villages. These funds will provide subsidised micro- and meso-loans to PG and PO members to finance on-farm investments needed to meet the quality standards of premium markets. The MFI has further provisions to supply group meso-loans to POs for investments in value-adding assets. TRRILD project funds are also available for increasing the equity contribution of members in PO-owned assets. The project's equity contribution could reduce the risks for potential strategic partners, incentivising their investment, while increasing the share of the added value accruing to PO members. Having a private sector enterprise partner with a PO in a shared equity arrangement not only leverages financial capital but also brings intangible assets and additional technical and management expertise into the PO. This arrangement would, in theory, enhance the ability of the PO to access term loans from commercial banks to further scale-up investments.

While the TRRILD project was designed to establish PGs that transition to POs, further quantitative analysis could provide insights into the types of specific institutional arrangements that promote both inclusiveness and long-term economic viability. Of particular interest is the mix of technical interventions and PO institutional arrangements that best promotes the inclusion of poorer producers, while also ensuring the PO remains financially viable. The development literature is replete with case studies of cooperative failure following the exit of project support or subsidies. As such, a pro-poor *ex-ante* evaluation should investigate the long-term sustainability of PGs and POs, while factoring in future price shocks, production risks (e.g., disease, drought, etc.), and capital constraints. With tight capital markets in Myanmar, the TRRILD project would further benefit from understanding the trade-off between retained earnings and price premiums/rebates in PGs and POs that would deliver both technical services to members and investments in value-adding assets. The use of an SD model could also provide insights into how and where the TRRILD project should allocate its cheap capital to incentivise investments from strategic partners. This decision would incorporate the level of pro-poor and financial impacts in the system generated from different MFI loan products, and the potential returns to a strategic partner's equity investment in a shared value-adding asset.

2.3.4 Knowledge gaps in the pro-poor value chain approach

Pro-poor VC approaches remain at the forefront of poverty reduction strategies; however, gaps regarding the effectiveness of commonly used pro-poor tools and their contribution to poverty reduction exist (Stoian et al., 2012). Traditional pro-poor VCA tools are primarily qualitative and descriptive, lacking rich quantitative data that captures the dynamic nature of agri-food VC systems (Rich et al., 2011). When present, quantitative data analysis generally covers profits and margins within segments and channels and is therefore insufficient to support robust decision making and consider critical horizontal elements (Bolwig et al., 2010; Rich et al., 2011). Stoian et al. (2012) further notes the tendency for pro-poor VCA tools to deduce household-level economic impacts from enterprise level outcomes and the failure to take into consideration external factors in the institutional environment or market context and the interconnectedness of VCs. This oversight into the interconnectedness of VCs, communities, and household systems, means traditional pro-poor approaches often fail to account for changes in livelihood assets (i.e., human, social, natural, physical, and financial) in their analysis, leading to positive (and negative) feedback loops being largely absent from decisions on high-impact upgrading strategies (Stoian et al., 2012).

Further, Riisgaard et al. (2010) assert that action research methods should be employed to diagnose problems, find and quantify solutions, and implement pro-poor VC upgrading activities, listing *ex-ante* impact evaluations as a tool to select a “best-bet” strategy. Rich et al. (2011) support this pragmatic shift, arguing that given the multi-functionality, complexity, and pro-poor relevance of agri-food VCs, the focus should move from tools that diagnose problems towards tools that quantify the impact of potential solutions. However, traditional descriptive VCA are limited in their ability to quantify, *ex-ante*, the impacts of potential upgrading strategies as they do not sufficiently consider the wider consequences and trade-offs (intended, or unintended) of upgrading strategies both within the VC system (i.e., impact on other nodes and actors) but also on small-scale farmers and the wider community (Rich et al., 2011; Stoian et al., 2011). Traditional approaches are essentially aspatial and temporal snapshots of a dynamic system, thereby allowing only static analysis at the enterprise or meso-level rather than a focus on household or farm-level livelihoods (Mitchel & Coles, 2011; Rich et al., 2011; Stoian et al., 2012) These gaps have led Rich et el. (2011) to propose quantitative system dynamics (SD) tools to capture the dynamic, interconnected nature of agri-food VCs and to model *ex-ante* impacts across multiple dimensions, various stakeholders, and time horizons. The use of multiple evaluation indicators (economic and non-economic impacts across different stakeholders across multiple time horizons) enables a comprehensive trade-off analysis, which in turn allows decision-makers to select a more targeted and effective strategy for VC upgrading that leads to poverty reduction (Stoian et al., 2012, p.57).

Humphrey and Navas-Alemán (2010) suggest there is a general lack of evidence as to the effectiveness of VC approaches on poverty reduction. The lack of *ex-post* impact evidence is related to a general absence of project monitoring data but also the narrow lens of research. Changes to employment and income at the farm level are typically measured, rather than the wider household impacts (e.g., poverty, assets and savings, livelihoods, environment, gender) or the impacts on non-farm households as they engage in production and non-production chain nodes (i.e., processing, provision of services or goods). The lack of evidence extends into rural Myanmar, where pro-poor VC initiatives are prioritised by the government (MoALI, 2018) and the donor community (LIFT, 2014), yet their effectiveness on poverty reduction is largely undocumented and lessons for future application are scarce.

While pro-poor VC action research is presented as a participatory, empowering methodology, evidence suggests that decisions on upgrading strategies are typically derived from expert-orientated processes (Mitchel et al., 2009). Group Model Building (GMB), a participatory SD modelling tool, has recently been applied to increase the involvement of small-scale farmers within pro-poor VCA and quantitative model building (Lie et al., 2017). Only a small number of GMB processes within the VC context have been documented and there are currently no examples of action research using GMB tools to select pro-poor upgrading strategies for implementation within a development project in either Myanmar or in other developing economies. The next section of the literature review will cover SD and participatory GMB tools and their current and potential application to the pro-poor VC approach.

2.4 System dynamics

2.4.1 Overview of system dynamics

System Dynamics (SD) is an analytical paradigm for modelling the structure and behaviour of complex systems, a field pioneered by Massachusetts Institute of Technology (MIT) Professor Jay Forrester in the 1950s. It was initially applied to understand problems in industrial systems (Forrester, 1961), and then further developed to provide quantitative insights into urban (Forrester, 1970), and world systems (Forrester, 1971). Central to this paradigm is the premise that the behaviour of a system is primarily determined by its structure and that systems are complex and interconnected (Sterman, 2010). Understanding the components, relationships and boundaries of a system is foundational for addressing complex problems, and as Lewis Thomas (1979, p.90) noted “If you want to fix something you are first obliged to understand…the whole system.” Though complex, systems can be modelled to increase our understanding by only including components and relationships which influence system behaviours.

SD is interdisciplinary, grounded in theories of nonlinear dynamics and feedback control from mathematics, physics, and engineering. The relationships in these complex systems are governed by nonlinear differential equations, which are expressed through graphical interfaces within an SD model, easing model conceptualisation, and sharing across disciplines (Sterman, 2010). Through qualitative and quantitative modelling, SD tools are used in multi-disciplinary settings to solve messy problems and support decision-making in complex environments. This includes diverse fields such as agriculture, healthcare, environmental science, social housing, defence, and management (Stroh, 2015; Vennix, 1999).

SD is commonly applied to solve complex, messy problems where policies (or interventions) are contested or have met with previous failures or resistance. Sterman (2001) believed that this "policy resistance" occurs when interventions or policies create unanticipated side effects and unforeseen reactions from within the system, which then negatively impact on the intervention's original purpose. Humans tend to address urgent, surface-level symptoms rather than underlying causes of problems (Stroh, 2015). These quick fixes may bring short-term success; however, when root causes are not resolved, the surface-level interventions can lead to unintended problems which further compound the original problem (Braun, 2002). Due to time delays in systems, there is a common disconnect between our action and the systems reaction, leading us to believe reoccurring problems are beyond our influence and our actions had no negative impacts on the system (Stroh, 2015). These failures are underpinned by the inability of mental models to cope with the dynamic complexity of the systems in which our interventions operate (Sterman, 2000). Humans have limited neural ability to process large amounts of information. We typically use simple mental models which struggle to consider feedback loops and consequently employ biases and heuristics based on previous experiences and our environment when making decisions (Kahneman, 2011; Vennix, 1999). By contrast, systems often produce counterintuitive results because of the changing interactions of multiple agents over time (Sterman, 2000). This dynamic complexity may arise from various causes, but the most challenging for our mental models are feedbacks, accumulations, time delays, and nonlinearities in the system (Sterman, 2001).

Complexity within systems arise from feedback (or interactions) among the components of the systems, rather than the complexity of the components themselves (Sterman, 2002). Feedback occurs when a change in one part of the system affects other parts of the system, which in turn impacts the original component. Given the closed-chain nature of systems, feedback "loops" are circular causalities that govern the behaviour of systems through delayed circular causal relationships between system components (Hamza, 2014; Ford, 2010). There are only two types of feedback loops which affect all SD models: (i) Positive (or reinforcing) and (ii) Negative (or balancing) (Sherwood, 2002). Positive loops are self-reinforcing, strengthening the original direction of the change and therefore amplifying behaviour in the system. As a result, these reinforcing (R) feedback loops bring either exponential growth or decay to the system. Negative or balancing (B) feedback loops are self-adjusting, counteracting and opposing change. Balancing feedback loops therefore seek to balance the system towards some level of stasis or equilibrium (Sterman, 2001). A simple example of a reinforcing and balancing feedback loop is shown in Figure 3, using a common SD tool, the Causal Loop Diagram (CLD). In Figure 3, pig births lead to a higher pig population which in turn lead to even more pig births and an increasing pig population, a reinforcing (R) feedback loop. This is counteracted by the balancing (B) feedback loop shown in Figure 3: when more pigs are born into the population and it grows, there are more deaths, which reduces the pig population and subsequent number of births.

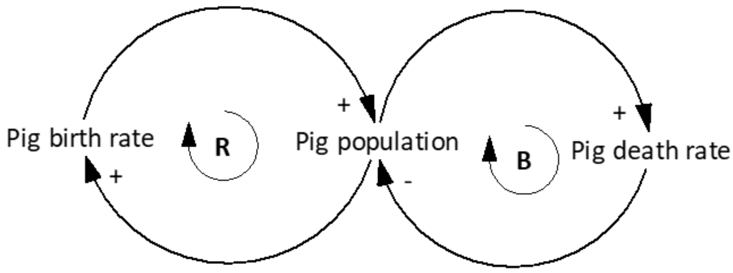

Figure 3: CLD of a simple pig population illustrating reinforcing and balancing feedback loops
Note: In CLDs the + sign indicates movement in the same direction as the origin of the change (i.e., when the pig population increases the birth rate increases and when the pig population decreases the birth rate decreases) and the - sign indicates movement in the opposite direction to the origin of change (i.e., when pig death rates increase the pig population decreases and when the pig death rates decrease the pig population increases).

Accumulation and dispersal of goods or services are central to the dynamic complexity of systems (Sterman, 2001, p.14). In SD language, the term "stock" represents the accumulation of goods or services (or simply "things") at any given time in the system (Ford, 2010). Stocks describe the state of critical system elements and can be either tangible, such as household income, or intangible, such as the technical knowledge of a farmer, provided that stocks of intangible goods can be measured through some sort of quantitative proxy (in the knowledge example, for instance, by use of a scored examination). A "flow" represents the actions that change the state of stocks over time (Ford, 2010). In other words, flows provide the entry and exit points for goods and services into or out of a stock. Continuing the livestock example, a pig population is considered a stock, which increases by the flow of births and decreases by the flow of deaths. In SD models, parameters (also called converters) are used to determine the rate of flows over time or to affect other parameters. For example, there are many factors which would influence births (in flow) in a pig population (stock), such as birth rate, number of sows, litter size, etc., as well as deaths (out flow) in a pig population (stock), including disease outbreaks, pig breed, etc. These influencing factors are considered parameters and comprise nonlinear differential equations and / or graphs over time in an SD model and change the rate of flows into and out of stocks. SD models are commonly represented by stock-and-flow diagrams (SFDs) with boxes representing stocks, pipes representing inflows and outflows, and parameters represented by circles. The earlier pig population example is expanded upon in Figure 4 to showcase a simple SFD.

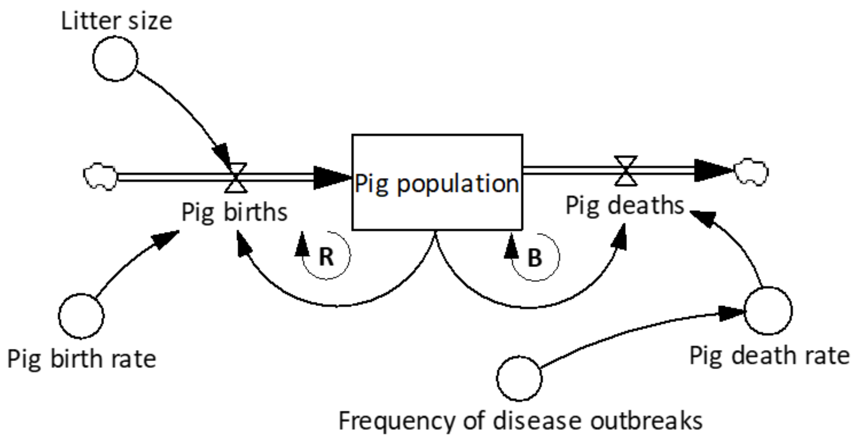

Figure 4: SFD diagram of a simple pig population model

Time delays between an action and its effects on another part of the system are another cause of dynamic complexity. When these occur in feedback loops, actors can fail to account for time delays in the design of policies and misjudge an intervention's outcome (Sterman, 2001). Delayed feedback can cause actors to continue to intervene and overcompensate, which leads to oscillations and instability in a system (Sterman, 2001). Our inability to recognize time delays in systems can result in assigning a false positive to a policy or failing to notice a delayed negative (or positive) consequence that arose from a specific action (Braun, 2002).

Within the field of SD, two primary tools are employed to support collective understanding and decision-making: qualitative CLDs and quantitative simulation modelling. CLDs are a qualitative tool that visually represents the most critical parts of any system (i.e., a closed boundary) and capture dynamic complexity through documenting the polarity of relationships between stocks, flows and converters and the identification of feedback loops and time delays (Sterman, 2010). Some SD practitioners, however, represent CLDs without delineating the system with stock-and-flow terminology, preferring to use a simple generic structure (as illustrated previously in Figure 3) to enhance learning (Sherwood, 2002). Within CLDs, common patterns of feedback processes that underpin complex problems are often present, known as system archetypes (Braun, 2002). System archetypes provide insights into reoccurring patterns of behaviour and are transferable across different system contexts to aid in the diagnosis and understanding of problems (Stroh, 2015). Proponents of CLDs argue that they increase the basic understandings of systems as mental models are shared and expanded, helped by the SD terminology providing a common language platform for stakeholders to converse with one another (Sherwood, 2002; Vennix, 1996). Moreover, simple CLDs help draw attention to the specific feedback loops that have a strong influence on system behaviour and outcomes, thus focusing discussions on interventions (Vennix, 1999). However, Sterman (2001) counters that given the complexity of feedback loops, delays, and stocks and flows within systems, beyond a system containing only a few simple feedback loops, it is virtually impossible to fully understand the dynamics of a system without the use of a quantitative computer-simulated model.

Computer simulation-based SD modelling (often referred to simply as SD modelling) uses computer software to run scenarios of a complex system, represented by stocks, flows, feedback loops, and parameters (Sterman, 2001). Mathematical equations are developed to represent relationships between the system's elements and variables assigned to each of the parameters. These non-linear differential equations are simulated over time to ascertain patterns of dynamic phenomenon rather than to forecast a particular equilibrium point (Rich, et al., 2016). The advantage of SD modelling over macro-economic optimisation models, such as partial equilibrium and general equilibrium, is that it allows the users to run various intervention (or policy) scenarios within complex dynamic systems over time (Sterman, 2001). The short-, medium- and long-term effects of interventions on the system can then be compared to a baseline (no intervention) and the outcome of other possible intervention scenarios. This type of simulation is particularly powerful in the modelling of biological systems, such as agri-food VCs, which are characterized by biophysical delays and cyclical behaviour (Rich et al., 2011).

Computer simulation SD modelling can build on participatory qualitative modelling processes. When system elements are developed through multi-stakeholder collaborative processes, computer SD simulations can further expand the mental models of participants by enabling them to visualise how their choices affect the system and impacts on others (Stroh, 2015). This expanded picture can foster consensus building on root causes of problems and leverage points as well as promote ownership over change initiatives (Stroh, 2015).

The nature of the problem under study and the purpose of the model should be clearly understood before SD approaches are selected as other system modeling options are potentially more appropriate (Millington et al., 2017; Vennix, 1996). SD modeling techniques are suited to understanding dynamic complex problems caused by endogenous feedback loops. Compared with other system modeling options, SD is particularly powerful when interactions between multiple system components (such as biophysical, institutional, and economic) determine dynamic behaviours, and a holistic picture of impacts are required to determine trade-offs among system actors (Millington et al., 2017; Rich et al., 2011). SD models also support participatory processes as they can accommodate perspectives and data from a wide range of stakeholders and can be updated iteratively within a stakeholder workshop setting. Rather than focusing on optimisation of one part of the system as within a general/partial equilibrium model, SD models allow the comparison of the impacts of interventions across diverse system elements. Thus, as opposed to situations that require precise economic forecasting instruments, SD models lend themselves to processes that need decision-support tools (Vennix, 1996). Multi-agent-based computer simulation models, however, can provide a more detailed picture of impacts than SD models as they accommodate a wider range of individual farm or household decisions (Ding et al., 2018). Meanwhile, partial/general equilibrium models are suited to macro-level economic analyses when a large body of quantitative data is available and region- or country-wide impacts of market policies and prices are sought. SD modelling is unique in that it can provide aggregation at the system level and multiple feedback pathways from macro- and micro-system elements (Ding et al., 2018).

2.4.2 Group model building

Group Model Building (GMB), as a field within SD, was developed to specifically involve a wider group of participants in the model building process (Richardson & Andersen, 1995; Vennix, 1996). Early SD model building exercises have been criticised by practitioners as expert-oriented processes that led to a narrow problem definition, subsequent difficulties in the communication of results, and low buy-in of recommendations by decision-makers and the public (Hovmand, 2014). The focus of GMB is on participatory processes, where group members exchange their ideas and perceptions and explore questions together on the nature and origin of the problem and possible solutions, rather than solely focusing on model accuracy (Vennix, 1996). GMB is particularly suited to development challenges which can be characterized as “messy problems,” i.e., problems in which there are large differences in opinions across diverse stakeholders (Antunes et al., 2006). Vennix (1996, pp. 4-6) put forward three purposes for GMB when tackling “messy problems.” First, GMB creates an environment in which participants can learn from one another, where an individual’s mental models are shared and transformed through interactions. These interactions create a shared understanding of the context and problem. Second, consensus among team members on the nature of the problem and potential solutions is sought only after sharing of viewpoints and deliberation. Finally, the GMB process should foster commitment to the resulting decision and buy-in to follow-up interventions. Applying these three principles lends itself to an interactive and iterative SD modelling process (Sterman, 2001).

Common steps have emerged to facilitate a GMB process (Cavana & Maani, 2000; Hovmand, 2014; Sterman, 2010; Vennix, 1996). The first step is for the group to clearly identify and define the problem and the purpose of the model. A focused problem is critical as SD models are useful in simplifying complex systems, seeking to create an understandable representation of relevant parts of a system, rather than the entire system (Sterman, 2002). This is built on an understanding that all models are inherently wrong and, therefore, models are only representations of a sub-system (Sterman, 2002). Next, the system is conceptualised to understand the nature and cause of the problems – a dynamic hypothesis. GMB processes facilitate stakeholders to discuss and define the system and its relationships using CLDs, SFDs, and model boundary diagrams. Depending on the nature of the problem and the background of participants, a basic preliminary model can be shared with participants for modification, rather than a blank-slate approach (Vennix, 1996). The output of this step is an agreed concept model of the problem, including root causes, feedback loops, and dynamic relationships. At this stage of the GMB process, the model can remain qualitative for the purpose of increasing understanding, or it can progress towards a quantitative model that is used to test solutions to the initial problems.

Formulating a quantitative simulation model is the next step in the GMB process. This involves quantifying the model's parameters by specifying mathematical equations for each of the relationships in the system and initial conditions (Vennix, 1996). Data for the parameters can come from a variety of sources, often starting with participants in the GMB process and then extending to key informants and secondary sources. Next the model is tested and validated to build confidence in the soundness and usefulness of the model (Forrester & Senge, 1980). Validation and testing are built on a number of premises, namely: i) there are no absolutely valid models and as such the model is built to generate insights for a specific problem; ii) tension between the validity and utility of the model should be resolved; and iii) exact validity can never be determined, hence validity is determined by the confidence of the end users of the model (Sterman, 2002; Vennix, 1999). Common tests focus on the structure and behaviour of the model with results routinely shared with key stakeholders to continue to refine the structure and its parameters (Vennix, 1996). Once the requisite confidence is built, the model is then used to design and test solutions to the group's selected problems, the stage often referred to as "policy analysis" or "scenario testing" (Vennix, 1996; Sterman, 2000). At this point, intervention scenarios are simulated through the computerized SD model to determine their effect on the behaviour of the system, measured by a variety of indicators. Considering the results of this "scenario testing," policies are then analysed and prioritised for implementation by the group.

The logical next step in a GMB process is the implementation of policies that were identified through the GMB process, though this conclusionary step remains contentious (Vennix, 1996). Sterman's (2001) five-stage GMB process leaves out this step and it did not take place in previous GMB processes that developed SD models of agri-food VCs (Lie, et al., 2018; McRoberts, et al., 2013). While Vennix (1996) included "model use or implementation" as part of the final stage, "modelling as learning" is highlighted as the key approach. In this approach, the critical insights from GMB processes are conceptual, i.e., improved understanding of the problem, rather than instrumental, i.e., actionable outcomes. While enhanced learning and mutual understanding are valuable outcomes of GMB, this should be balanced with the original intent of SD tools – providing pragmatic and considered decisions to real-world problems, such as those facing small-scale farmers in developing economies (Rich et al., 2011).

A representative group of stakeholders is selected to participate in the GMB sessions, striving to find a balance between local insights, expert knowledge, and participants with the authority to implement decisions and motivate others (Hovmand, 2014). Tensions typically exist in participant selection between smaller group numbers that encourage participation and harmony and larger groups that increase diversity, potential for conflict, and commitment to a decision (Vennix, 1996). Vennix (1996) suggested that it is better to have one group member too many than one too few, and that groups larger than twelve will require special attention to mitigate negative side effects. For VC research, GMB participants would include producers, processors, traders, and retailers as well as those from the enabling environment, such as government representatives, and those who will implement selected interventions, such as project staff and producer associations (Lie et al., 2017). Inherent to participatory processes, special attention needs to be paid to power dynamics among participants, definitions of community, the level of participation in group sessions as well as the inclusion of female and minority stakeholders (Cook & Kothari, 2001; Gaventa & Cornwall, 2008; Guijt & Shah, 1998).

Facilitation is one of the most crucial elements in a GMB process, with a particular focus on the facilitation team's attitudes, skills, and teamwork (Vennix, 1996). The use of a facilitation team is strongly encouraged; the common roles include a lead facilitator, a modeler, a process coach, a recorder, and a gate keeper (Hovmand, 2014). To aid in the facilitation of GMB processes, the use of scripts is advised (Andersen & Richardson, 1997). Scripts are developed in planning sessions by the facilitation team and aim to provide a roadmap for each GMB session, guiding the facilitation team in the process, team roles and behaviours, time available, and desired outputs (Hovmand et al., 2012; Luna-Reyes et al., 2006).

GMB was originally conceptualized as a participatory process for engaging clients in SD modelling exercises. As Vennix (1996, p.4) stated, "in group model-building the model is created in close interactions with a group of policy makers or managers." Mediated Modelling (MM) extended GMB participants beyond "clients," to include stakeholders in industry, government, academia and the public (Antunes et al., 2006), while Community Based Systems Dynamics (CBSD) emerged within the GMB discourse in response to the limited number of GMB cases involving community stakeholders (Hovmand, 2014). CBSD focuses on engaging communities in the modelling process as a key stakeholder, assisting communities to co-create models to problems which affect them and empowering and mobilizing communities to advocate for and implement identified change interventions (Hovmand, 2014, p.6). While definitions of community are contestable, for the purposes of pro-poor VC upgrading, community participation in a VC GMB process would entail representatives of small-scale farmers and other VC actors as active participants in building SD model, scenario testing, and selecting upgrading interventions.

A further evolution of GMB has been the recent addition of spatial group model building (SGMB). SGMB builds upon CBSD and GMB principles to include participatory GIS tools to explicitly address the spatial aspects and drivers of agri-food systems (Rich et al., 2018). One of the limitations of a traditional GMB approach to agri-food VCA is that concerns around space and association with place do not inform the analysis. However, Rich et al. (2018) postulate that in agriculture or VC systems, prospective interventions will likely have a spatial element, such that nodes in the VC are impacted differently according to their geographic location, and patterns of trade and land use co-evolve with policies and have corresponding feedback loops. The addition of participatory GIS tools helps stakeholders visualize system phenomena, thus improving the quality and pace of information collected. It also facilitates greater participation in GMB sessions by accounting for the spatial elements that influence the participatory process itself as well as the resulting SD model (Rich et al., 2018).

Spatial information can be collected using participatory GIS platforms such as “Layerstack,” a physical facilitation tool that uses a series of transparent plastic acetates over a local map. Each of the plastic acetates equates to a different data collection layer (similar to a computer-based GIS) that enables spatial representation to the system (Mumba, et al., 2017). Layer definitions can include patterns of trade, resource use, socio-economic characteristics, and disease outbreaks. Various consumables are used to label spatial characteristics by participants, and reference modes and running legends are directly drawn on the edges of the map to illustrate trends in spatial elements. Mumba et al., (2017) noted that SGMB methods increased participation and motivation among stakeholders with the visualisation tools contributing to the quality of data collected. This supports earlier findings that visualised SD presentations of complex information aid strategic decision making (Fisher, et al., 2003). Rich et al. (2018) suggested that further research is needed to test, validate, and codify the SGMB process in terms of informing agricultural assessments and the development of SD models.

2.4.3 Application of system dynamics to the pro-poor value chain approach

Various toolkits and methodologies to support the pro-poor VC approach have been developed by INGOs and development donors. These include the ValueLinks 2.0 Manual on Sustainable VC Development (Springer-Heinze, 2018), Market Systems Development (WV, 2019), and M4P: Making VCs work better for the Poor (M4P, 2008). Rich et al. (2011) identified limitations to these methodologies (see Section 2.3.4) and proposed the use of SD modelling within agri-food VCs to simulate and conduct *ex-ante* impact evaluations of potential interventions.

The characteristics of agri-food VCs are well aligned to a systems dynamic approach, as Boehlje et al. (2011, p.54) noted, "one should view the decision process in the food and agricultural industry as a complex adaptive process…characterised by nonlinear processes…that require broader and more powerful analytical frameworks." SD models can take into consideration the complexity of agri-food systems that include, biophysical delays, cyclical behaviour, consumer preference changes, climatic changes, land use, institutional effects as well as the resulting dynamic interactions within the VC nodes (Fisher et al., 2000; Rich et al., 2011). This includes the ability to model interactions across the three parts of a market system, stylised within the Market System Development approach: supporting functions, core supply and demand nodes, and the formal and informal rules that shape behaviour (WV, 2018). Additionally, exogenous shocks which characterize agri-food VCs, such as weather and price volatility can be included in intervention scenarios (Rich et al., 2011). Traditional VCA typically maps and diagnoses the VC at one point in time – a static snapshot –, while in contrast SD models can address evolving dynamics. Additionally, SD modelling enables quantitative analysis and comparisons of intervention scenarios targeting different components of the VC system. For example, micro-level interventions targeting a small-scale farmer's production, such as improving access to quality inputs, could be compared to meso-level interventions, such as regional infrastructure development, or macro-level policy strategies, such as decreasing tariffs on fertilisers. Fisher et al. (2000, p. 282) aptly termed SD models "flight simulators," as they enable agribusiness decision-makers to reflect and experiment with strategic changes that would take years or even decades to bear results given time lags and uncertainty in the agribusiness environment. Importantly, SD models can analyse the impact of potential interventions on the performance of the entire chain and the distributional effects among the VC actors (Lie et al., 2018). This enables *ex-ante* analysis of intervention scenarios on small-scale farmers and other poor households involved in the chain, as well as the communities they live in, to ensure upgrading strategies have a pro-poor orientation. Within projects with limited funding and discrete timelines, SD models can therefore consider the costs and benefits of upgrading interventions to identify leverage points or catalytic action points. This trade-off analysis would enable decision-makers to select interventions that have a multiplying effect across the VC, to help ensure "win-win" scenarios, that specifically deliver sustained, positive impacts to small-scale farmers and surrounding communities.

Over the last decade, a body of research has demonstrated the utility of SD models to analyse agri-food VCs and conduct *ex-ante* analysis of policy interventions. This includes applications covering (i) the impacts of disease outbreaks and policy options on livestock systems (Naziri et al., 2015; Dizyee et al., 2017; Ouma et al., 2018); and (ii) policy and intervention options for agricultural VCs, including beef (Rich et al., 2009; Dahlanuddin et al., 2017), goats (McRoberts et al., 2013; Hamza et al., 2014), amaranth (Dizyee et al., 2020), and dairy (Lie et al., 2018). These case studies comprise theoretical studies (in which policy interventions were recommended at the systems or macro- level) and applied studies (where micro-level interventions were recommended for operationalization within a geographically defined agri-food VC or development project).

This research extends the methodology used within the applied case studies that generally use a standard format. First, once problem statements are agreed upon, an SD model of the VC is constructed, typically starting with a qualitative CLD. From the CLD, modules are agreed upon that correlate to key constraints and these form the basis of the quantitative, computer-simulated model. When the SD model structure is agreed upon by stakeholders, it is parametrized using data from GMB sessions, key stakeholders, and secondary sources, and the baseline is simulated to test and validate the model. VC upgrading interventions are then simulated to test their impacts on the VC, a stage known as scenario testing. These scenarios are aptly described by Lie et al. (2017) as "what if scenarios," for example "what if the quality of livestock feed improves?" The results of the what-if scenarios are then analysed against key performance metrics and analysed to derive policy recommendations.

Dizyee et al. (2017) developed a conceptual framework for SD models of agri-food VCs. More recent applications have modelled fewer nodes in the VC and / or restricted the model's boundary to a smaller geographic location (Ouma et al., 2018; Lie et al., 2018; Reinker & Gralla, 2018). Building on Dizyee et al.'s (2017) conceptual framework, Figure 5 presents an overview of the modules that typically constitute a VC SD model.

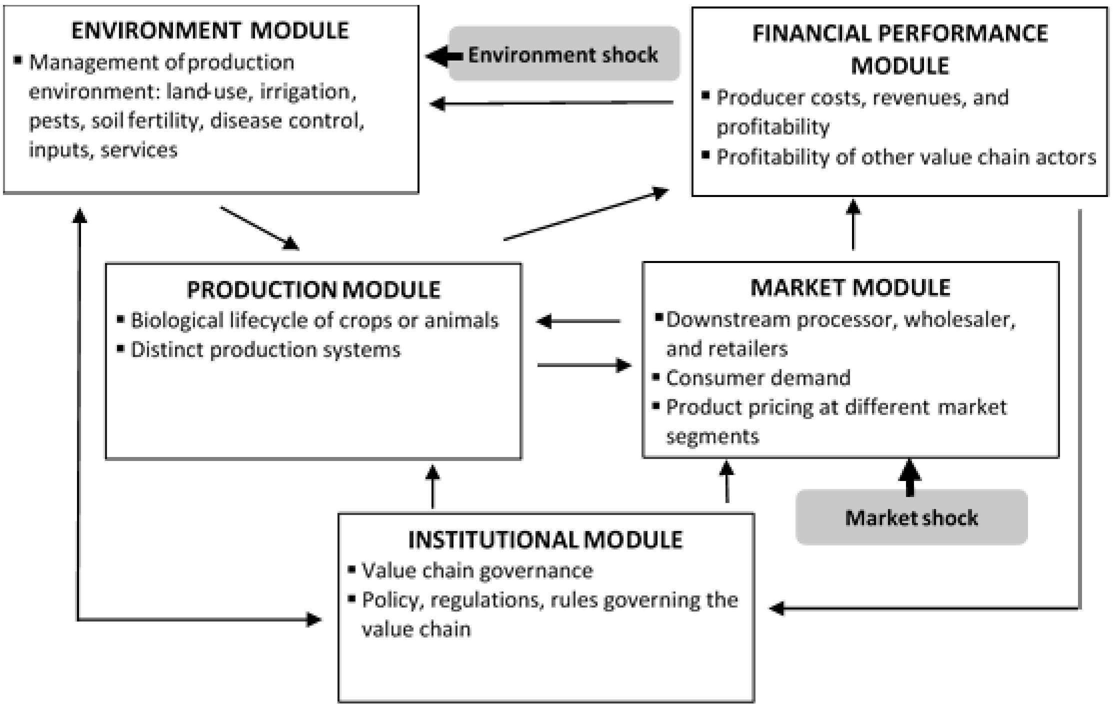

Figure 5: Overview of the common modules within agri-food value chain models
Source: Developed by the Author based on Dizyee et al.'s (2017) conceptual framework

The production module covers the biological lifecycle of the agri-food product at the farm-level. This can include distinct farm enterprises within production systems that supply inputs to one-another; for example, wean-to-finish and farrow-to-finish pig systems (Rich et al., 2018; Lie et al., 2018). The environment module covers factors that impact production systems, such as climate variability (rainfall patterns, seasonal temperature variations); resource management (allocation of land and water), biology (pests, disease), and the provision of critical inputs and services (such as the quality of seeds, fertiliser, feed, and production equipment). After the production module, agri-food products flow into a marketing module that covers the various post-farm segments, such as processors, wholesalers, retailers, and consumers. In the marketing module, prices for products are calculated along the different VC nodes, typically starting with the farm-gate price. These prices are either exogenous variables or computed endogenously. Sterman's inventory pricing method is a common approach for developing endogenous farm-gate prices for products (2010). Costs and revenues derived from the production and marketing modules input into the financial performance module that calculates the profitability of producers and other VC actors. Typically, expected profitability is the main driver of VC actor behaviour. This includes changes in production, processing, wholesaling, retailing, and consumption behaviours as well as changes within the coordination among VC actors. For farmers, expected profitability alters farm management practices in the environment module. The institutional module effects the production, market, and environment module through changes to policy, rules, and regulations. These can include changes to price controls, input subsidies, extension services, and import/export restrictions.

SD models generally include structure to model shocks that affect the VC system. While these shocks can operate on any part of the system, typically environmental shocks (drought, floods) or price shocks (rapid change in demand or supply) are simulated. Additional modules beyond those represented in Figure 5 are routinely added to SD models to represent potential policy or intervention scenarios. For example, Dizyee et al. (2017), included a module covering improved disease control and partial easing of the monopsony of the Botswana Meat Commission. Likewise, Lie et al. (2018) developed a knowledge module to simulate the impacts of training farmers, while Reinker and Gralla (2018) developed an agricultural input dealer module to simulate the effects of various options for providing quality seeds to farmers.

2.4.4 Gaps in the application of system dynamics to pro-poor agri-food value chains

SD modelling techniques have been used to test *ex-ante*, "what-if" scenarios across a range of agri-food VCs, demonstrating the applicability of SD techniques to VCA and their ability to analyse, prioritise, and recommend upgrading strategies. The recent introduction of participatory modelling techniques has also been shown to increase stakeholder understanding of the dynamic and complex nature of VCs (Mumba et al., 2017; Kopainsky et al., 2017; Lie et al., 2018). SGMB has recently evolved as a promising technique to incorporate critical spatial elements and participatory facilitation techniques. However, it has only been applied in a handful of cases, and therefore further research is required to test its applicability more generally to agri-food VCs in developing economies and to begin to codify processes.

Previous studies using SD modelling have been largely theoretical operating outside of an existing VC project and therefore did not follow pro-poor action-research principles as recommended by Riisgard et al. (2010). Apart from recent work by Cooper et al. (2021), there has been little emphasis on a cost-benefit analysis of recommendations (Lie et al., 2017), trade-offs across different impact measurements, VC actors and time horizons, or the capacity and willingness of stakeholders to implement interventions (Stoian et al., 2012). Moreover, while these case studies analysed the impacts at the small-scale farmer level, they did not incorporate pro-poor principles to extend the analysis to horizontal elements identified by Bolwig et al. (2010), such as employment, risk profiles, gender, the environment, and the intersection of other livelihoods. Hence, research has not yet fully documented the use of SD modelling to select pro-poor, agri-food VC upgrading interventions for implementation in a project and then used the model's findings to continue to guide the project's activities.

While there are various additional modules that can be built on the core SD model structure outlined in Figure 5, there are two notable gaps in the literature. Firstly, the impacts of credit are largely absent from agri-food VC SD models, even though credit is a common pro-poor upgrading action point (London et al., 2010; Milder, 2008). Reinker and Gralla (2018) noted that importance of credit to help farmers purchase quality inputs but omitted this from their model, while Dizyee et al. (2017) suggest including credit providers to extend VC models. Second, while the different types of collective action are widely discussed in the development literature, a collective action module that model's member behaviour and different institutional arrangements has yet to be developed. A simple collective action module was constructed by McRoberts et al. (2013). However, this did not capture the decisions that small-scale farmers make regarding patronising the producer association or the ability of the produce association to alter the level of retained earnings and price rebates based on their desired investment strategy.

Chapter 3
Methodology

This chapter presents the research's methodology, beginning with the research rationale in Section 3.1 and strategy in Section 3.2. The research methods are discussed in Section 3.3, including the key steps in developing the SD model and other data gathering techniques. Section 3.4 describes the research's ethical considerations. Finally, Section 3.5 outlines the creation of two new SD modules, which covers the provision of credit and collective action.

3.1 Research rationale

The purpose of this research is to identify, describe, and quantify the impact of pro-poor interventions to upgrade the pork VC in the Tanintharyi region of Myanmar. The research is grounded in the interpretative social science paradigm as it seeks to understand and describe complex human and social interactions with biological phenomena (Neuman, 2011). Further following interpretivist principles, the Researcher interacted closely with the phenomenon under study, using participatory and qualitative tools to develop quantitative models of agri-food VCs. Rather than maintaining a distance from the research subject to avoid bias, the Researcher was fully engaged in the process of upgrading VCs with a partiality for pro-poor interventions that benefited the project's target population (Neuman, 2011; Riisgard et al., 2010).

In the research's model-building phase the ontological position is interpretivist: agri-food VCs are represented by system dynamics (SD) models, following their interpretation and reconstruction by the Researcher and model builders (Flood, 2010; Pruyt, 2006). Within the research, system concepts are employed in the process of constructing reality, which reflects an assumption that the world is systematic (Flood, 2010, p. 276). This position is aligned with Sterman's assertion that as a representation of reality, "all models are wrong" and therefore the focus is on creating "useful models" (2000, p.251), and Flood's (2010, p.276) view that models act as "a pair of spectacles through which we can look at and interpret reality." From a pragmatist position, the research's logic is both inductive and deductive (Pruyt, 2006). Real-world observations, facts, and previous findings are induced to construct a "useful" or "least wrong" structural micro-theory, the quantitative SD model, which is then deduced to evaluate, *ex-ante*, the impact of upgrading interventions (Pruyt, 2006, p. 22).

The research is both descriptive and explanatory. A rich description of the pork VC (Objective One), the *ex-ante* results of upgrading interventions (Objective Two), and the recommended pro-poor upgrading interventions (Objectives Two and Three) are built through mixed methods. Operating within an SD framework, the research highlights critical feedback loops, time delays, and stocks to explain the dynamic and complex behaviour of the VCs (Objective One). The research explains the rationale for recommending specific upgrading interventions (Objective Two and Three) and highlights initial implementation efforts (Objective Three), explaining challenges as well as enabling factors that draw conclusions transferable to the wider pro-poor VC literature. Finally, the research describes and reflects on the SGMB process, explaining its effectiveness on engaging participants and drawing lessons for future application (Objective Four).

3.2 Research strategy

This study employed action research for its principal strategy as recommended by pro-poor VC literature (Riisgard et al., 2010). According to Reason and Bradbury (2008, p.1), "Action research is a participatory, democratic process concerned with developing practical knowing in the pursuit of worthwhile human purposes, grounded in a participatory worldview." Integrated within a development project, this research fulfils the action research mandate of identifying effective solutions to real-world problems: using participatory processes to select high-impact interventions to upgrade a pro-poor VC in Tanintharyi region of Myanmar (Stringer, 2007). With a focus on action, the Researcher was actively involved in bringing about change, rather than investigating and documenting a change process from the outside (Piggot-Irvine, 2009). This change process was grounded in systems thinking, i.e., SD tools were used to construct meaning that represents people's experiences within VC systems (Flood, 2010, p.282). In terms of positionality, the action research aimed for reciprocal collaboration (insider-outsider teams) with TRRILD project partners and VC actors, striving for equitable power relations where knowledge is jointly developed and owned (Herr & Anderson, 2015).

Four distinctive features of action research underpinned the research strategy. Firstly, action research fosters participatory and collaborative partnerships (McNiff, 2016). The research used participatory processes that engaged small-scale farmers, VC actors, TRRILD staff, and government officials. Moving beyond subjects of the research, these actors collaborated with the Researcher and one another to develop the VC SD models and implement upgrading interventions. Relationships and knowledge fostered by the model-building process (i.e., the research) extended into non-research spaces as VC actors begin to partner and collaborate with each other to improve their enterprises. The research's results were also shared with actors outside of the SGMB process, as powerful actors beyond the immediate VC are often required to implement successful upgrading activities (Riisgard et al., 2010). This resulted in preliminary discussions with a national supermarket chain to supply them with premium pork products.

Secondly, a "research in action, rather than a research about action", approach was taken (Coghlan & Brannick, 2014, p.6). The goal of action research is practical knowledge that makes an action more effective, while simultaneously extending the scientific body of knowledge (Stringer, 2007). Embedded in a development "action," the research was shaped by the TRRILD project's boundaries, such as resources, budget, and timeline, and its requirement for practical, easy-to-implement solutions. Beyond the local and practical, the research broadened the understanding of participatory SD modelling techniques and pro-poor VC interventions in developing economies, which benefited the wider body of scientific knowledge.

Thirdly, the research sought to practise transformation towards human flourishing, defined as positive and sustainable change to actors, relationships, systems, and the environment (Reason & Bradbury, 2008; Coghlan & Brannick, 2014). This included expanding participant mental models of the VC system, facilitating positive working relationships among chain stakeholders, encouraging wider participation in determining upgrading strategies, and ultimately improving the lives of small-scale farmers. To answer the call for sustainable change, the research measured impact across short-, medium-, and long-term time horizons as well as based on a typology of farmers and other key actors in the chain.

Lastly, a systematic approach to problem solving defined the research (Coghlan & Brannick, 2014; Reason & Bradbury, 2008). Lewin's cyclical understanding of action research was followed, which as he describes (1948, p.206), "proceeds in a spiral of steps, each of which is composed of a circle of planning, action and fact-finding about the results of the action." The research drew on common cyclical approaches to follow four steps of (i) observation and evaluation, (ii) reflection, (iii) planning, and (iv) action which leads to further observation and evaluation (Reason & Bradbury, 2008; Stringer, 2007). While explained as steps, the research was iterative rather than linear and functioned as a continuing spiral of working through the four steps, a practise echoed within GMB literature (Rich et al., 2015; Vennix, 1996).

Two main action research cycles took place and are outlined in Figure 6. The first cycle developed the SD model and selected upgrading interventions, starting in July 2018, and finishing in August 2019. The second cycle that followed started in September 2019 and finished in December 2020. This cycle monitored the TRRILD project and contextual changes in order to revise the SD model and steer subsequent upgrading actions. Within the four steps, further action research micro-cycles occurred as described by Cardno (2003). For example, after each workshop, an open reflection session was held with the SGMB team, which led to updates to future scripts and workshop practices. Additionally, as social science research, the study systematically documented the methods used to collect data, build models, and to select and implement interventions. To support this, an action research journal recorded the Researcher’s reflections and insights along with any notable incidents as recommended by Bartlett & Piggot-Irvine (2008).

The research strategy incorporated a longitudinal case study, an approach strongly associated with action research (Neuman, 2011). According to Yin (2009, p.18), a case study is an empirical inquiry used to understand a real-life phenomenon in depth, particularly when the boundaries between the phenomena and the context are not clear. In this research, the real-life phenomena of agri-food VCs are deeply embedded within context, i.e., location, time, culture, and project. Rather than divorcing the phenomenon under study from its context, a case study approach draws out critical features and highlights key relationships and influences. Yin (2009, p.19) further adds that a case study approach relies on multiple sources of evidence and triangulation to cope with a situation in which there will be many more variables of interest than data points. To manage such data complexity, only variables which had a strong influence on system behaviour were included in the SD models, hence, defining the boundary of the system under study. Newman (2011) recommends triangulating data to improve research validity. In the SGMB process, model data was triangulated by involving multiple actors in each SGMB workshop, rechecking critical information over time, and having a reference group serve as a technical backstop to the process. Outside of the SGMB process, triangulation was also achieved through key informant interviews (KIIs), focus group discussions (FGDs), observations, and the use of comparable secondary data.

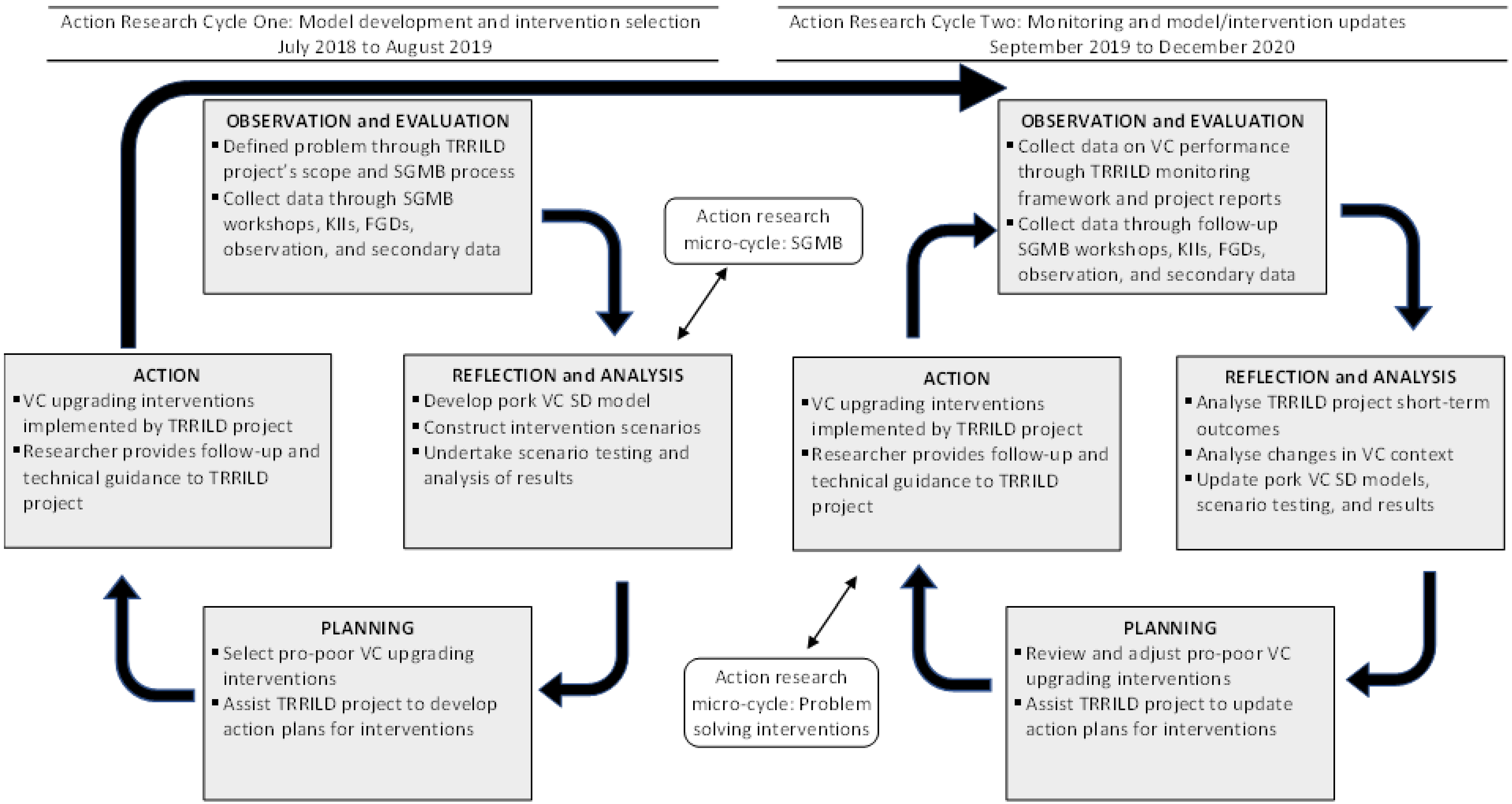

Figure 6: Overview of the action research process
Source: Developed by the Researcher

3.3 Research methods

The research employed mixed methods to achieve its objectives. The chosen methodology was, to a large extent, determined by the action research orientation and the subsequent requirement to integrate within the TRRILD project's logical framework, deliverables, and timelines (Neuman, 2011). The research used qualitative tools and processes to build an SD model which generated quantitative results, enabling the TRRILD project to select pro-poor upgrading interventions. For clarity, this section presents the research methods in a series of linear steps; however, in practice these steps often overlapped and oscillated.

3.3.1 Research scope

The TRRILD project's approved design and contractual obligations to MFAT provided clear boundaries for the research's scope:

- Coverage to include 32 peri-urban and rural villages in Myeik and Palaw Townships of Tanintharyi Region, Myanmar.
- Establish agri-food VCs that have wide smallholder participation, commercialisation potential, are inclusive (of gender and ethnic minorities), and are environmentally sustainable.
- Develop interventions which have a demonstrable pro-poor impact (as defined by the project's Results Measurement Table) on small-scale farmers within the project's lifetime (2017 to 2022).
- Include interventions that fit within the project's activity and budget categories.

The selection of pork and rice VCs as a focus of the TRRILD project was undertaken by the TRRILD's project advisory committee (PAC[2]) prior to the commencement of the research's field work. A three-step selection process was used between March to October 2018. First, participatory processes narrowed down the wide scope of potential VCs to a shorter, "long-list" of candidate chains. Economic, environmental, social, and institutional criteria were then used to judge and rank candidate chains as per the guidelines developed by Schneemann & Vredeveld (2015). This ranking process selected paddy rice, rubber, dried prawns, pigs, fish paste, cashew nuts, chicken, dried fish, and gourds as potential agri-food chains. Second, a rapid assessment of these VCs was conducted. For each VC, approximately ten key informants were interviewed to collect quantitative information

[2] The TRRILD's PAC consisted of representatives from each of the partner organisations and provided management oversight to the project.

of VC processes; constraints and solutions; rankings based on economic, environmental, social, and institutional criteria; and qualitative information on chain governance. Secondary data was also collected and analysed to triangulate information from these interviews. Finally, rapid assessment data were analysed and discussed in plenary during a three-day workshop with TRRILD project partners. From this workshop, two products were prioritised, paddy and pigs, and subsequently approved by MFAT in November 2018, from which the pork VC forms the focus for this thesis.

3.3.2 Development of system dynamics models

The research combined tools and techniques from GMB, CBSD, and SGMB to develop qualitative SFDs that were extended into quantitative SD models of the pork VC. Figure 7 provides a high-level map of the key steps to develop the SD model and provide upgrading recommendations to the TRRILD project. In Figure 7, non-shaded objects represent activities conducted in Myanmar that support the model-building process, light grey shapes highlight SGMB and reference group (RG) sessions and their outputs, while objects shaded in dark grey represent remote modelling work conducted in New Zealand. Model-building workshops were held between January and March 2019 in Myanmar. The preliminary SD model and upgrading recommendations for the pork chain were provided to the TRRILD team in August 2019.

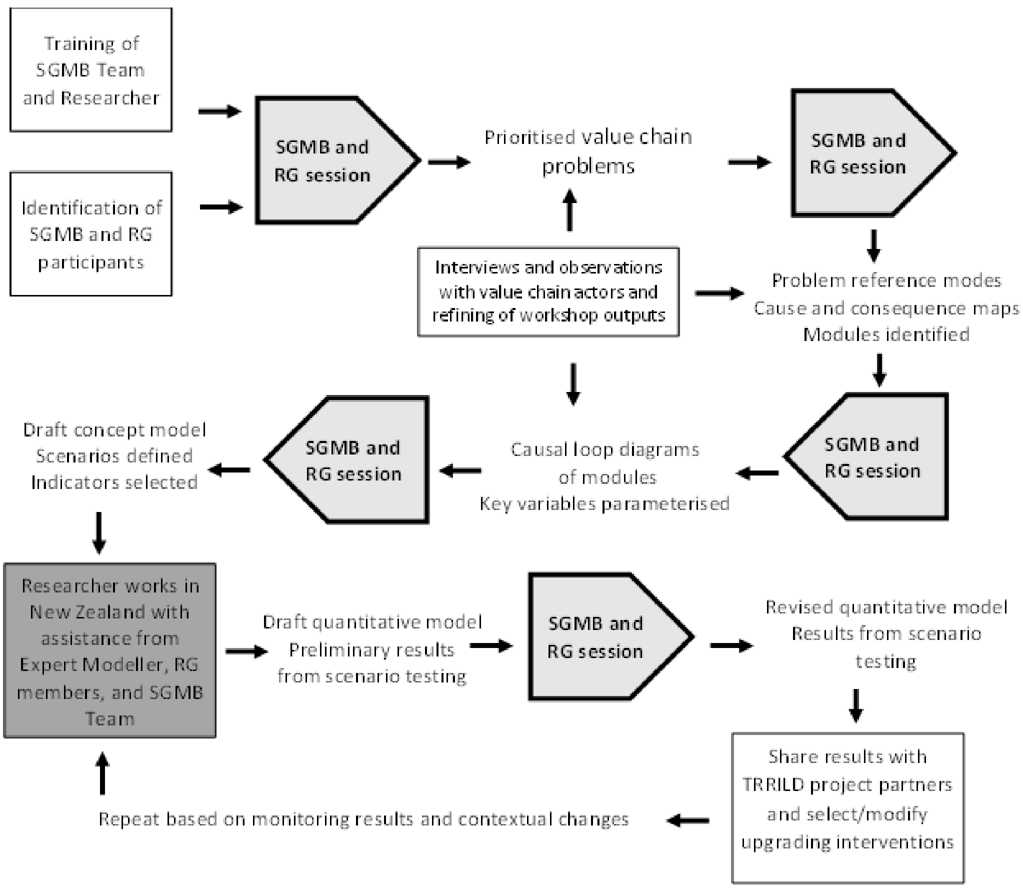

Figure 7: High-level map of the model building process

Source: Developed by the Researcher based on GMB process outlined by Lie et al. (2017)

3.3.2.1 Participants

The model-building process was centred around two core platforms, SGMB workshops and RG sessions. Most model-building outputs originated from SGMB workshops, which represented actors directly involved in the VCs. RG sessions helped refine SGMB outputs and provided an additional layer of technical analysis and information triangulation. The division into two separate model-building groups followed the methodology of Lie et al. (2017) and was considered crucial to reducing power dynamics among participants to allow more open and robust discussions. Further tools and techniques were used within workshops to mitigate power imbalances amongst SGMB and RG participants, these included small group work, a balance of small group, plenary, and individual tasks, and the training of the MBT in participatory group facilitation techniques (Hovmand, 2014; Lie et al., 2017).

The selection of participants for the SGMB workshops and RG sessions was undertaken by the TRRILD staff with support from the Researcher. To ensure SGMB and RG participants represented the pig industry in Myeik and Palaw the initial participant selection criteria was developed by the Researcher by drawing on both secondary data (Ebata et al., 2018; Soe, 2018) and a recent VCA conducted by the TRRILD team in December 2018 and January 2019 (ACCESS, 2019). These sources revealed distinct sub-categories of pig producers in Myanmar, common nodes in the value chain, and key power brokers that should be included in SGMB workshops and RG sessions. Most of the TRRILD staff had previously worked in the target area and used their local knowledge and connections to select participants which fulfilled the criteria provided by the Researcher, including actors representing critical nodes in the VCs as well as a diversity of age, gender, ethnicity, and wealth rankings. After the Researcher and MBT visited farms and value chain actors prior to the first SGMB workshop, there were a small number of adjustments to SGMB and RG participants to improve representation of the target area. Two World Vision Myanmar staff acted as the primary gatekeepers for workshops, both of whom held over five years of experience working in livelihoods projects within the partner INGO. They provided access to key VC actors and helped motivate their attendance at formal sessions and facilitate meetings for the Researcher outside of the workshop settings. Purposive sampling was used by gatekeepers to identify and invite workshop participants that matched the selection criteria. Importantly, gatekeepers maintained a close link with local government authorities, drawing in senior technical officers to the RG sessions whose attendance brought credence to the process, and helped the Researcher to gain the necessary approvals to visit remote field locations.

Two concurrent SGMB processes were held: workshops in Myeik focusing on the pork VC and workshops in Palaw focusing on the rice VC. Fifteen people representing different nodes in the VC were invited to participate across five SGMB workshops in each location. While this number is at the upper end of recommended group size, a larger number helped ensure broader representation of VC nodes and allowed for dropouts as suggested by Vennix (1996). An average of 13 VC actors attended the Myeik SGMB workshops, including five small-, two medium-, and two large-scale pig producers, one broker, three slaughterhouse managers, and two slaughterhouse licence holders whose businesses operated across brokering, slaughtering, and wholesale functions. Of these SGMB participants, 53% were female, and all but one were of Burmese ethnicity.[3]

The RG sessions involved technical experts covering both VCs and had a more fluid membership as participants attended sessions aligned with their expertise. An average of eight people attended from a pool of 12, with 25% female representation. Participants were technical specialists from INGOs, technical officers representing the Township or Regional Livestock Veterinary and Breeding Department (LBVD) and Agricultural Departments, and experienced farmers. In addition to providing specific technical inputs on paddy or pig production, RG members also brought to light differences between the contexts (and variables used in the model) in Myeik and Palaw. This allowed for further generalisation of results, important to the project which would implement upgrading interventions across both townships.

Out of the twelve weeks of field research, approximately two-thirds of the time was dedicated to preparing and running SGMB and RG sessions and to the refining of workshop materials. This left sufficient time for the Researcher to use KIIs, FGDs, and observations to triangulate and expand the knowledge base of the model and the research.

3.3.2.2 Model building team

A six-person model building team (MBT) was established to facilitate SGMB and RG sessions. Discrete roles and responsibilities were assigned to each team member and training provided with additional focus on attitudes, skills, and teamwork. The roles and responsibilities of team members are detailed in Table 4. The Researcher took on the Team Leader role, which covered facilitator, process coach, and modelling, a common practise in participatory research (Voinov & Bousquet, 2010). As all workshops and interviews were conducted in the Burmese language, a translator supported the Researcher in all interactions and translated notes from other MBT members into English. While sessions were steered by a Lead Facilitator, Assistant Facilitators enabled workshops to flow, by guiding small-group sessions, helping struggling participants to understand (translating from Burmese to Karen) and write, and taking care of physical functions, like posting notes to whiteboards and collating data. Importantly, Assistant Facilitators were able to raise points to the attention of the Lead Facilitator which they had missed or had gone unnoticed during robust group discussions. A

[3] An average of 13 participants attended the paddy SGMB workshops, including seven paddy farmers, three rice millers, two paddy traders/brokers, and a rice wholesaler. Participants came from the both the two main ethnic groups, Burmese (10) and Karen (3), and 25% of participants were female (one farmer and two traders).

Notetaker documented the workshops by taking a written and visual record of key discussion points and materials.

Table 4: Roles and responsibilities of the MBT

Role	***Position in TRRILD project***	***Key responsibilities***
Team Leader	PhD Researcher	- Lead MBT - Prepare agendas and scripts for each model building session - Lead reflection exercises - Support Lead Facilitator to lead and direct each model building session - Finalise CLDs and SD model
Lead Facilitator	TRRILD Market Facilitator	- Work with gatekeepers to identify RG and SGMB participants - Facilitate RG and SGMB sessions - Maintain connection with local government officials
Expert Modeler/ Process Coach	ILRI Principal Scientist	- Train MBT - Evaluate and provide feedback on first RGs and SGMB workshops - Advise on agendas and scripts for model-building sessions - Support development of CLDs and SD models
Assistant Facilitator	TRRILD Community Development Facilitator	- Organise logistics for each session (location, inviting participants, transport, stationery, food/drinks, koha[4]) - Bring to the attention of Lead Facilitator any issues or concerns during sessions - Support Lead Facilitator to facilitate all sessions, i.e., small group discussions, hanging posters on walls, etc.
Assistant Facilitator/ Translator	TRRILD Field Enumerator	- Support translation for Team Leader for workshops, KIIs, and FGDs - Bring to the attention of Team Leader any issues or concerns during sessions - Support Team Leader to facilitate sessions (when required)
Notetaker	TRRILD Community Development Facilitator	- Take notes of key processes/discussions during model building sessions - Record observations on participant's behaviour during sessions - Photograph and store all workshop material

Source: Developed by the Researcher

With no previous background in SD modelling, apart from the Expert Modeler, training, agendas, scripts, and reflection exercises were applied to build the capacity of the MBT. The Researcher attended a five-day training workshop in India prior to field work in Myanmar. This training was led by the Expert Modeler and covered Layerstack, CLDs, SFDs, and quantitative systems modelling, including practise sessions with participants. Once the MBT was assembled in Myanmar, a two-day intensive training was delivered by the Expert Modeller in Myeik. This covered basic SD theory but focused on practical exercises which would form the core of upcoming workshops, like Layerstack, reference modes, cause-and-consequence maps, and CLDs. Detailed agendas, including GMB scripts, were prepared for each workshop and tools were rehearsed during the full-day planning sessions held before each workshop. The use of agendas and scripts helped the team, by articulating common steps for each exercise, and defining outputs and the associated roles, materials, and time allotments. A summary of the agendas for each SGMB workshop are found in Appendix A. The Plus-

[4] The term "koha" is a Māori word that refers to a gift, present, offering or contribution.

Minus-Interesting (PMI) technique as outlined by Sharma & Priyamvada (2017) was used after each SGMB and RG session to critically reflect on the process and generate consensus for improvements in subsequent actions.

3.3.2.3 Model development

As illustrated in Figure 7, a total of five SGMB and RG workshops were held to build the SD model, which were structured around key steps of problem definition, causal loop modelling, developing a quantitative dynamic model, scenario testing, and implementation (Cavana & Maani, 2000). A brief overview of the steps in the model-building process follows, with Table A6 in Appendix A providing a detailed timeline, including timing, objectives, and participants involved in each step. The first four sessions were conducted over a seven-week block (January to March 2019) in Myanmar, resulting in the development of concept models of the VCs along with the interventions and indicators for scenario testing. This concept model consisted of interconnected CLDs that represented key modules and were replete with stocks, flows, and converters. This was translated into a quantitative SD model using the Stella Architect software package (http://www.iseesystems.com) by the Researcher in New Zealand over a four-month period. Following model validation, the Researcher undertook scenario testing and analysed the model's results to determine the preliminary upgrading interventions. The SD model and preliminary results were then reviewed and validated during a fifth combined SGMB and RG session. Following minor adjustments to the model, results of the scenario testing and recommendations for upgrading interventions were then presented to the TRRILD's PAC in August 2019.

A systematic participatory approach was taken to prepare and deliver each RG and SGMB workshop. Preparation began with the Researcher developing a draft agenda for each upcoming workshop. This was then discussed and modified with the MBT, resulting in a final agreed copy which was disseminated to all MBT members. A summary agenda was written in Burmese on a large sheet of paper and placed on the workshop wall for ease of access. During preparatory sessions, key tools and exercises, like Layerstack, were practised among MBT. These practise sessions enabled the MBT to trial Burmese equivalents of key English SD or VC words and phrases in order to agree on easy-to-understand equivalents. Apart from the final SGMB and RG sessions, no PowerPoint slides or digital media were used. Instead, all concept models and variables were hand drawn and written on large posters in Burmese prior to the workshops. Tactile, low-tech materials were chosen so that materials were more accessible to participants, encouraging them to make physical changes to models through markers, pens, and post-it notes. Once written onto posters, the Burmese text was then crosschecked for understanding and accuracy by a member of the MBT verbally translating it back into English for the Researcher. Special attention was given to the organisation of the workshop spaces as suggested by Hovmand (2014). WV Myanmar offices were used for each of the model-building sessions after being cleared of any redundant furniture or posters, and desks were placed in a C shape to aid the ease of movement, communication, and concentration. Participants were registered on their arrival by the Notetaker and provided a name tag, complete with a coloured background that corresponded to their function in the VC; for example, farmers had a green background, and butchers had a grey background. This system helped the MBT to encourage participation across all VC nodes during group exercises and note any nuances related to VC function.

The first workshop in the series was held with RG members and introduced the TRRILD project and SD concepts. An overview of the VCs was discussed, and critical problems prioritised by participants. This workshop afforded buy-in by key government officials that attended and allowed the MBT to have a practise run facilitating key scripts and tools and using SD terminology in the Burmese language. Following this initial workshop, RGs sessions followed a similar pattern of reviewing and revising CLDs and associated parameters.

The goal of the first SGMB workshop was to prioritise problems in the VC. To start defining the model's boundary, the TRRILD project's scope was introduced to participants, stressing its focus on pro-poor VC interventions for the target population. The SGMB process and timelines were introduced, and participants were reminded of the need to attend all five sessions if possible. Following participant introductions, the "Hopes and Fears" script developed by Luna-Reyes et al. (2006) was used to identify expectations for the SGMB process and clarify any concerns or misunderstanding. The basic language of SDs was introduced in this first session and reviewed in each subsequent session to allow participants time to become familiar with new concepts. A modified version of the water glass script ("coke on a hot day") introduced stocks, flows, converters, and behaviour-over-time graphs. Participants then gathered around the Layerstack tool and, after a demonstration by the MBT, proceeded to draw the VC layers with reference to spatial elements on the underlying geographical map. The recently introduced SD terminology was used by the facilitator to prompt discussions, with behaviour-over-time graphs of dynamic behaviours sketched alongside the VC layers.

The VC discussions generated by Layerstack segued into identifying problems faced by VC actors. Problems were individually written on coloured cards and presented in plenary by participants which allowed for further refinement. Any spatial associations of problems were also identified by participants on the large maps of Myeik and Palaw which were positioned at the front on the room. Once grouped under common issues on the whiteboard, participants voted for their top three problems by placing sticker dots on their choices. A maximum of two stickers per person per problem was allowed. The top three problems were then further discussed in plenary to end the first session. In addition to the workshop, a baseline survey of participant knowledge regarding VCs was completed at the start of the session, as was the completion of a consent form to comply with ethical research practices.

In the second SGMB workshop, VC problems were further explored to determine key modules to develop into CLDs. Participants were divided into small groups, containing participants from each VC segment, to sketch reference modes for the prioritised VC problems. Reference modes took the form of behaviour-over-time graphs covering the last ten years and were drawn in the centre of a whiteboard. Participants then wrote the causes of the problem on individual coloured cards, that were placed on the left side of the reference mode. The facilitator grouped similar causes together and prompted a discussion on root causes by asking the question, "What causes this?", to sketch the causal relationships of the problem. The process was repeated on the right side of the reference mode for the consequences of the problem through the question prompt, "And then what happens?" Relationships between consequences and causes were then identified and emerging feedback loops discussed, documenting the polarity between variables. Each small group's work was then presented for plenary discussions and revision by consensus, which was the pattern for all small-group work in SGMB and RG workshops. The MBT facilitated plenary discussions on themes which emerged from the causes and consequences mapping to identify modules that were to be further developed into CLDs. Clearly identifying modules enabled the basic boundary of the model to be established at that point. To prepare for the next session, basic CLDs of production and finance modules that utilised SD structures were introduced to participants and adjusted based on plenary discussions.

The third SGMB session concentrated on developing qualitative CLDs for each module. Small-group work was used to draw module structures on large paper sheets. These CLDs contained stocks, flows, converters with key causal relationships and feedback loops assigned positive or negative polarity. Small groups presented their CLDs to the wider audience, highlighting causal relationships, and the facilitator sought revision and adjustments through open discussion. Most discussions were solved through reaching a consensus, with lingering disagreements going with the majority while the minority views were recorded by the Notetaker. Differences between pig production systems were common and a lot of time was spent identifying production categories which would later become the arrays within the quantitative SD model. Once agreement on the structure was reached, key module structures were then parametrised in plenary, taking note of differences across production systems.

Typically, SGMB workshops were separated by five days to allow refinement of workshop outputs, debriefing, preparation with the MBT, and KIIs with VC actors. The longest time gap occurred between the third and fourth workshop as two weeks was needed to refine and combine the CLD modules into a simple concept SD model, while undertaking individual follow-ups with SGMB and RG members. This concept model used SD structures and each variable was parametrised. However, the two weeks was insufficient for the Researcher to present a working quantitative SD model for the fourth workshop, contrary to the original plan.

In the fourth SGMB and RG workshops, the concept model was validated, and scenarios and indicators prioritised for later stages. The Researcher presented the concept model (which had earlier been drawn on multiple paper sheets and attached to the workshop walls) in plenary, highlighting feedback loops and relationships which led to the problems and behaviours identified in the second workshop. A particularly useful tool was requesting volunteers to present the concept model to the group, as it enabled the Researcher to identify and clarify any misunderstandings. Participants recorded any final changes to the structure on coloured cards and these were placed on the model if there was group consensus. Model data was validated in a similar manner. Following lunch, the Researcher explained how the concept model would be converted into a quantitative SD model using Stella Architect which would allow for scenario testing. Participants individually wrote on coloured cards their preferred intervention scenarios which were then grouped by themes on a white board. Again, participants prioritised intervention scenarios through voting with three stickers. This process was repeated to select indicators to use during the model to measure the impact of intervention scenarios on the VC. The fourth workshop finished by thanking participants and outlining the remaining tasks to finish the model, including a provisional date for the fifth workshop.

Once back in New Zealand, the Researcher spent around four months to convert the concept model into a quantitative SD model of the pork VC. During this time, iterations of the model were shared with the Expert Modeler for advice. When data gaps emerged, the Researcher connected remotely to RG members or to SGMB members through the MBT who remained employed by the TRRILD project. When primary data were not available secondary data were used. Priority was given to sourcing secondary data from Myanmar, but when this was absent, data from similar contexts in Southeast Asia were applied to the model.

3.3.2.4 Model validation and scenario testing

Model validation was undertaken to establish confidence in the reliability and usefulness of the SD model (Forrester & Senge, 1980). Four commonly prescribed tests for model validity were performed throughout the model process, rather than as a single discrete step as recommended by Vennix (1996), Sterman(2000), and Ford (2010). The validation process is described in more detail in Section 4.2.1.

After the validation exercises established requisite confidence in the baseline model, preliminary scenario testing and the analysis of results were conducted in New Zealand. Scenarios and indicators derived from the SGMB and RG participants were added to by TRRILD project partners. The TRRILD's

PAC then worked with the Researcher to narrow possible interventions to a short-list by considering their pro-poor orientation, environmental impact, and alignment to the TRRILD project's logical framework, scope, budget, and technical capacity.

Generating results and upgrading recommendations continued in New Zealand. The results of each upgrading scenario were compared to the model's baseline and evaluated around the following questions:

i. What are the short-, medium-, and long-term impacts of each intervention?

ii. What are the costs (financial, human resources, etc.) of each intervention?

iii. How are the costs and impacts (positive and negative, intended and unintended) distributed among the VC actors?

iv. How are intervention impacts affected by shocks to the system?

v. What combination and timing of interventions bring the highest impact?

vi. How sensitive is the rank order of interventions to changes in uncertain parameters?

3.3.2.5 Sharing results and model refinement

The baseline SD model and findings from scenario testing were shared with RG and SGMB participants through a fifth and final workshop held in Myanmar in August 2019. Feedback from participants was provided on both the model's structure and data, as well as the findings. This also provided an opportunity to double-check data for critical variables and determine uncertain variables in the model for sensitivity analysis. Once this feedback was incorporated into the SD model, it was considered a "final" draft and scenarios were re-run and a final package of findings and recommendations developed.

The model's findings and upgrading recommendations for the pork VC were provided to the TRRILD's PAC in August 2019. Findings and recommendations were discussed in plenary, with the Researcher fielding questions on methodology and analysis. Following the PAC's acceptance of upgrading recommendations, the Researcher assisted TRRILD staff to develop the project's workplan to operationalise the upgrading interventions. A final field visit took place in January 2020 for monitoring the implementation of upgrading recommendations and collecting data for further model refinement.

Originally, the Researcher had planned field trips for June 2020 and January 2021 to monitor the short-term outcomes of the project and to hold one last SGMB workshop (June 2020) to further refine and update the SD model. As a result of the COVID-19 outbreak, however, the Researcher was unable to travel to Myanmar for the remainder of the PhD research. Regular contact through Skype was maintained with the MBT and TRRILD project staff to understand any contextual changes and project outcomes, and a decision was made in June 2020 to finalise the SD model for inclusion in this thesis.

3.3.3 Spatial group model building questionnaire

A written pre- and post-SGMB questionnaire was developed by the Researcher to investigate the effectiveness of SGMB in transforming participant understanding of the VC (Outcome four of the research). Pre- and post-questionnaires have been frequently used to evaluate the effectiveness of GMB processes (Lansu, et al. 2016; Rouwette et al., 2011, Vennix, et al., 1993). The pre- and post-SGMB questionnaire, including Burmese (Myanmar) translations, are found in Appendix H, Table H1. The questionnaire was divided into three parts: Part A covered participant understanding of the VC; Part B centred on relationships between actors in the VC; and Part C looked at the effectiveness of the SGMB workshops in engaging participants in VCA and upgrading. A total of 33 questions were included. From these, 29 employed a five-point Likert scale, which is extensively used within social science and GMB research for measuring changes in attitudes and behaviours (Joshi et al., 2015; Lansu et. al, 2016). The remaining four questions were open-ended.

The questionnaire was developed by the Researcher and shared with the MBT during the training workshop. First prepared in English, the questionnaire was translated into Myanmar by the MBT. Following translation, it was then tested for accuracy and understanding with other staff of the TRRILD project. Alterations were then made following the testing to simplify the language and finally the questionnaire was translated from Myanmar to English to verify that the original intent of questions was maintained.

Parts A and B of the questionnaire were collected prior to the start of SGMB workshop one and then Parts A, B, and C of the questionnaire were undertaken at the end of SGMB workshop five. This resulted in five months between the pre- and post-SGMB questionnaires for the pork VC workshops and eleven months for the paddy VC workshops. To aid in understanding and mitigate the different literacy abilities among participants, questions were read aloud by a member of the MBT so that participants could request help if there were any misunderstandings. Two members of the MBT worked alongside Karen language speakers for additional help with translation.

Questionnaire data was coded in New Zealand by the Researcher and analysed using SPSS (Statistical Package for Social Scientists). A paired sample t-test was undertaken to determine if there were statistically significant differences in responses between the pre- and post-SGMB questionnaires.

3.3.4 Key informant interviews

KIIs were conducted in Myanmar throughout the field visits, acting as a tool to further explore, supplement, and/or triangulate data obtained during the model building sessions. Semi-structured interviews were selected because of their ability to yield "thick," descriptive data and their compatibility to action research (Davidson & Tollich, 2003). Interviewees were selected through purposive and snowball sampling, with respondents often providing referrals or introductions to other prominent actors in the chain. KIIs were loosely structured around pre-prepared open-ended questions, with a conversational style employed. The relaxed, interactive nature of KIIs meant the interviewee was treated as the "expert" who told their story while the interviewer used questions to probe and guide. As found by Sarantakos (2005), the informality and flexibility of KIIs helped reveal new information and fresh perspectives on the VCs under study.

KIIs were held in Yangon, Myeik, and Palaw. In Yangon, a total of ten KIIs were undertaken over the three visits with individuals from pig feed companies, government departments, livestock federations, pork wholesalers and retailers, and supermarkets. KIIs in Myeik and Palaw took place during each field visit. The KIIs undertaken before SGMB and RG sessions helped to lay the knowledge foundations needed in order to facilitate participatory processes and to develop question probes used within the workshops. Meanwhile, KIIs conducted after the SGMB and RG process assisted in the monitoring of project outcomes and led to micro updates to the model. A total of 24 interviews were held in Myeik and Palaw, covering institutions and actors in the VCs. This included farmers, brokers, slaughterhouse workers and owners, input supply shops, government officials, wholesalers, retailers, restaurant owners, and hotel owners. KIIs not only added to the richness of research data, leading to a more robust model, but also strengthened project outcomes by establishing networks and connections which helped the TRRILD project to successfully implement upgrading activities.

Members of the MBT acted as translators during the KIIs. While the Researcher had previously lived and worked in Myanmar for two-and-a-half-years, his Burmese language ability was minimal. The PhD Researcher's basic understanding of Myanmar's history, culture, and socio-economic structures helped facilitate these exchanges; however, translators and TRRILD staff were encouraged to openly share any cultural or contextual nuances to build the Researcher's understanding. Written notes were taken by the Researcher during the interviews. These were discussed with the translator and any other staff or Researchers present after the interview to ensure key points were accurately recorded.

3.3.5 Focus group discussions

Alongside the group discussions in the formal SGMB and RG sessions, a small number of FGDs were held. FGDs are used to gather data from a group of people who share in a common situation or are impacted by a similar phenomenon (Collis & Hussey, 2014). In the research, five FGDs were held with PGs established within the TRRILD project to discuss their engagement in the VC and the impact of selected upgrading interventions. In three of these, PG leaders had been participants in the SGMB workshops.

3.3.6 Observations

Observations of actors, inputs, products, and physical infrastructure in the VCs added to the data set. The Researcher spent many hours meeting with actors in the VC, which afforded the opportunity to observe and record their day-to-day operations, such as the conditions of pig farms and slaughterhouses, the use of pig feed, the type of pork products available in restaurants, etc. Observations helped to layer real-life examples onto information elicited through workshop settings and allowed the Researcher to probe and focus discussions through his experiences to workshop settings, e.g., “When I saw pig farms in Pyi Gyi village, I experienced…. Is that typical?” Even though this technique enriched discussions, a frequent critique of observational techniques in research is the effect of the Researcher’s subjective judgements and the validity and reliability of observations (Brockington & Sullivan, 2003, Collis & Hussey, 2014). To help mitigate this, observations were recorded in the Researcher’s notebook and triangulated through KIIs, FGDs, and the SGMB and RG workshops.

3.4 Research ethics

The basic ethical principles of research as described by Davidson and Tollich (2003) were followed throughout the research: do no harm; voluntary participation; anonymity and confidentiality; avoidance of deceit; and the faithful analysis and reporting of data. Moreover, following the action research principles, this study sought not only to protect participants but to improve their situation and “to do good” (Scheyvens et al., 2003). Corbridge (1998) states that development research has a moral and ethical obligation to not only interact and extract, but to inform development practise. Answering this call, the research’s results and learning were disseminated to participants, TRRILD staff, Myanmar stakeholders, and the development community through presentations and articles.

In this research, information was obtained from participants working within the TRRILD project. As the implementing partner, WV Myanmar facilitated and sponsored the research, obtaining all necessary permissions and approvals within Myanmar (primarily from the Department of Social Welfare). WV Myanmar has an INGO operating licence in Myanmar and permission from the national and regional governments to implement the TRRILD project, which cover all the field work activities for the research. Both WV Myanmar and the government of Myanmar's Department of Social Welfare applied their standards to monitor ethical considerations in the research. In this research, information was obtained from VC actors in their professional capacity as they chose to participate in the TRRILD project. As such, no application was required or made for human ethics clearance from the Lincoln University Human Ethics Committee. However, ethical considerations were addressed in all aspects of the process.

Prior to participating in data collection activities, written and verbal consent was sought. Participants were informed of the research's background, objectives, voluntary nature, and expectations through an information sheet in both English and Burmese. Written consent was obtained, when appropriate, prior to data collection and participants were informed of their rights to voluntarily withdraw from interviews and workshops at any time. The contact information of the lead PhD supervisor, Researcher, and TRRILD staff were made available to participants to follow up on any concerns they may have. Due to cultural dynamics and literacy levels, many participants did not care for the formality of the information sheets and consent forms. In this situation, a thorough verbal explanation was offered, and any questions answered as they arose.

The research did not employ any deceit or pressure on participants at any time. Given the context and history of Myanmar, the Researcher was careful to avoid any political discussions or sensitive issues. As per protocols for official foreigner visits within Myanmar, a government representative should, in principle, have accompanied the Researcher during data collection. However, as the research did not touch on any sensitive political topics, the presence of government officials at workshops and field visits typically occurred less than 20% of the time. To lessen any risk, all information was treated with confidence and anonymity preserved for all participants.

Workshops and meetings were organised in public or private spaces, such as the WV office or the village community hall, and permission sought from relevant authorities. Most of the KIIs, FGDs, and observations took place within individual homes, farms, or businesses, with permission always sought prior to entering and engaging participants. As SGMB and RG sessions took more than half a day, the research provided lunch and refreshments for participants. Transport arrangements were made by the TRRILD project to ensure participants did not incur any financial penalties for their attendance at workshops. At the end of the SGMB and RG process, participants were provided with a participation certification and a modest koha, such as a bag or bath towel, which is standard practice within the TRRILD project. Prior to the commencement of workshops and interviews, permission was sought for the Researcher or Notetaker to record the workshop (through notes or a voice recorder) and to use all materials, diagrams, charts, etc., that were created by participants. Data were treated confidentially, with a data management plan employed to preserve and protect information as per LU protocols. This included password protecting all digital data and storing data electronically in three places: (i) on the hard drive of the Researcher's computer, (ii) on cloud storage, and (iii) on a portable hard drive.

3.5 Creation of new credit and collective action modules

The SD model developed by the Researcher for the *ex-ante* impact evaluation of the pork VC built upon modules used within previous SD models of agri-food VCs as highlighted in Figure 5. This research's model starts with a production module that covers the biological processes of pig production and changes in farming systems within target villages. Pig volumes from the production module combine with the region's total pig supply within a marketing module to calculate the price of live pigs. A financial performance module calculates aggregate costs, revenues, savings, cashflow, and profit margins of different pig producers and other value chain actors. On-farm decisions take place in an environmental module and are influenced by expected profits from the financial performance module. The structure of this research's pork VC SD model is described in more detail in Section 4.3, with a copy of the final Stella Architect-designed SD model found in Appendix B and associated data located in Appendix C. The exception, however, was the structure for the credit and PG/PO collective action modules. These modules have not previously been included within any previous SD models, beyond the collective action cashflow structure modelled by McRoberts et al. (2013) within a case study of a dairy VC in Mexico and deserve additional exposition. The basic SFD of the finance and collective action modules will be highlighted in this section to allow for further application to agri-food VC SD models beyond the pork VC. This section will also outline potential adaptations of these two modules, drawing on variations used within the paddy SD model developed by the Researcher for the TRRILD project.

3.5.1 Credit module

The purpose of the credit module is to model the impacts of different financing options for small-scale farmers in the VC. In the simplest form, shown by SFD in Figure 8, there are two providers of credit to small-scale farmers: (i) formal lenders, representing MFIs and commercial banks; and (ii) informal lenders, representing moneylenders, pawn brokers, friends, and relatives. Formal lenders have a limited amount of credit available to small-scale farmers which is represented by the stock, *formal lender: available loan capital*[5] (US$). Informal lenders meet any additional credit requirements from small-scale farmers, but at a higher interest rate.

[5] Through the thesis, structures from CLDs and SFDs are *italicised* to aid the reader in linking text to corresponding figures.

The module contains two types of loan products for small-scale farmers: (i) seasonal production loans that cover key farm inputs, like seeds, fertiliser, and pig feed; and (ii) upgrading loans that are used by farmers to invest in assets, such as tractors, harvesters, hybrid sows, and hygienic livestock shelters.

In the module shown in Figure 8, upgrading loans are prioritised by the formal lender with the converters, *formal lender interest rate* (percentage/week), and *formal lender loan term* (weeks)*,* determining loan characteristics and the initial value of the stock, *formal lender: available loan capital*, the total volume of credit available for upgrading loans. Any remaining capital in the stock, *formal lender available loan capital*, is then made available to small-scale farmers for seasonal production loans. Some formal lenders, such as MFIs, have *mandatory savings requirements* (percentage loan/week) for borrowers, and this increases farmer stocks of *savings*, lowering the *production loan capital required*.

Farmer decisions to invest in upgrading assets are driven by the *expected profitability of upgrading*. This variable forecasts the annual profitability of the farm given the *expected farm revenue* with the new upgrading investments and the *expected farm costs* with *upgrading costs* and *upgrading cost savings* applied. For example, investments in productive assets like a tractor bring increased revenue through higher yields and from hiring out of the tractor but also alter farm costs because of loan repayments and lower costs for field preparation.

Loan repayment costs for upgrading investments are determined by the *upgrading interest rate* and *upgrading loan term* and are calculated based on the type of the loan, i.e., amortised, balloon, etc. These two variables are system variables such that they are computed as the weighted averages of the interest rates and loan terms applied by both formal and informal lenders. As the number of *farmers upgrading* increases, the stock of *upgrading loan capital in the system* rises. At the same time, farmers upgrading draw down the stock, *formal lender: available loan capital* which increase flows into the stock, *formal lender: loan capital in use*. The ratio of the two stocks, *formal lender: loan capital in use* and *upgrading loan capital in the system* determines the *upgrading loan term* and *upgrading interest rate*. When the stock of *formal lender: available loan capital* is exhausted, the *proportion of loans covered by formal lenders* decreases, causing both the *upgrading loan term* and *upgrading interest rate* to rise. This sequence of events raises *upgrading costs* which dampens the

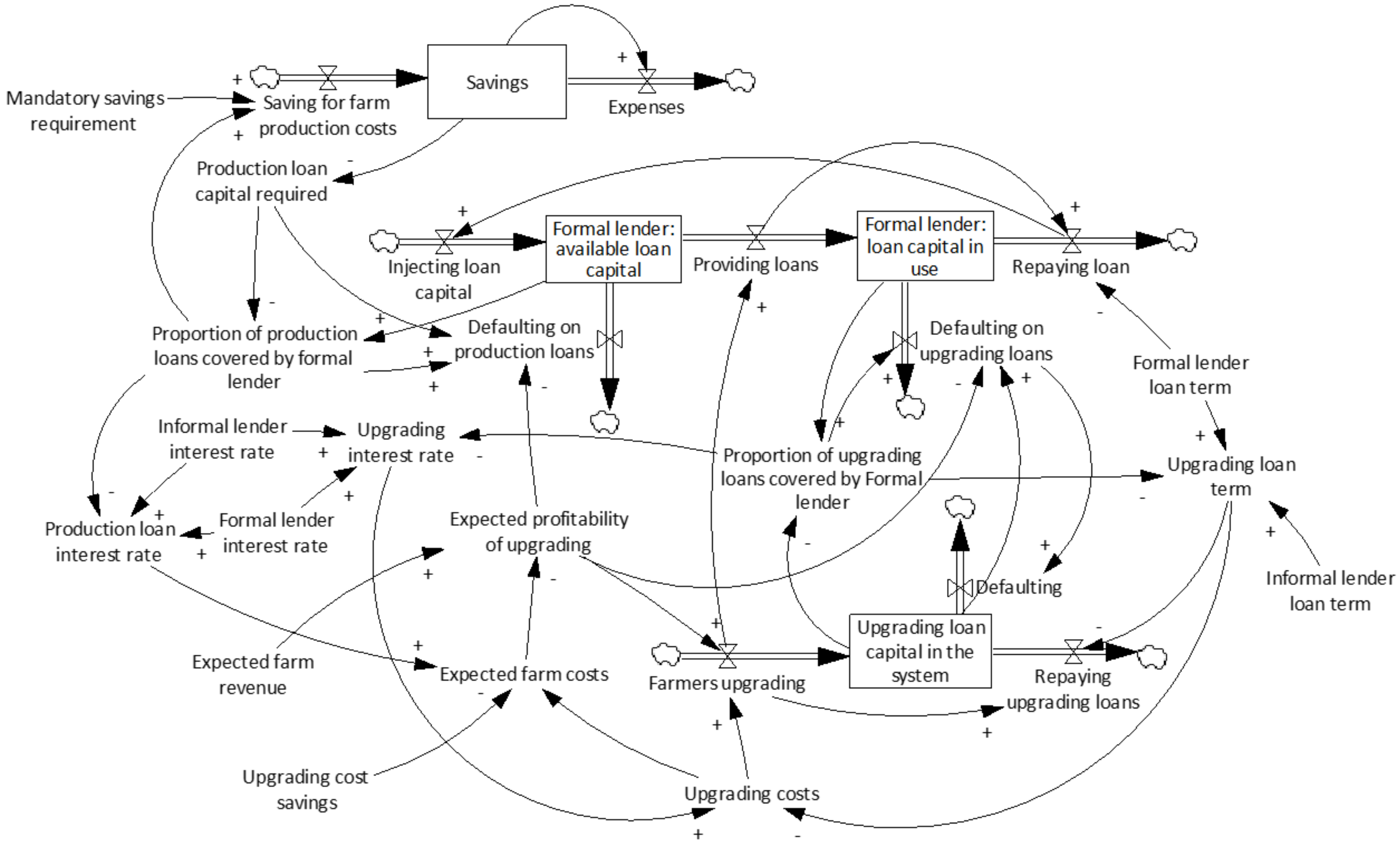

Figure 8: SFD of the credit module

Source: Developed by the Researcher

expected profitability of upgrading. In a similar vein, the *proportion of production loans covered by the formal lender* determines the *production loan interest rate*.

Small-scale farmers default on loans when their newly upgraded enterprises remain unprofitable over a sustained period. When the variable, *expected profitability of upgrading* declines, loan capital exits from the stock of *formal lender: loan capital in use* through the flow, *defaulting on upgrading loan*. The rate of this flow is determined by both expected profitability and the volume of outstanding upgrading loans from the formal lender with the latter calculated by multiplying the *proportion of loans covered by the formal lender* by the stock of *upgrading loan capital in the system*. In a similar manner, *defaulting on production loans* draws down the stock*, formal lender: available loan capital*. The magnitude of this flow is determined by multiplying the *production loan capital required* by the *proportion of production loans covered by formal lenders* along with the *expected profitability of upgrading*. Small-scale farmers without upgrading loans but with production loans from the formal lender can also exit from farming and this causes further losses to the stock of loan capital through defaults on production loans.

The module described in Figure 8 provides a basic credit module, allowing for further adaptations to assist in scenario testing or to accommodate for further complexity in the system. Firstly, key exogenous variables can be altered to compare different financial products, including the initial amount of loan capital available from the formal lender and the corresponding interest rates and loan terms. In the basic credit module, upgrading loans are prioritised over production loans, but this can easily be changed to a fixed proportionality by restricting the flow of capital from the stock *Formal lender: available loan capital*. The addition of arrays covering different types of small-scale farmers and upgrading investments can further layer complexity into the module. For example, in the paddy VC SD model, four long-term investment opportunities were modelled: harvesters, tractors, land-levelling, and paddy storage facilities, while the pork VC SD model contained six sub-types of small-scale pig producers. In the basic credit module presented, there is a sole formal lender; however, additional providers can also be added into the system either through arrays or the addition of further stocks. For instance, the paddy SD model developed by the Researcher included a stock of production loan capital from MADB and a stock of loan capital for hire purchase loans for tractors and harvesters provided by retailers with loan guarantees from commercial banks. While Figure 8 only contains loans for small-scale farmers, this structure can also be applied to other VC actors. For example, in the pork VC model meso loans were provided to the PO for investing in a hygienic slaughterhouse, while in the paddy model developed by the Researcher, meso loans were provided to rice millers. Finally, structure can be added to the basic credit module to allow small-scale farmers and PGs/POs to allocate their savings and loan capital across various investment options based on profitability, investment time horizons, and discounted rate of returns. These options were included in the paddy SD model which will be published in a forthcoming academic paper.

3.5.2 Collective action module

The purpose of the collective action module is to understand the financial and pro-poor performance of different PG and PO institutional structures and their impacts on the wider VC system. The basic collective action module developed is bipartite, reflecting the TRRILD project's strategy of establishing PGs that would later become POs by extending their transactional activities to include value adding strategies. The PG elements of the collective action module are presented in Figure 9, with Figure 10 highlighting the additional PO structure.

PG membership can take two forms in the module, represented by the stocks, *active PG members* and *non-active PG members*. These stocks can be further arrayed to represent distinct farming systems available to members. *Active PG members* become *non-active PG members* when it is more profitable for them to stop patronising the PG and side-sell their products. When side selling becomes less profitable than patronising the PG, they start *re-engaging in the PG* (PG producers/week) and increase the stock of *active PG members*. When profits (PG member and non-member) are consistently negative, *active PG members* and *non-active PG members* leave farming all together, while less substantial shifts in profits cause PG members to change their farming system (upgrade/downgrade), resulting in movement between arrays in the stock of *active PG members*.

The cashflow portion of the PG module extends the work of McRoberts et al. (2013) with additional stocks representing *PG capital* (US$) for providing services and *PG rebates* (US$) for paying rebates to members. The stock of *PG cashflow* increases through premiums obtained for PG member products that meet the requirements of premium buyers (e.g., quality, volume, timing, etc.). If the stock of *PG cashflow* becomes negative, *PG capital* is diverted into the flow of PG revenue and the *price paid for PG member products* is reduced. The PG has three outflows for its revenue. Taking priority are *PG costs* that are incurred as operational costs (e.g., management, training of members, etc.) and depend on the number of *active PG members* and the *price paid for PG member products*. If the PG has sufficient cash on hand, determined by the *maximum flexible cash* variable (see McRoberts et al., 2013), it then allocates cash through the flow of *retained earnings* to the stock of *PG capital*. Any remaining cash on hand increases the stock of *PG rebates* that are paid to members according to the variable, *rebate payment schedule*, which can be adjusted to reflect quarterly, six-monthly, or annual arrangements.

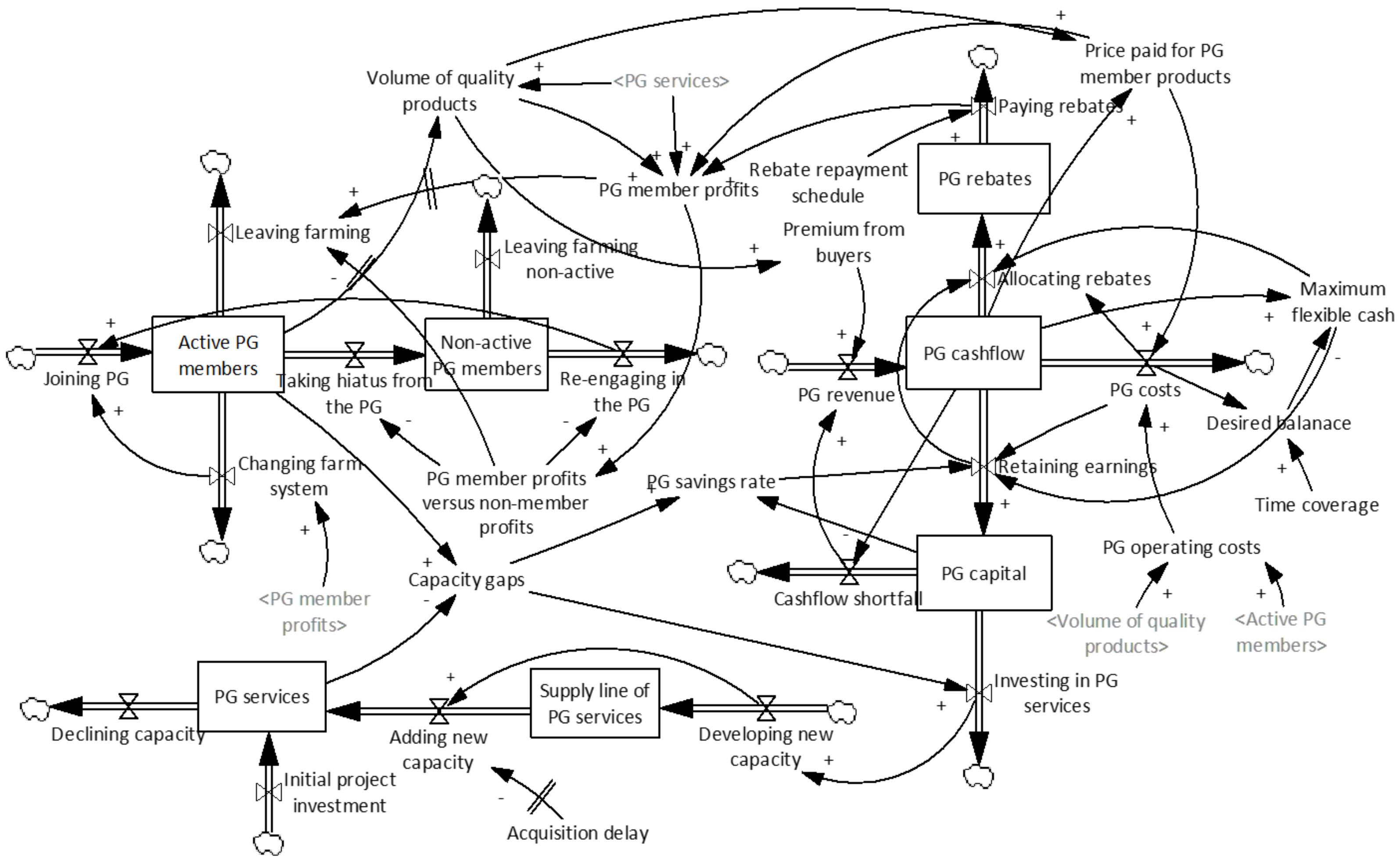

Figure 9: SFD of the PG portion of the collective action module

Source: Developed by the Researcher based on McRoberts et al. (2013)

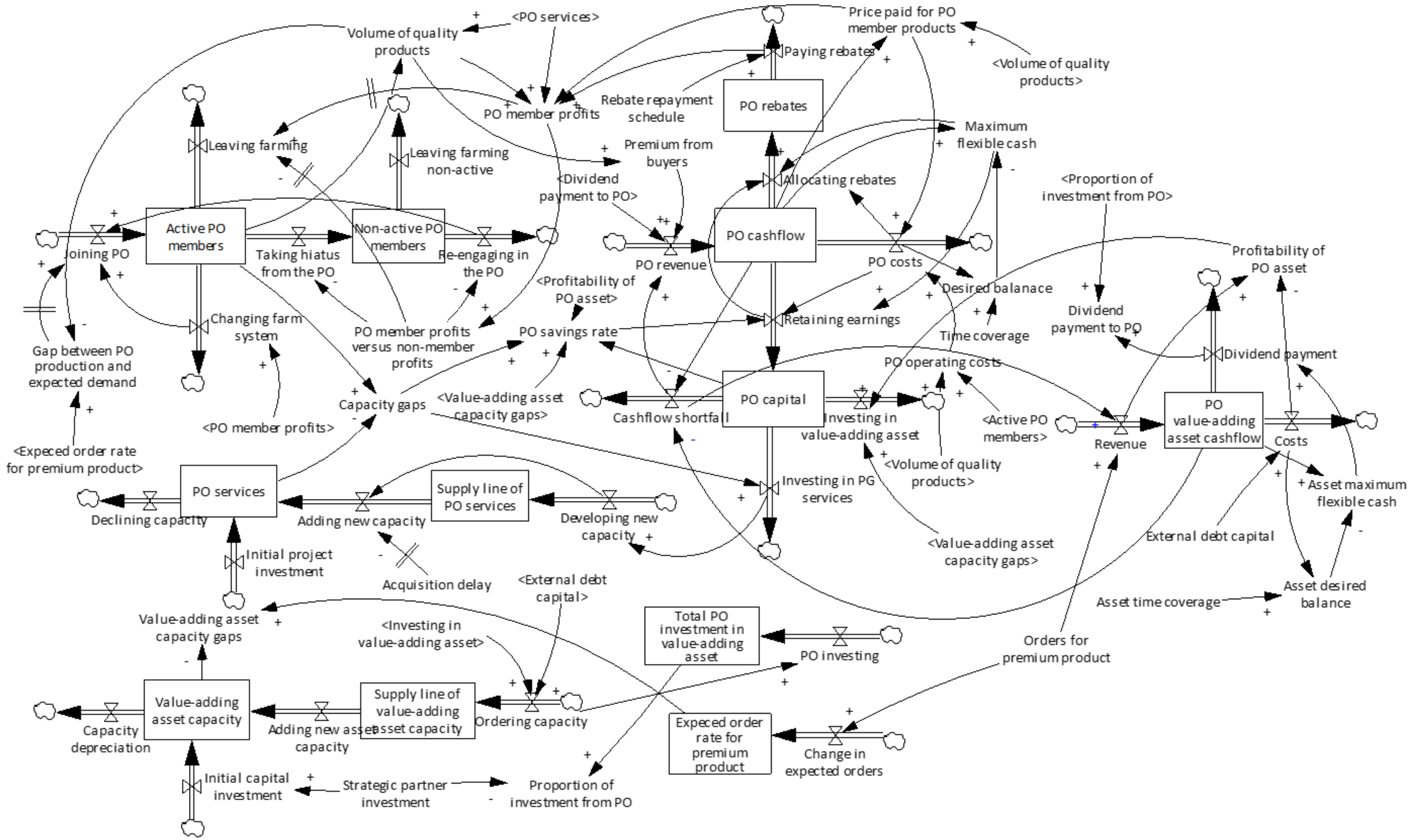

Figure 10: SFD of the PG and PO portions of the collective action module

Source: Developed by the Researcher

The stock of *PG capital* is used for *investing in PG services* when there are capacity gaps. The stock of *PG services* represents the transactional services that PGs provide to members, such as bulk purchasing, collective marketing, and training and are modelled through a simple capacity stock and flow structure as described by Sterman (2010). The level of *PG services* determines the *volume of quality products* that members can deliver through the PG as well as *PG member profits*. *Capacity gaps* occur when the number of *active PG members* outweighs the *capacity of PG services* to cover all PG members. If the stock of *PG capital* is insufficient to cover any *capacity gaps*, then the *PG savings rate* (proportion/week) increases. The stock and flow structure also allows project investment into the stock of *PG services* and declining capacity from those services over time. For example, if the PG is providing animal health services, an initial project investment could be the training of animal health workers, while a certain proportion of these animal health workers leave the profession every year.

The extension of the collective action module, representing the evolution from PG to PO status,[6] is shown in Figure 10. The additional structure captures the ability of the PO to invest in value-adding assets, such as a pig slaughterhouse or rice mill, to allow access to premium markets. The cashflow of this new venture is represented by the stock, *PO value-adding asset cashflow* (US$), which increases by *revenue* inflows from *orders for premium product* and decreases via *costs* from operational expenditure and loan repayments for *external debt capital*. If the maximum flexible cash of this venture is sufficient to cover operating costs, a *dividend payment* to the PO's owners takes place. If the value-adding venture falls into negative cashflows any shortfalls are covered by drawing down the stock of *PO capital* through the flow, *cashflow shortfall*.

The PO makes investments in the stock, *value-adding asset capacity*, from the stock of *PO capital*. Growth in the *value-adding asset capacity gaps* increase the stock of *PO capital* allocated to *investing in the value-adding assets*, with the rate of investment driven by the *profitability of the PO value-adding asset*. Further capacity gaps and increases in the *profitability of the PO value-adding asset* increases the *PO savings rate*. *Value-adding asset capacity* can also increase through the investment of a strategic partner that provides the *initial capital investment* or through *external debt capital*. When the *expected order rate for the premium product* increases the *gap between PO production levels and expected demand*, the PO responds by recruiting more members to join the PO. There is a delay in this action, however, to allow *active PO members* to upgrade their farming systems or increase individual production in response to rises in *PO member profits*.

[6] This transition from a PG to a PO is a discrete process in the pork VC model as premium markets expand; however further structural evolutions could allow for PGs to POs to transition based on endogenous factors in the model.

The collective action modules illustrated in Figures 9 and 10 provide a basic SFD that can be modified for scenario testing or to accommodate further contextual dynamics. In terms of institutional arrangements, savings and rebate functions can be adjusted to mimic various options available. For example, reducing PG savings rates and allocating further PG cashflow to members as rebates would orientate the PG towards a more traditional cooperative. Meanwhile the additional PO structure, complete with investment from a strategic partner that leverages external debt capital closely resembles the arrangement of an investor-share cooperative (ISC) with NGC features.

The optimisation functionality of Stella Architect could be applied to the module to investigate the institutional arrangements that best enables POs to acquire sufficient production and processing capacity to meet volume and quality standards of premium markets while ensuring the PO remains inclusive of poorer members. In the basic form, shown in Figures 9 and 10, PGs provide generic services to members and the PO invests in a single value-added venture. By adding arrays or additional stock-and-flow structure to the module, further services and value-added ventures can be modelled. Furthermore, investments from the stock of PO capital can be allocated across services and value-added ventures dependent on their relative profitability. For example, in the paddy VC model developed by the Researcher, the PO distributes savings and investment capital across paddy milling, dehulling, and paddy drying assets.

The credit and collective action modules were created to link into existing agri-food VC modules as illustrated in Figure 11 that expands Figure 5 from Section 2.4.3. The credit module interacts with the financial performance module by providing capital for purchasing seasonal inputs and for investments in upgrading, while receiving loan repayments to maintain financial providers' capital stocks. The institutional module provides information that determines loan parameters as per government financial regulations. The PG component within the collective action module links to the financial performance and environment module by providing transactional services to members, such as bulk purchase discounts, training, and collective marketing. The PO component strengthens linkages to the environment module through investments in input and service operations while also extending linkages to the marketing module given the PO's strategy to invest in value-adding assets for accessing premium markets. The production module links to the collective action module through the provision of products that meet quality standards for collective marketing or as part of member tradeable delivery rights for accessing premium buyers. The collective action module is also influenced by the institutional module given changes to government cooperative policies.

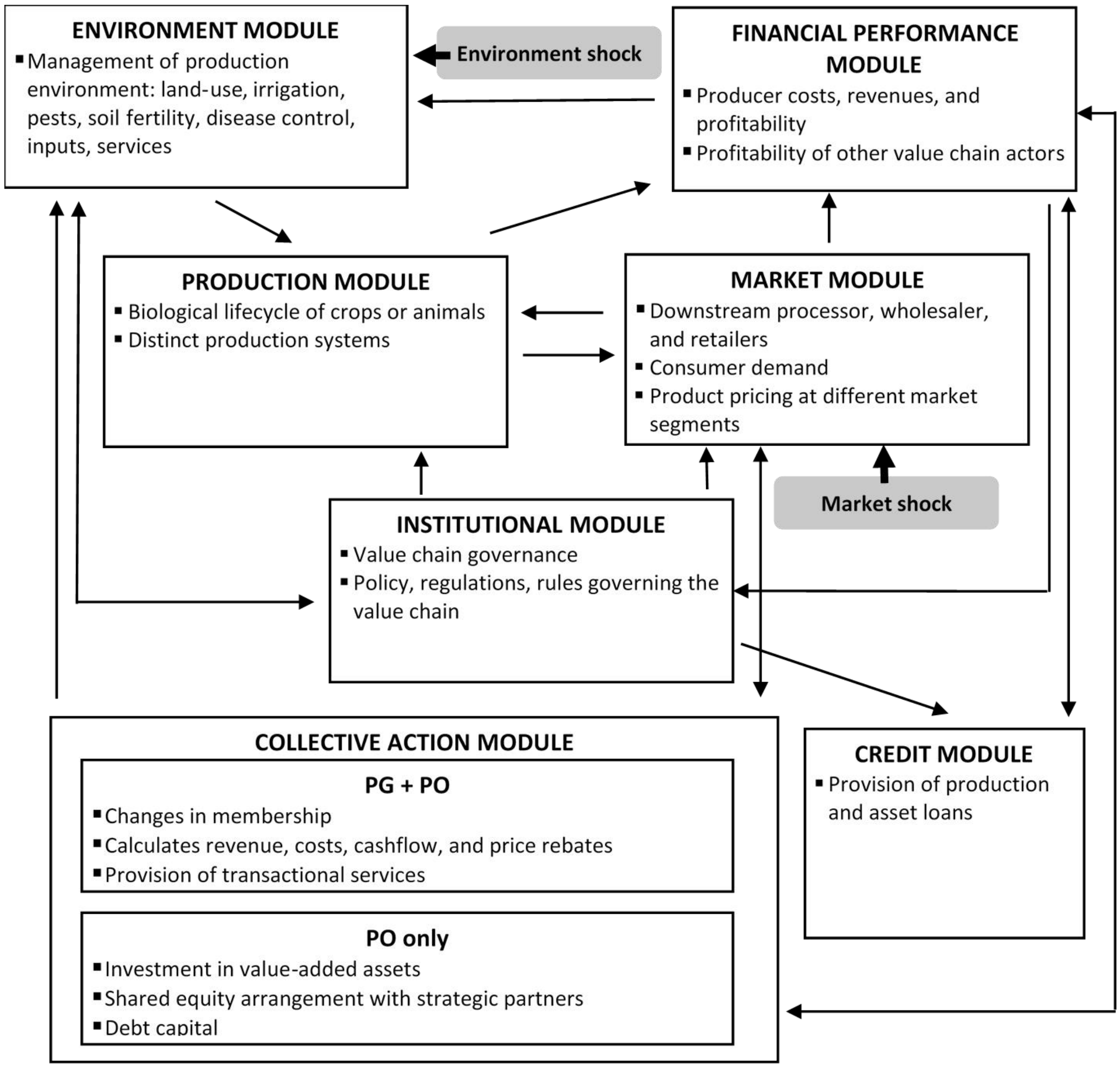

Figure 11: Overview of credit and collective action module linkages within agri-food VC models
Source: Developed by the Researcher based on Dizyee et al.'s (2017) conceptual framework.

Chapter 4

Description of the pork value chain

The foundations for a multi-layered understanding of the dynamic nature of the pork VC in Myeik and Palaw were built through SGMB and RG workshops and supplemented by additional interviews with VC actors. During the first SGMB workshop, the Layerstack tool was used to explore changes and problems in the pork VC and orient findings vis-à-vis temporal and spatial domains. Six Layerstack acetates were used to discuss: (i) livelihood zones and pig farm locations by type; (ii) production inputs and services; (iii) flows between pig farms and slaughterhouses; (iv) flows from slaughterhouse to end consumers; (v) investments and costs occurring along the VC; and (vi) the participation of women/men/ethnic groups and the poorest. Building upon the Layerstack findings, SGMB participants then identified the priority problems within the chain and their causal dynamics.

Section 4.1 presents the context of the pork VC, highlighting spatial and temporal dynamics. Next, Section 4.2 discusses the three prioritised problems, illustrated by problem reference modes and cause-and-consequence maps. The chapter concludes with Section 4.3, which provides an overview of the SD model of the pork VC, highlighting key structures and feedback loops. Combined, these findings provided the basis for a comprehensive VC description, both from the standpoint of VC structure and as a platform for the quantitative analysis based on this structure that is discussed in Chapter 5.

4.1 Context and dynamics of the pork value chain

During the last decade, there has been steady growth in the consumption of pork in Myeik and Palaw Townships. While there are no official data available at the township-level, workshop participants indicated that pork sales had increased by 5%-10% per annum for the last decade. At the time of the research, between 80 and 120 pigs were slaughtered daily in Myeik, and 15 to 20 per day in Palaw. The resulting pork products serviced local markets, apart from a small volume of pork sausages made in Palaw (equivalent of one to two live pigs per day) which were exported to restaurants outside of the region. This level of consumption growth reflects patterns in other urban centres across Myanmar where official data are collected, such as Yangon, Mandalay, and Nya Pi Taw (Charoen Pokphand [CP], 2019) and trends in neighbouring countries of the Greater Mekong Region (Ebata et al., 2018).

The rise in demand for pork products was attributed to three key factors. First, there had been an overall growth in population —Myanmar's annual population growth rate has averaged 0.72% per annum from 2008 to 2018 (World Bank, 2020) with Myeik slightly higher than the national trend

(Ministry of Immigration and Population [MoIP], 2015). Second, rising household income levels and urbanisation had shifted protein consumption patterns towards animal proteins and, within that, a shift towards pork (Huynh et al., 2007). Accordingly, Myanmar's pig population has risen from 10.3 million heads in 2010 to 17.6 million heads in 2016 (Soe, 2018), pork imports have increased from four tonnes in 2010 to 2,373 tonnes in 2017 (FAO, 2020), and per capita pork consumption has doubled between 2010 and 2018 (CP, 2018; Soe, 2018). Lastly, the tourism industry has expanded rapidly in Myeik. In Myanmar, the number of international tourists increased by 400% between 2008 and 2018 with the Ministry of Hotels and Tourism (MoHT) reporting that available hotel beds rose from 65 to 538 over this time in Myeik township (2009, 2019). While no further data are available, given Myeik's pristine beaches, its proximity to Thailand, and the addition of domestic tourist numbers, growth is likely much higher, resulting in increased pork sales in restaurants and hotels.

Resulting from the growing consumption of pork, pig production has increased in importance as a livelihood activity, augmenting the region's traditional rural livelihoods of rubber, paddy, betel leaf, and areca nut production. Figure 12 highlights the spatial orientation and changes in importance of livelihood strategies in Myeik. Simple behaviour-over-time graphs drawn by participants in SGMB workshops showed that farmer investment in paddy had decreased, while rubber had increased but plateaued in the last three years due to stalling prices. Meanwhile, there was a general trend to replace local pigs with hybrid pigs. For farmers with access to arable farmland, pig production provided a secondary or supporting livelihood. Pig farming diversifies household incomes that are often primarily dependent on either paddy, rubber, or betelnut, thus lowering vulnerability to economic and climate shocks. For the poor, pigs were often treated as a form of savings, a "livestock bank" to alleviate temporary cashflow problems and to finance inputs for subsistence crops and non-farm enterprises. This finding is reinforced by the TRRILD baseline survey which showed pig farming had the lowest revenue per grower and smallest level of asset investment out of the region's five main livelihoods (Lyne & Snoxell, 2018). However, the introduction of more profitable hybrid varieties had raised the importance of pig farming as a household livelihood strategy. This was especially significant for poorer community members, typically characterised by small or non-existent landholdings, as hybrid varieties increased the potential for higher incomes within existing natural resource constraints (Ebata et al. 2018).

The pork VC is differentiated by two pig breeds, broadly categorised as local and hybrid (hybrid is also referred to locally as "high quality"). The smaller, hairy, local Myanmar variety of pig is considered more robust and produces pork with a higher fat content than hybrid varieties. Hybrid varieties are a cross between Duroc, Yorkshire, and Landrace breeds. Local breed pig farmers source breeder sows and boars from nearby villages, but hybrid pig farmers focus more on quality, occasionally going outside of the Tanintharyi region to source from commercial farms in Mawlymine, Yangon, or Thailand.

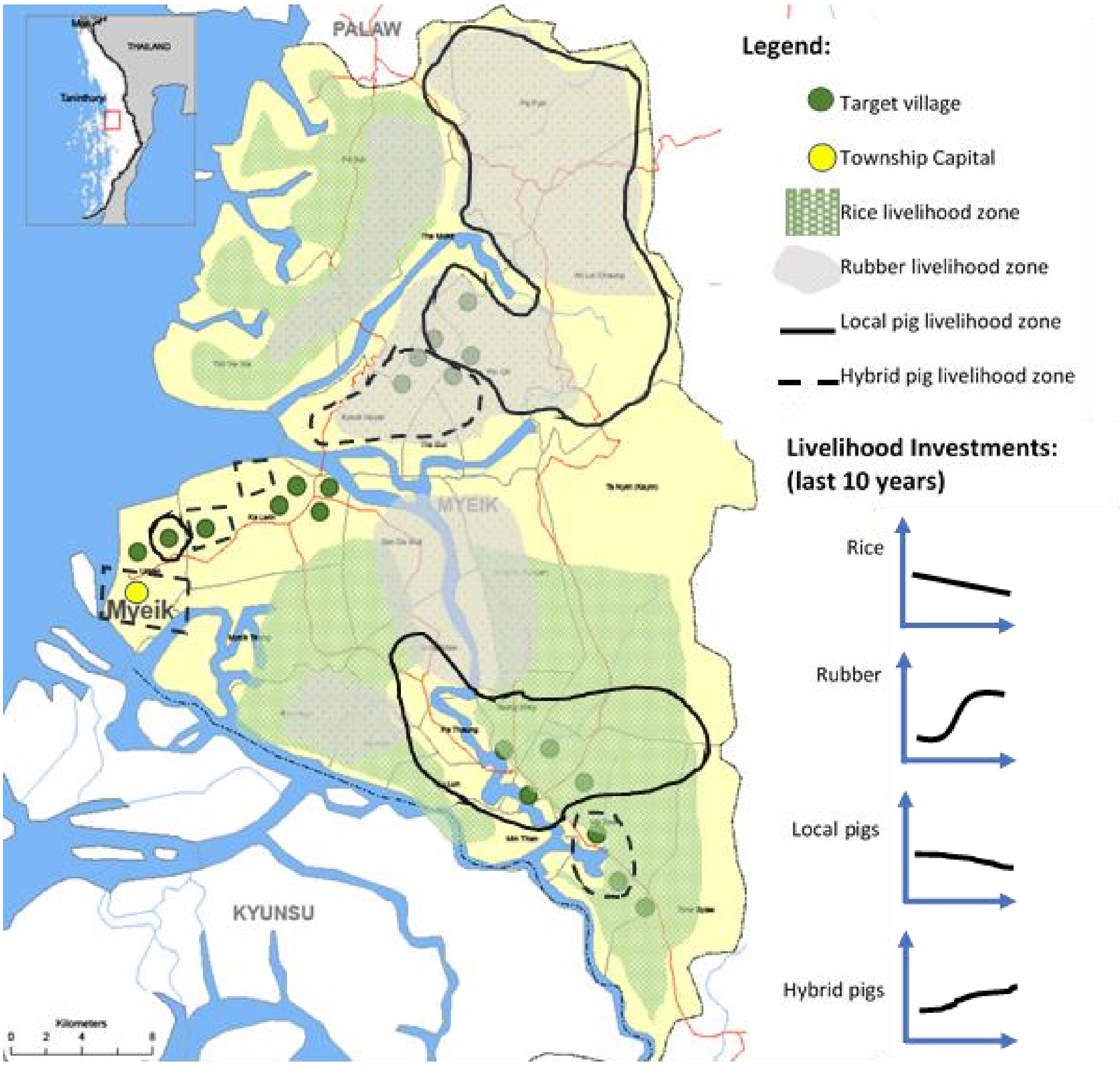

Figure 12: Spatial overview of the livelihood dynamics in Myeik
Source: Developed by SGMB participants

Hybrid fatteners are heavier than the local breed (average of 88 kgs [55 viss[7]] compared with 56 kgs [35 viss]) and receive around a 60% higher price per kg. In the year before the field research (2018), hybrid live pig prices had ranged from 1.88 to 2.17 US$/kg (equivalent to 4,500 to 5,200 Myanmar kyats [MMK[8]]/viss) and local pigs fetched between 1.17 and 1.46 US$/kg (equivalent to 2,800 and 3,500 MMK/viss). Research participants noted that consumer demand was slowly shifting towards the less fatty pork produced through the combination of hybrid breeds and commercial feed. Increasing consumer preferences, favourable prices, and weight differences helped cause the steady

[7] Viss is the standard weight measurement used in Myanmar pig production and equates to 1.6 kg.
[8] The Myanmar Kyat (MMK) is the unit of currency in Myanmar. At the time of the field research, one New Zealand dollar (NZD) equated to approximately 1,000 MMK, and one United States dollar (US$) equated to approximately 1,500 MMK.

shift from local to hybrid pig production. The Layerstack maps, highlighted in Figure 13, show a clear spatial dimension to this shift: the proportion of hybrid pig farmers declined in relation to the distance from downstream actors and service providers which were principally located in Myeik municipality. Workshop participants estimated that hybrid varieties made up 50% of Myeik's total pig production. However, this number dropped to around 20 to 30% in the TRRILD's target area owing to the project's focus on rural communities. Participants noted the dynamic nature of hybrid pig farming. In recent times, rising live pig prices prompted farmers to transition from local to hybrid pigs. However, widespread pig mortalities following a recent disease outbreak had halted this transition for many. These mortalities were linked to low vaccination rates and poor access to veterinary services.

Pig farmers were broadly categorised into three farming systems:[9] small, medium, and large, across the two predominate breeds. These three sub-systems along with changes in their market share are illustrated in Figure 13 and described below:

I. *Large-scale pig farms* focus exclusively on hybrid varieties and farm within the government-established "pig farming zone" located within the Myeik municipal boundary. Production units range from ten to 30 breeding sows with the capacity to produce up to 500 fatteners annually. Pigs are fed commercial rations mixed with locally available products (broken rice, rice bran, and fish meal). These farms have well-constructed housing including concrete floors, wet areas, piped watering systems, and drainage systems, and follow simple bio-security practises such as regular cleaning with disinfectant and footbaths. Farmers typically deal directly with slaughterhouses to negotiate delivery times and prices. Due to the falling pig prices after 2017 (described in Section 4.2.1), the number of large-scale farms had declined from 50 to less than ten. Large-scale farms accounted for around 20% of pig production in Myeik, having dropped from 50% just a few years earlier.

II. *Medium-scale pig farms* have between three to ten predominantly hybrid sows and produce piglets for sale to nearby villages while also retaining some piglets for fattening and replacing of breeding sows. These farmers are typically located in peri-urban areas of Myeik or Palaw, with production units situated alongside household dwellings. Pig-housing conditions and animal husbandry practises closely mirror those of large-scale farms, though fewer durable materials are used, and bio-security measures are generally absent. Medium-scale pig farms usually work through a broker to negotiate sales prices. The production capacity of medium-

[9] The categorisation of small, medium, large and local/hybrid is used by other authors but with differing definitions in other locations across Myanmar, see Ebata et al. (2018) and Soe (2018).

scale farmers has remained steady, accounting for around 30% of total pig production in both townships.

III. *Small-scale farms* dominate the pig systems located in the project's target villages, generating 50% of local production in Myeik and 70% in Palaw. These farms are predominately located in rural villages and can be categorised into two sub-systems. The first system, named Farrow-to-Finish (FF), has one to three sows and produces piglets for sale to nearby households while retaining a portion for fattening and sow replacement. The second system, called Wean-to-Finish (WF), purchases one to two piglets per year from FF farms for fattening and sale. About 70% of small-scale farmers use local breeds as they are considered more resistant to disease and heat stress, though, as noted previously, a number of farms were transitioning to hybrid pigs. FF farmers use a mixture of commercial and local feed, while WF farmers typically feed food waste and rice by-products. Housing is basic, with larger farms investing in bamboo pens and concrete floors, while smaller farms use simple bamboo or wood pens to house pigs when they are not roaming free through the village. Around two-thirds of pig-farming households in TRRILD target villages practise the WF system.

A system of brokers connects peri-urban and rural pig farmers to slaughterhouses. Brokers typically use personal client networks to search for live pigs to fulfil slaughterhouse orders. A typical broker sources between eight to 15 pigs per week and is paid either a flat search fee or commission by slaughterhouses. Along with searching and aggregating, brokers negotiate prices, and occasionally store pigs on behalf of slaughterhouses. The negotiating power of brokers is stronger in more remote areas, where pig farmers have less direct interactions with downstream VC actors, such as slaughterhouses and wholesale markets, and less horizontal coordination with other farmers from whom they can gauge recent prices. Brokers estimate pig weights and subjectively assess pig quality with no agreed standards on which to base negotiations. Overweight and diseased pigs, or older sows are purchased at a discounted rate even though they can be sold in the wholesale market without a means to differentiate the meat from healthy animals.

The government licensing system has enabled pig slaughterhouses to take on a role akin to "lead" actors (Gereffi, 1999) within the pork VC. The local government authority (known as the Township Development Committee [TDC]) operates a licensing system for pig slaughtering. Licences are auctioned annually, granting holders the legal right to slaughter a fixed number of live pigs per year. Slaughtering by non-license holders is illegal but tolerated by the TDC in small volumes at the village-level for household consumption. In Myeik, two licenses are granted, each costing US$86,666 per year, for the rights to slaughter up to 60 live pigs per week. Given this significant financial investment, these licenses are further sub-divided. In Myeik, one license is divided into two sub-licenses and the other is divided into ten sub-licenses for a total of twelve license holders. A similar system operates in Palaw, but with smaller volumes; one main license is split evenly among four slaughterhouses granting each the right to slaughter four live pigs per day. Slaughterhouses also operated as meat wholesalers in the Townships' wet markets. The licencing system creates significant power asymmetries in the chain as pig producers have limited alternatives for their products (Woods, 2004). Slaughterhouses and their networks of brokers and wholesalers are therefore able to exert some oligopsony power over producers and oligopoly power over consumers.

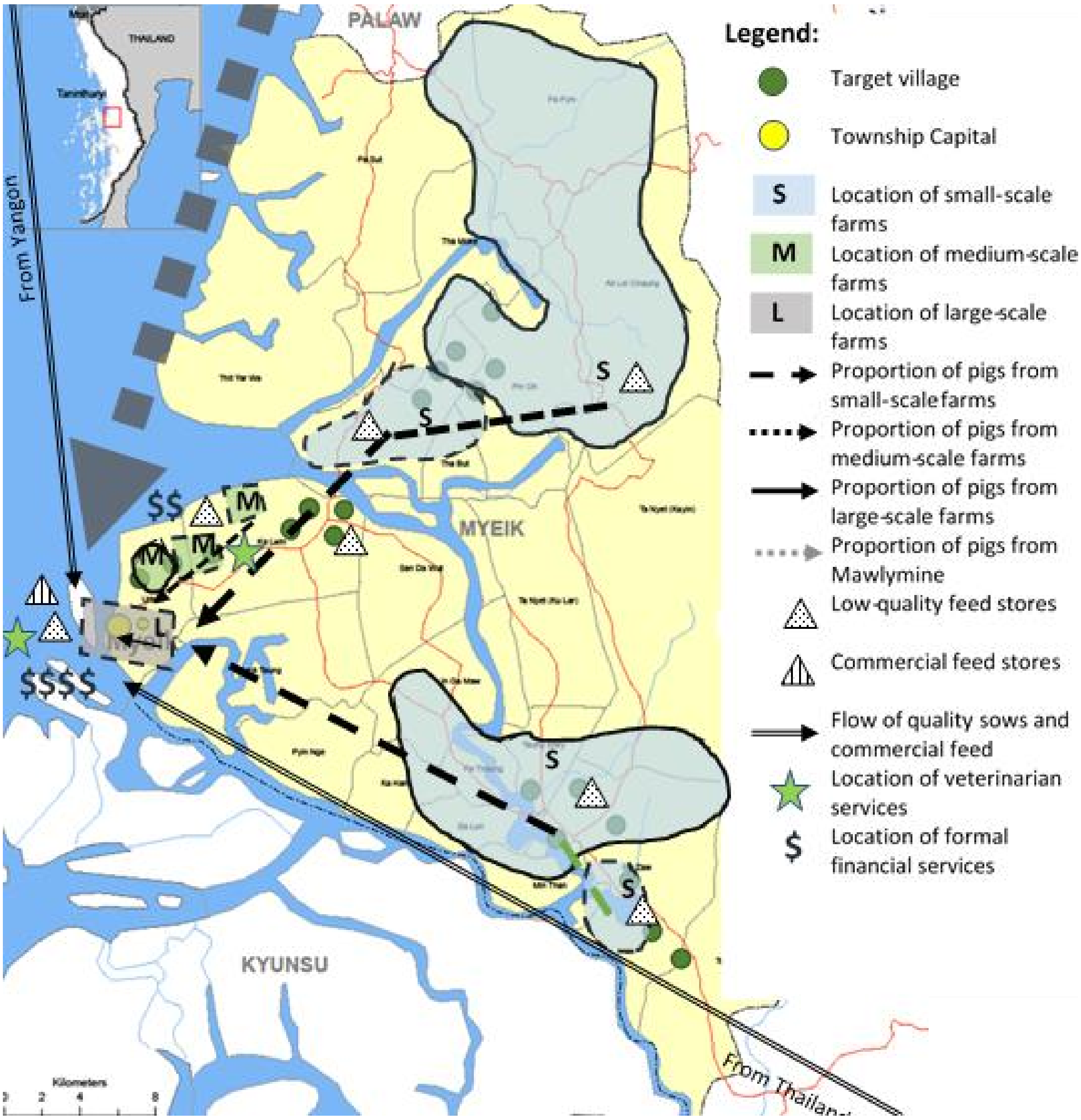

Figure 13: Spatial overview of production, service, and market flow in the pork VC in Myeik
Source: Developed by SGMB workshop participants

Slaughtering facilities operate at very low standards of food safety. Slaughterhouse owners have little incentive to invest in a hygienic, food-safe slaughtering facility because of a cap imposed on wholesale pork prices by Myeik's TDC, weak demand for differentiated pork products, and the absence of TDC inspections. Moreover, the annual licensing system creates uncertainty, as investments in fixed improvements and equipment cannot be recovered within the twelve-month license period. Accordingly, all slaughtering takes place in either the government-allocated slaughtering area next to the wet market, or at slaughtering facilities attached to residential houses. Pigs are slaughtered in the open on basic concrete slabs, with unsterilized implements and no biosecurity or waste management measures, as shown in Figure 14. Basic hygiene practices are not followed, meat is neither chilled nor frozen, and waste is typically disposed of into open sewers or nearby lakes and rubbish dumps. None of the slaughterhouses observed by the Researcher met even basic food safety standards as outlined by FAO (1991).

Figure 14: Government-allocated slaughtering facility in Myeik
Source: Picture taken by the Researcher in January 2019

The majority of live pigs supplied to slaughterhouses come from outside Tanintharyi Region, further increasing competition for local producers and the slaughterhouse's oligopsony. According to SGMB and RG participants, approximately 70% of all pigs purchased by slaughterhouses are transported from Mawlymine and Thailand. The volume of Thailand live pig imports has been in decline since 2010 to now sit below 5%; however, imports from Mawlymine have been gradually increasing. Located 570 kilometres north, Mawlymine is a twelve-hour truck drive from Myeik and a key trading hub connecting Myanmar to Thailand and Southern Myanmar to Yangon and Northern Myanmar. Myeik and Palaw slaughterhouses have stronger coordination with large-scale pig farms and traders in Mawlymine due to repeated exchanges. Orders of up to 50 pigs can be filled within 24 hours, often through a transaction with a single farmer or trader. The landed price of live pigs from Mawlymine ranged between 2 to 2.09 US$/kg including transport charges. Slaughterhouses in Myeik and Palaw favoured ordering from Mawlymine because of the lower transaction costs. It takes only one or two phone calls to order higher volumes at a consistent quality with a price point comparable to purchasing from medium and small-scale pig farmers scattered throughout Myeik and Palaw.

The pork VC in Myeik and Palaw is dominated by one product: undifferentiated wholesale pork sold in each town's wet market by slaughterhouses. Pork from local and hybrid varieties are sold without distinction in wet markets, though consumers have a growing preference for lean cuts that originate from hybrid carcasses. In 2016, the Myeik TDC imposed a ceiling on retail pork prices when live pig prices increased suddenly following a shortage caused by disease outbreaks. After pig production and supply stabilised, the price ceiling remained in place. The TDC- imposed ceiling prices operate across a range of pork products, for example, 3.33 US$/kg for three-layer meat,[10] 3.75 US$/kg for two-layer meat, and 2.08 US$/kg for ribs. As a result, there was little opportunity for price premiums associated with quality, safety, or hygiene attributes within the wholesale market.

As wholesalers, slaughterhouses sold undifferentiated products directly to households (50% of their market), restaurants (30%), hotels (10%), and retailers (10%). In recent years, there has been a small increase in demand from restaurants and hotels for direct delivery of pork to their business. These customers were starting to select premium pork cuts. This attracted a small premium (5% to 10% above wet market prices) and appeared to avoid the price ceiling as pork to this channel did not pass through the wet market. Otherwise, retailers purchased in bulk from the wet market and packaged pork into smaller volumes (i.e., 0.5 to 5 kgs) for sale in urban suburbs and rural communities. A premium of 10% to 20% is charged for this service. Due to concerns about quality and hygiene standards in farms and slaughterhouses, it was reported that a small number of high-end restaurants in Myeik had started importing frozen pork cuts, such as cutlets and ribs, directly from Thailand. Meeting with key informants in Yangon revealed an accelerating demand for premium pork products in the capital city. A number of wholesalers in Yangon were importing from abroad the equivalent of one tonne of premium cuts per week and looking to vertically integrate with Myanmar producers and slaughterhouses to protect their supply chains against any import restrictions. At the time of this study, VC actors in Myeik and Palaw were not connected to buyers in Yangon.

Owing to the low levels of vertical and horizontal coordination among actors, the pork chain governance fits within the "informal market" category as defined by Bhattarai et al. (2013). Workshop participants were unaware of any active pig producer groups, which is consistent with findings from the TRRILD project's baseline survey (Lyne & Snoxell, 2018). In the project's target region, small-scale farmers sell live pigs in villages at spot rates negotiated with brokers or

[10] Three-layer meat refers to pork belly, which consists of skin, fat, and pork meat.

slaughterhouses. There is little or no information exchange prior to sale; instead, brokers arrive at the village and commence canvassing pig producers to find those willing to make an immediate sale. This practise enhances information asymmetries and mitigates against collective selling. Small-scale farmers are unable to access current market information or organise themselves to negotiate higher prices based on bulk sales. Moreover, there are no consistent quality standards used across brokers and producers to guide negotiations, with even the weighing of pigs not common. Given the infrequency of broker visits, lack of information, and limited alternative markets, small-scale producers face hold-up problems as they are unsure of alternative opportunities and prices (Klein, 1996). Small-scale producers had to weigh up low spot-rates from brokers against ongoing production costs, such as feed, and an unknown future price for their pigs. This hold-up problem is further exacerbated by pressure to repay loans taken at high interest from informal moneylenders.

The lack of coordination also extends to support services within the chain. The Livestock Breeding and Veterinary Department (LBVD) has the primary responsibility to maintain the regulatory environment of the pork industry. According to workshop participants, limited resources result in LBVD restricting activities to training and veterinarian support to urban and peri-urban producers. Furthermore, LBVD is not able to maintain slaughterhouse pre- and post-mortem inspections or enforce importation bans. Figure 13 above highlights the spatial distribution of veterinarian services and input supply shops, which are both clustered around township centres. The supply of piglets for WF farms and boar services for FF farms also suffer from coordination problems. The more remote pig farms experience more shortages of piglets and sows, higher costs for boar services, and a lower quality of products and services.

The pork VC is impacted by regular and irregular demand and supply shocks. Local festivals and celebrations by ethnic and religious groups cause small demand spikes which have little effect on live pig prices as increased pig numbers can be sourced from the large market in Mawlymine. Chinese New Year celebrations occur across all of Myanmar as well as in Thailand, and this routinely increases live pig prices as local, regional, and national demand increases. Small- and medium-scale producers generally sell the bulk of their fattened pigs between April and June because of concerns over disease outbreaks during the wet season and to finance inputs for paddy production. This leads to excess local supply which results in a reduction in live pig prices during this period. Disease outbreaks cause the most significant shocks to the system. While small and isolated disease outbreaks (e.g., blue ear) were frequent, there are also less frequent – but significantly larger outbreaks – that affect most villages, such as the Hog Cholera outbreak in 2015/2016. Disease outbreaks result in panic selling by pig producers, who must accept the lower prices offered by brokers. Once the public becomes aware of the disease outbreak, demand falls sharply due to customer fears around purchasing diseased meat as there is no traceability or safety standards in the VC. Weak demand combined with the oversupply of pigs results in falling live pig prices. Significant disease outbreaks can also bring regulatory action. The Hog Cholera outbreak of 2015/2016 prompted the LBVD to impose an import ban on live pigs from Mawlymine and to set ceilings on wholesale prices.

Gender differences are evident across the different nodes in the VC. Within the production node, small and medium-scale farms are typically managed by women, with men supporting more labour intensive and off-farm activities, such as building pig pens and purchasing pig feed. SGMB participants linked the requirements of travel and the physical demands of transporting live pigs to the predominantly male brokers. The physical nature of slaughtering also means that most slaughterhouse employees are men, though half of slaughterhouses are owned and managed by women. Most employees of the wholesale and retail markets are female.

4.2 Identification and prioritisation of problems within the pork value chain

The first SGMB and RG workshops introduced the project's goal of selecting pro-poor upgrading interventions as well as the project's geographic area: 32 predominantly rural villages in Myeik and Palaw. Participants appreciated that the goal of the SGMB process would be to improve the profitability of small- and medium-scale pig farms in peri-urban and rural villages in the project's target area. After the Layerstack exercise, participants individually identified key problems to achieving this goal. Table 5 lists the ten problems identified. These problems were discussed in plenary, and then prioritised through individual voting. Listed in order of priority, the top three problems were: (i) the unstable price of live pigs, (ii) insufficient capital for successful pig farming, and (iii) the high cost of quality pig feed. These problems were also noted in Ebata et al.'s (2018) research into governance and biosecurity along the pig VC in Yangon. A more detailed description of the problems follows, drawing on problem reference modes and cause-and-consequence maps created by SGMB workshop participants.

Table 5: Problems identified within the pork value chain

Rank order of pork VC problems
Unstable price of live pigs
Insufficient capital for successful pig farming
High cost of quality pig feed
Lack of support from LBVD
Low knowledge on systemic hybrid pig farming
Unable to easily purchase high-quality hybrid pigs
TDC-mandated slaughterhouse license system limits competition
Lack of technical support from government
Fixed wholesale pork price
Price of piglets is expensive, and it is difficult to find high-quality piglets

Source: Developed by SGMB participants

4.2.1 Problem one: Unstable price of live pigs

The unstable price of live pigs was identified as the foremost problem to profitable pig farming. Two related reference modes were developed by SGMB and RG participants. The first, illustrated by Figure 15, shows the estimated farmgate price of live pigs between 2010 and 2019, and the second, presented in Figure 16, highlights the monthly price oscillations of live pigs across the most recent calendar year.

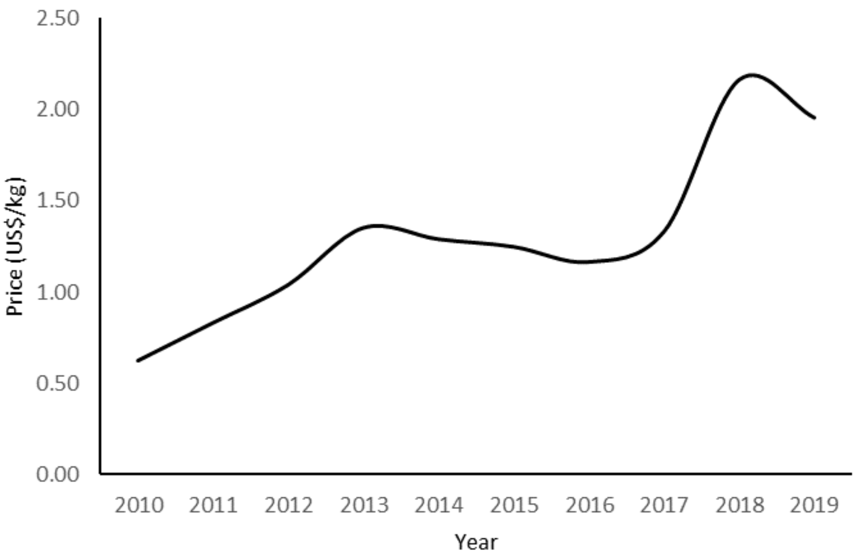

Figure 15: Reference mode of farmgate price of live pigs in Myeik
Source: Developed by SGMB and RG participants

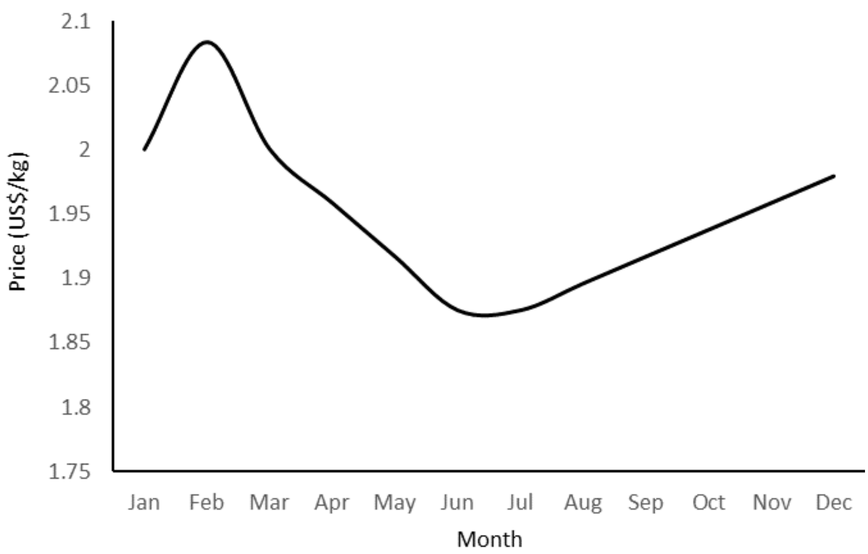

Figure 16: Reference mode of annual fluctuations of live pig price in Myeik
Source: Developed by SGMB and RG participants

Workshop participants reached a consensus on historical events that led to the price fluctuations shown in Figure 15. Prior to 2012/2013, slaughterhouses in Myeik sourced pigs from surrounding villages; however, the short supply resulted in rapidly rising farmgate prices which caused slaughterhouses to start purchasing live pigs from outside the region, mainly from Mawlymine and Thailand. The rapidly increasing imports stabilised, and then lowered, live pig prices until 2015/2016 when there was a significant disease outbreak. In response to this, panic selling ensued along with lower consumer demand. The TDC also banned the importation of live pigs from outside Myeik as a biosecurity measure. The lack of imports from Mawlymine and Thailand and low numbers of local pigs resulted in rapid live pig price increases in 2017/2018, reaching highs of 2.25 US$/kg. These record-high prices encouraged rapid expansion in Myeik-based pig enterprises, particularly among larger farms with access to financial capital. In pig production cycles, returns on production investment are delayed by at least six months. Due to this production time-lag and high local prices, slaughterhouses in Myeik circumvented the TDC ban on importing pigs from outside of Myeik. The TDC was unable to enforce the importation ban, nor trace the origin of live pigs ready for slaughter, which further encouraged slaughterhouses to quickly reinstate imports. The combination of restoring pig imports from Mawlymine and subsequent increases in local pig production resulted in a large increase in the inventory of pigs ready for slaughtering. This glut of supply drove prices down in 2018/2019 and resulted in many large-scale pig farms ceasing operations, as they could not repay investment loans, while medium-scale farmers were forced to scale down production.

According to SGMB and RG participants, the annual fluctuations of live pig prices followed a regular pattern as shown in Figure 16. The annual January/February price increase was linked to increased consumer demand over Chinese New Year. Meanwhile, the June/July trough was related to the oversupply of pigs as small-scale farmers sold fatteners to cover paddy input costs and because of concerns over monsoonal disease outbreaks.

Workshop participants developed the related cause-and-consequence map, shown in Figure 17,[11] identifying two feedback loops: “underinvestment” and “debt spiral”. In the underinvestment loop, unstable prices cause uncertainty and lower profits for pig farmers who are then unwilling or unable to make investments in their businesses. Low levels of on-farm investment in animal health, quality feed, and technical expertise reduce pig supply and pig quality in Myeik. This encourages slaughterhouses to purchase pigs from Mawlymine rather than Myeik, which in turn affects farmgate pig prices. The uncertainty around profit also discourages farmers from investing in collective action, which reduces opportunities to address information asymmetries, making farmers susceptible to low spot-rate offers at the farmgate. In the debt spiral loop, low and uncertain profits for pig farmers reduce their ability to pay back seasonal production and asset loans. To continue farming, farmers with no other credit options take additional loans from informal moneylenders at high interest rates

[11] The cause-and-consequence maps shown in this section reflect the specific discussions held in the SGMB and RG workshops and as a result they do not include the polarity of relationships. The SFDs which were developed from these cause-and-consequence maps are found in Section 4.3 and include relationship polarity.

(5 to 10% per month). The rising debt from high-interest loans increases pressure on farmers to sell pigs at lower-than-expected spot rates.

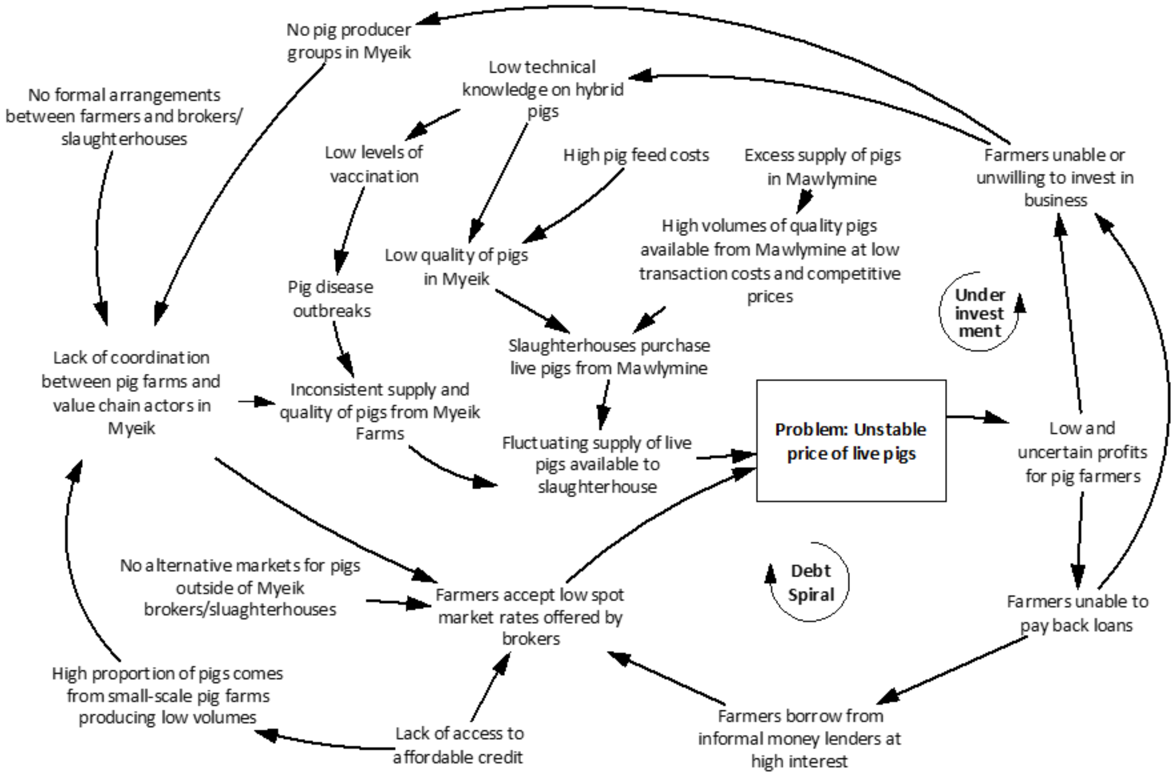

Figure 17: Cause-and-consequence map of unstable price of live pigs
Source: Developed by SGMB and RG participants

4.2.2 Problem two: Insufficient capital for successful pig farming

The next most significant problem identified was insufficient financial capital for successful pig farming, which was also a root cause of the other two priority problems. As shown earlier in Figure 13, access to credit in the pork VC in Myeik and Palaw is spatially related, which is widely noted in the literature (Milder, 2008). Large-scale and medium-scale farms, being located closer to Myeik had access to a wider range of credit options, such as MADB, commercial banks, MFIs, moneylenders, and pawn shops. As distance from Myeik increases, credit options for medium- and small-scale farmers diminish and, in some cases, reduce to a choice between moneylenders and the informal lending of animals. This supports the findings of Jefferies et al. (2018), who found that large- and medium-scale farmers in Myanmar are twice as likely to engage with formal institutions and to use multiple sources of credit than small-scale farmers.

The problem reference mode illustrated in Figure 18 shows that while the number of formal financial institutions (banks and MFIs) has grown, credit access for pig farmers is lagging. As noted by Jefferies at al. (2018), the expansion of formal credit in Myanmar has focused on paddy farmers through the MADB, with limited expansion in other agricultural sectors. Workshop participants reported that over 80% of small- and medium-scale pig farms relied solely on informal loans from moneylenders and friends to operate their businesses. This large proportion support findings of the ACCESS Advisory VC report commissioned in 2018 by the TRRILD project and the TRRILD project's baseline report that reported 80% of farming households requiring credit borrowed from moneylenders (Lyne & Snoxell, 2018).

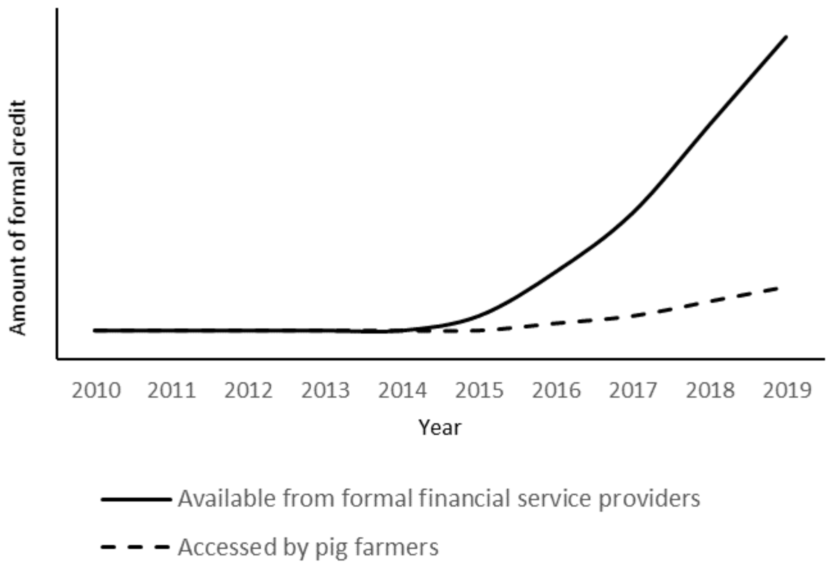

Figure 18: Reference mode of provision of formal credit in Myeik and Palaw
Source: Developed by SGMB and RG participants

As shown by the problem's cause-and-consequence map in Figure 19, the inability to access formal credit on reasonable terms forces pig farmers to take high interest loans from informal moneylenders which reduces their ability to expand production, invest in quality inputs, and make upgrades to their businesses (such as purchasing of hybrid breeds). The "debt spiral" loop is again present as mounting pressure to pay back high-interest loans, combined with information asymmetries, make small-scale farmers susceptible to accepting low spot-market rates for their products. The cause-and-consequence map also highlights significant barriers for pig farmers to access services from formal institutions, termed the "rural credit gap" by SGMB participants. SGMB participants reported that banks and MFIs operating in Myanmar frequently require loan collateral (such as land, savings, and assets) and onerous documentation (such as applications, guarantees, and land titles). As reported by Duflos et al. (2013), these requirements exclude many small- and medium-scale pig farmers from applying for formal loans. Furthermore, loans for pig farming are not a priority for these institutions as they are considered high-risk due to the fluctuating live pig prices and recent history of low profitability. The terms of loan products on offer were also reported as unsuitable for pig farming. Short loan lengths (less than one year), low initial loan amounts (less than US$300), and fixed monthly repayment schedules did not match the realities of pig farming, which include production delays and high investment costs (feed and piglet/sow purchasing).

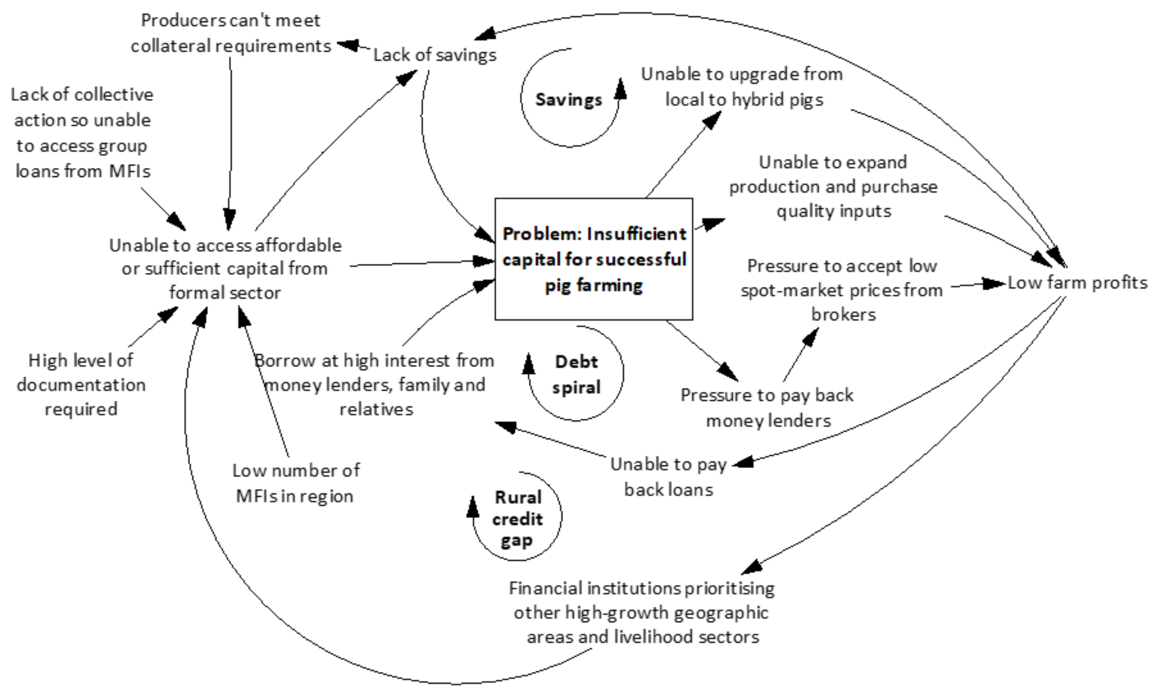

Figure 19: Cause-and-consequence map of insufficient capital for successful pig farming
Source: Developed by SGMB and RG participants

4.2.3 Problem three: High cost of quality pig feed

The high price of quality pig feed in relation to live pig prices was identified as the third most significant problem in the VC. Participants distinguished between two types of pig feeding systems: high- and low-quality. The high-quality system uses commercial feed as either a concentrate mixed with quality local ingredients (rice brain, broken rice, and fish meal) or as a complete feed package. A low-quality feeding system was defined as using only locally available ingredients at little or no cost to farmers, such as rice bran, broken rice, and kitchen/food scraps. The reference mode drawn by SGMB and RG participants in Figure 20 shows a slow transition of feeding systems from low- to high-quality. Workshop participants linked the increasing use of high-quality feed systems to investments made in hybrid pigs on large- and medium-sized farms. The plateauing of high-quality feed usage was attributed to the recent downturn in large-scale pig farms as described previously. The reference mode also demonstrates changes in pig feed costs, with the high-quality system showing gradual increases and the low-quality system showing a gradual decline.

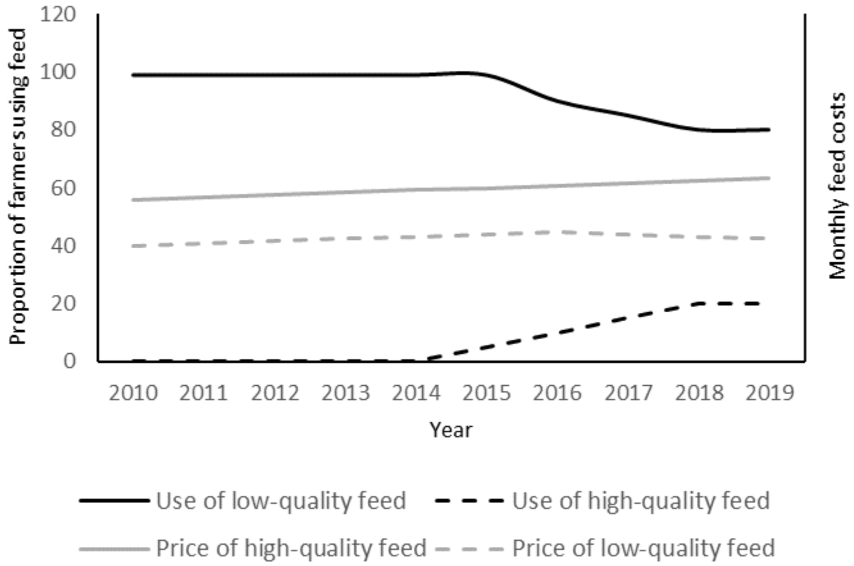

Figure 20: Reference mode of costs and use of pig feed systems
Source: Developed by SGMB and RG participants

This problem's corresponding cause-and-consequence map, shown in Figure 21, includes underinvestment and debt spiral feedback loops (like those discerned in Problem one), and an additional feedback loop, termed "scales of economy." The underinvestment loop in Figure 21 adds upgrading to hybrid pigs and investing in quality pig feed to the farmer's investment options. The high cost of commercial pig feed causes farmers to either mix in more local ingredients with commercial concentrates or to forgo commercial feeds altogether. This behaviour delays the fattening process and reduces the overall quality of the pig, which lowers farmgate prices. When farmer profits are lower than expected, farmers delay investments in hybrid breeds and commercial feed systems. Participants contended that the weak demand for commercial feed had delayed the construction of a commercial feed plant in Tanintharyi.[12] With no local supply, commercial feed must be sourced from Yangon or Thailand incurring significant transport costs that raise commercial feeds costs, referred to as the "scales of economy" loop by workshop participants.

[12] RG members reported that discussions had been held with several investors and donors to establish a pig feed company in Myeik to capitalise on the by-products of the large fishing industry in the area. However, this did not eventuate during the research period.

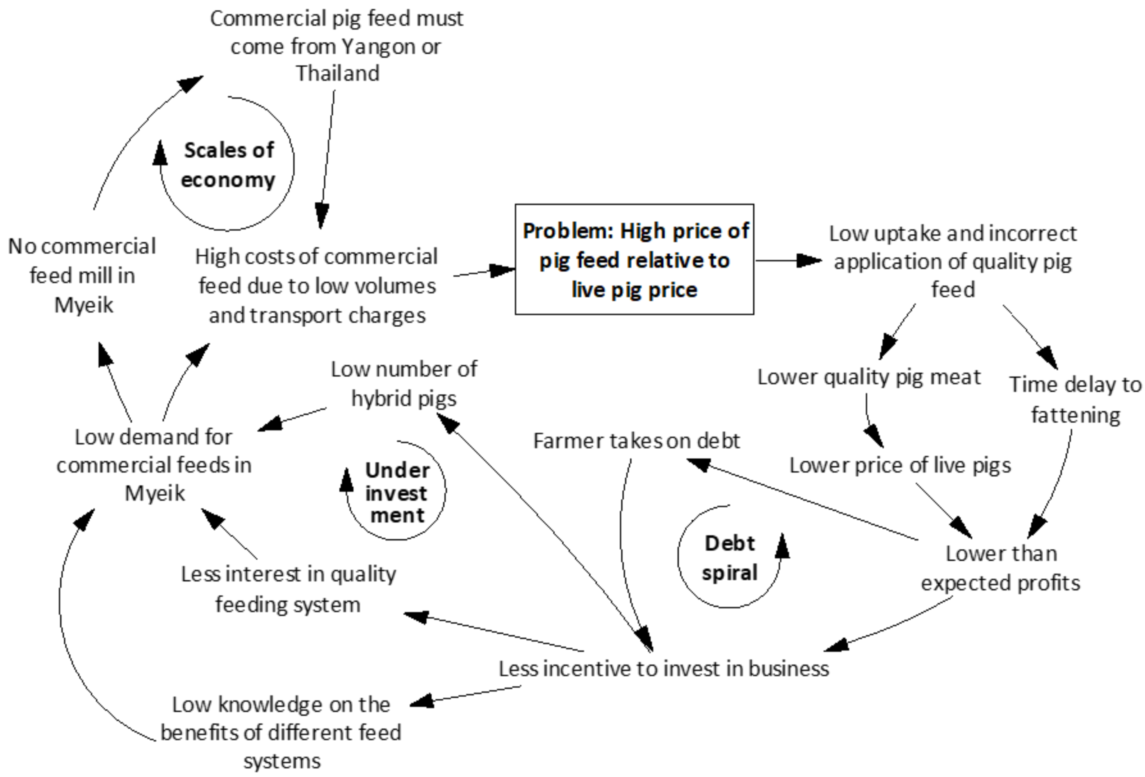

Figure 21: Cause-and-consequence map of the high price of pig feed
Source: Developed by SGMB and RG participants

4.3 Overview of the system dynamics model of the pork value chain

The next step in developing the system dynamics (SD) model was to identify critical sub-systems, or "modules," that represent relationships and variables that determine dynamic behaviour within the VC. By the end of the second SGMB session, participants had drawn on cause-and-consequence maps to select three modules to develop further: pig production, farmer investments, and farmer finance. During the construction of the pig production module, it became clear that the model needed to consider market forces beyond the farmgate. As a result, the module "pig system pricing and marketing" was added. The third and fourth SGMB and RG workshops involved participants working in small groups to develop modules into simple SFDs, containing key variables and feedback loops. Modules were discussed in plenary and subsequent changes to the module structure and parameters made through consensus. In the initial stages, causal relationships within and between modules were simplified to positive (+) and negative (-) effect. As modules were refined, causal signs (+ and -) were replaced by equations and graphical functions. A further three modules were developed by the Researcher upon returning to New Zealand: farmer knowledge, credit, and collective action (containing both PG and PO structure). The structure and parameters of these modules were reviewed by RG members through online platforms and discussed in-person during the fifth SGMB workshop. Figure 22 shows a high-level map of the model's structure, highlighting the information (black arrows) and material (dashed arrows) flows between the component modules along with each module's core functionality.

This section presents simplified SFDs of the modules, highlighting the key stocks, flows, variables, causal relationships, and feedback loops[13] that determine the dynamic nature of the system. The complete structure of the SD model (developed in Stella Architect) appears in Appendix B, while related parameters and equations are found in Appendix C.

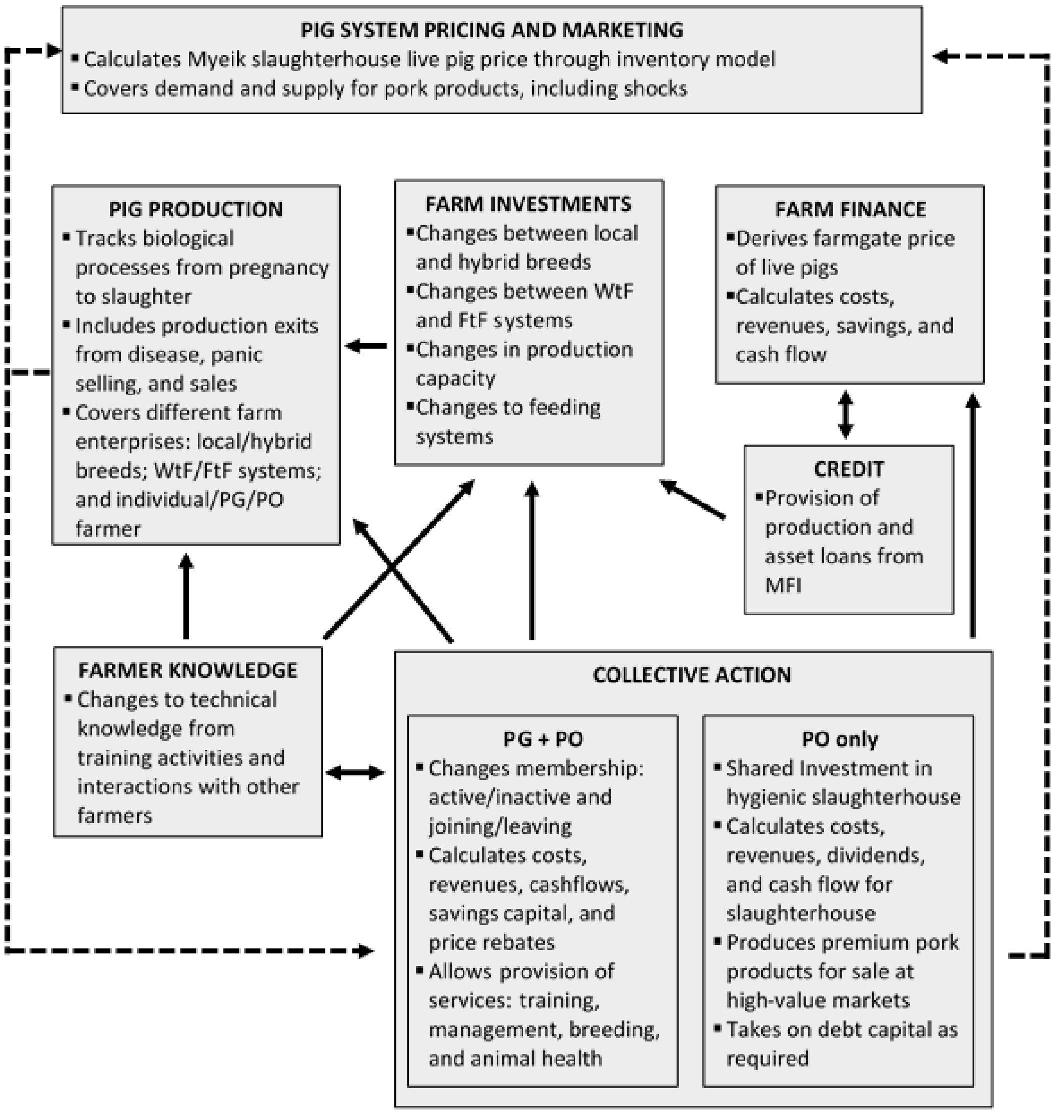

Figure 22: High-level map of the pork VC SD model
Source: Developed by the Researcher

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[13] Sherwood (2011, p.132) advises against "…[using] terms such as 'increase in' or 'decrease in'", when describing causal relationships, instead recommending terms such as "…'increase or decrease'…'pressure on'…'change in'." However, to aid readability and in the pattern of journal articles on similar topics (Lie et al., 2016; Lie et al., 2018), relationships and feedback loops are presented in language which describes the typical behaviour of the loop, such as "increase" or "decrease." Related diagrams in the text present the polarity of causal relationships for ease of reference, so that the reader can understand the variable will either increase or decrease depending on the behaviour of related variables.

4.3.1 Pig system pricing and marketing module

The pig system pricing and marketing module, shown in Figure 23, calculates the base price at which slaughterhouses in Myeik will buy live pigs from local pig producers. This variable, s*laughterhouse price of live pigs from Myeik,*[14] is used by the farm finance module to generate the *farmgate price of live pigs*. Previous pig production and inventory pricing models developed by Meadows (1970), Sterman (2010), Ford (2015), and Hamza and Rich (2015) form the basis for the module's equations and structure. The module contains a central stock, *inventory of live pigs ready for slaughter*, to represent all fattened pigs available for purchasing by Myeik slaughterhouses. This stock has three inflows representing sources of fattened pigs: Myeik producers (*pigs in production Myeik*), TRRILD project producers (*inventory of live pigs in TRRILD project area*), and Mawlymine (*Mawlymine live pigs available for export*).

In the model, slaughterhouses have two options for purchasing: from Mawlymine or from Myeik, with the decision on purchase origin determined by price differences associated with quality and lower transaction costs. This decision is represented by the variable, *effect of price difference on ordering from Mawlymine*, a graphical function which favours Mawlymine pigs when no price difference exists due to the lower transaction costs and higher quality. The price of live pigs from Mawlymine and Myeik are both calculated through an inventory pricing model: as the inventory of pigs changes relative to slaughterhouse orders the price moves in the opposite direction. In the model, the Mawlymine price of live pigs is less responsive to changes in pig inventory than in Myeik (Mawlymine sensitivity of price to inventory coverage is -0.05 compared to -0.1 for Myeik), representing the larger and more stable supply from Mawlymine. The supply of pigs from Mawlymine grows at 6 % per annum as reported by RG members. However, unlike Myeik pig production, Mawlymine's production capacity is delinked from the price of live pigs in Mawlymine. This is related to Mawlymine's position as a regional trading hub for Yangon, with sales to Myeik accounting for only a small fraction of its overall market.

In the baseline model, a significant[15] *disease outbreak* occurs every four years and lasts for 26 weeks, with a death rate of 15% of pigs per week as proposed by RG and SGMB participants. *Panic selling* by producers quickly ensues resulting in initially higher numbers of pigs for sale; however, disease outbreaks eventually reduce all three pig flows, decreasing the i*nventory of live pigs ready for slaughtering*. The more prolonged a disease outbreak, the greater the chance that there will be an *importation ban* imposed by the Myeik TDC that reduces the stock of *Mawlymine live pigs available for export*. This delayed reduction in available pig imports, reduces overall inventory and causes

[14] The names of model variables have been *italicised* to assist in linking descriptive narrative to module figures.
[15] Regular but isolated disease outbreaks occur every year. This function models a significant region-wide swine disease outbreak, such as the hog cholera event of 2015/2016 that affected most pig producers.

prices to rise; however, price changes are initially offset by the reduction in demand as consumers become aware of the pig disease and change their purchasing patterns.

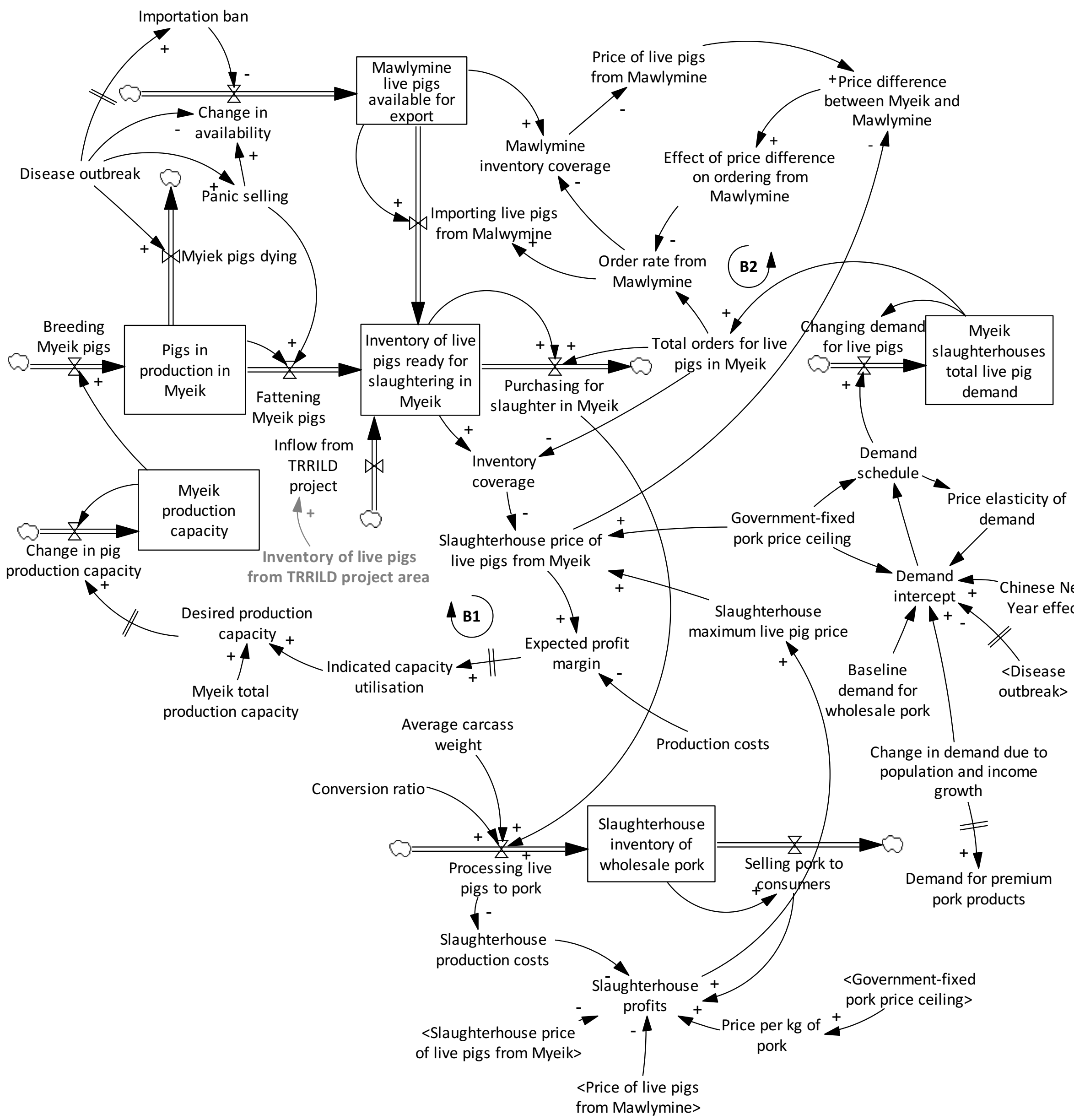

Figure 23: Pig system pricing and marketing module

Note: Grey variables indicate structure from a different module.

Source: Developed by SGMB and RG participants and the Researcher

Slaughterhouse ordering of live pigs is determined by the stock, *Myeik slaughterhouse total live pig demand*. Quantity demanded by slaughterhouses is driven by exogenous variables owing to the local government's price on wholesale pork, which is fixed per regulations at 3.54 US$/kg in the baseline model and rises by 7% every seven years (as observed and reported by RG members who noted one price rise since the TDC fixed wholesale pork prices). *Baseline demand for wholesale pork* starts at the equivalent of 700 pigs/week and is regulated by the *change in demand due to population and income growth* (increase of 6% per annum). Demand also increases by 20% for four weeks during the

Chinese New Year celebrations and decreases by 30% during disease outbreaks with a four-week time lag to account for delays for disease information to reach consumers. These demand dynamics were widely discussed and confirmed within SGMB and RG workshops.

The module also calculates the profits of slaughterhouses and brokers based in Myeik. As shown in Figure 23, slaughterhouse profits are constrained by the *Government-fixed pork price ceiling*, which limits the maximum prices they pay Myeik producers even in times of scarcity. While demand for premium pork products within and outside of Myeik rises, slaughterhouses have yet to access these markets, which would increase their price per kg of pork.

The module contains two notable balancing feedback loops which produce the fluctuations in prices described during SGMB workshops. The first, B1, is a capacity utilisation loop, the essential part of the module's price-setting structure adapted from Sterman's commodity model (2010). In the capacity utilisation loop, rising live pig prices results in higher profits for Myeik pig producers which causes them to increase their production capacity by either purchasing more piglets/sows or allocating more gilts as breeding stock. The model uses the graphical function, i*ndicated capacity utilisation*, to determine the effect of profitability on pig production capacity. There is a significant delay between price shifts and higher numbers of fatteners becoming ready for sale: a 26-week delay for producers to respond to price signals by changing production levels, and a further 26-week delay to account for biological processes of breeding and fattening. Completing the loop, the higher volume of fatteners increases the *inventory of live pigs ready for slaughtering in Myeik*, which results in a lowering of slaughterhouse pig prices.

The second feedback loop, B2, is a product substitution loop (Sterman, 2010) for Myeik pigs, that further balances the *slaughterhouse price of live pigs from Myeik* and causes price oscillations. When the *slaughterhouse price of live pigs from Myeik* increases, the price difference between Mawlymine and Myeik pigs falls, which causes slaughterhouses to increase orders from Mawlymine. This results in increases in the *inventory of live pigs ready for slaughtering in Myeik* which lowers the s*laughterhouse price of live pigs from Myeik*. There are no material delays in this feedback loop, and as such it dominates the price setting process system unless there is a significant disease shock. When a disease outbreak coupled with an importation ban occur, the usually steady stock of *Mawlymine live pigs available for export* is extinguished and loop B2 ceases to function. This causes B1 to dominate the system, with falling inventory causing rapid increases in pig prices and pig producers in Myeik responding by investments in production capacity. When the disease outbreak ceases or the importation ban is circumvented by slaughterhouses, flows of live pigs from Mawlymine quickly enter the *inventory of live pigs ready for slaughtering in Myeik* due to the large price difference, which causes prices in Myeik to fall. The timing of reinstating the B2 loop (once a disease outbreak ends) combined with biological delays in the B1 loop can result in large oscillations of pig prices. For example, if the reopening of the importation channel occurs in conjunction with Myeik pig producers' capacity investments entering the market, a large volume of fatteners will flow into the *inventory of live pigs ready for slaughter in Myeik*, which will rapidly decrease the *slaughterhouse price for live pigs from Myeik*.

4.3.2 Pig production module

The Pig Production Module, presented in Figure 24, covers the biological processes of pig production and changes in farming systems applied by the 1280 pig farmers located in the project's 32 target villages. The biological stocks and flows follow a similar structure to that applied in other pig production models (Sterman, 2010; Hamza and Rich, 2015; and Ouma et al., 2018), but with contextual modifications made through the SGMB process. The production section of the module contains five stocks to represent the life cycle of pig production: g*estation*, *piglets*, *growers*, *breeding sows,* and *inventory of live pigs from TRRILD project area* (which are "fatteners" ready for sale). An additional stock, *purchased piglets*, represents hybrid and local piglets purchased by WF farmers. Biological delays conditioned on pig breed determine flow rates between these stocks. Hybrid and local pigs have the same period for gestation (114 days) and piglet weaning (45 days); however, average fattening time is less for hybrid pigs (135 days) than for local breeds (255 days). Pig losses occur at each stage of production due to common illnesses (10% during gestation, 13% for piglets, 10% for growers). These mortality rates are affected by significant disease outbreaks (an additional loss of 15% per week for 26 weeks), type of breed (local pigs are 30% more resilient to diseases), and level of good animal husbandry practices (GAHP). Pig biological and production data was discussed at length within SGMB and RG workshops in order to reach a consensus for inclusion in the SD model.

Two key determinants of GAHP are used in the model: *number of Animal Health Workers* (AHWs), and *application of biosecurity and hygiene measures* (with full coverage of GAHP reducing death rates by 80%). Sales of piglets and fatteners are driven by exogenous variables: FF farms sell 50% of their piglets to WF farmers, and all fatteners not set aside for breeding purposes are sold to brokers and slaughterhouses when they reach their target weight (88 kgs for hybrid and 56kgs for local breeds). When a significant disease outbreak occurs, SGMB and RG participants reported that farmers panic sell 5% of piglets, fatteners, and breeding stock at reduced weights (40% of optimal) and prices each week for a ten-week period.

A reinforcing feedback loop, R1, regulates pig production capacity in this module. Pig farmers select gilts from the stock of *growers* for breeding purposes. Increases in breeding sow numbers grow the number of pregnancies, piglets, and growers which in turn enlarges the number of sows available for

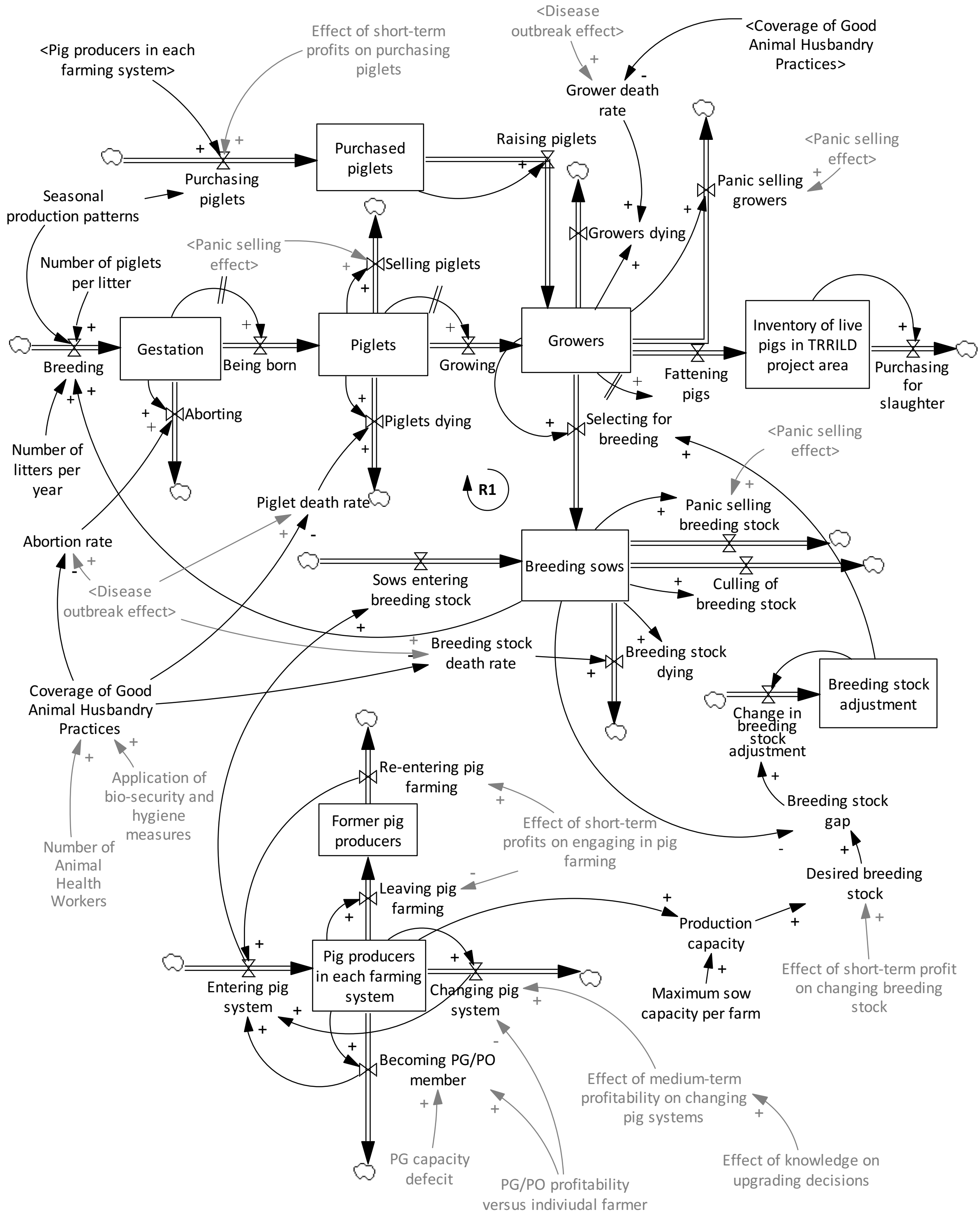

Figure 24: Pig production module

Note: Grey variables indicate structure from a different module.

Source: Developed by SGMB and RG participants and the Researcher

breeding. The pace and magnitude of change in the R1 loop are greater for hybrid pig production due to fertility and fattening practices. Hybrid sows produce 24 piglets per year (two litters of 12 piglets) while local breed sows typically produce eight piglets from a single litter per year. Additionally, hybrid pig farmers generally take half as long to complete a production cycle (26 weeks for hybrid breeds compared with 52 weeks for local varieties). This reinforcing loop is also moderated by seasonal production patterns; for example, 60% of FF farmers sell their fatteners in the two months preceding the monsoon, while breeding stock is culled after two years due to declining fertility.

The combination and timing of farmer profits and disease outbreaks determine whether the R1 loop is virtuous or vicious in nature. When a significant disease outbreak strikes the target population, the number of pigs in the system reduces through deaths and panic selling. These losses decrease the number of gilts available for breeding as well as current breeding stock, which brings further reduction in pregnancies, piglets, and growers and the R1 loop works to decrease pig numbers. Farm profitability also affects this loop. As farm profits rise, the R1 loop operates in a virtuous manner, and farmers increase breeding stock numbers to raise production capacity to deliver more fatteners for market. This increases the numbers of gilts available for further breeding and production increases, which raises farm profits. When disease outbreaks reduce overall inventory and live pig prices eventually rise as a result, the R1 feedback loop can magnify biological delays. Pig farmers who have lower stock levels due to livestock deaths or panic selling are unable to rapidly increase their breeding stock due to the low numbers of gilts. As a result, pig producers without capital reserves or networks to buy in new breeding stock or piglets are unable to take advantage of the high live pig prices and move production quickly towards the virtuous side of this reinforcing loop.

The R1 loop also has an impact on WF farmers. The majority of WF farmers source piglets from local villages; hence, a reduction in breeding stock also decreases their availability of piglets. Although WF farmers can source piglets from outside of their local villages, this brings further costs and is not always possible if disease outbreaks are system wide. Thus, WF farms have a similar dynamic to FF in that they are unable to take advantage of rising live pig prices due to delays in accessing piglet supply and the high price of piglets.

The pig production module further governs farmer evolution across different production systems. A central stock, *pig producers in each farming system,* categorises pig producers into six different farming enterprises, with inflow and outflows allowing producers to transfer between these systems. This, and other stocks in this module, use a three-by-two array to cover six producer categories: (i) pig producers farming local breeds within the FF system; (ii) pig producers farming local breeds within the WF system; (iii) pig producers farming hybrid breeds within the FF system; (iv) pig producers farming hybrid breeds within the WF system; (v) PG/PO members farming hybrid breeds within the FF system; and (vi) PG/PO members farming hybrid breeds within the WF system.[16] Pig producers move to different production systems based on the expected medium-term profitability of each system. A farmer's technical knowledge also influences the decision to upgrade a production

[16] The last two categories are not used for the baseline model but are included to allow for scenario-testing.

system and links this module to the knowledge module through the variable – *effect of knowledge on upgrading decisions*.

A simple upgrading pathway between the pig systems that was developed by SGMB participants is used in the module. This pathway is illustrated in Figure 25, showing that farmers typically move from WF to FF systems and from local to hybrid pig breeds. The module also enables pig producers to leave and then re-engage with pig farming based on short-term profits. When re-entering pig farming producers start pig production at one-level down the upgrading hierarchy outlined in Figure 25.

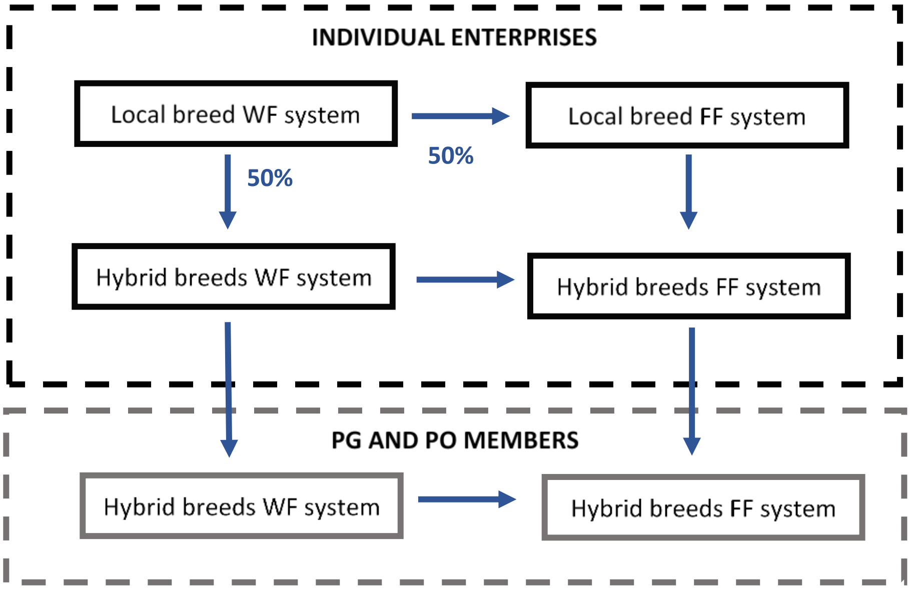

Figure 25: Upgrading pathways for pig producers in pig production module
Source: Developed by SGMB participants and the Researcher

4.3.3 Farmer finance, credit, and investment modules

The farmer finance, credit, and investment modules are intricately linked by feedback loops and are therefore explained in combination and represented together in Figure 26. The farmer finance module calculates *pig farmer profits* for each of the six farm enterprises. Farm costs are attributed to two sources: *farm production costs*, which change proportionally to the number of pigs in each production system, and *loan costs*, which are incurred by producers to finance pig production costs or investments to upgrade production systems.

The main *farm production costs* come from boar servicing, applying GAHP, purchasing piglets, and providing feed. Across all six pig systems, pig feed consumes the majority of production costs. Feed costs are greater in hybrid systems compared with local breeds, and higher in FF compared with WF systems. In the baseline model, around 80% of FF farmer production costs and 50% of WF farmer production costs relate to pig feed. For WF farmers, piglet purchase costs are the other significant cost, starting at US$30 for local breeds and US$60 for hybrid breeds. In the module, piglet prices are positively correlated with the *slaughterhouse prices of live pigs in Myeik;* thus, piglet prices rise as the inventory of live pigs in Myeik falls.

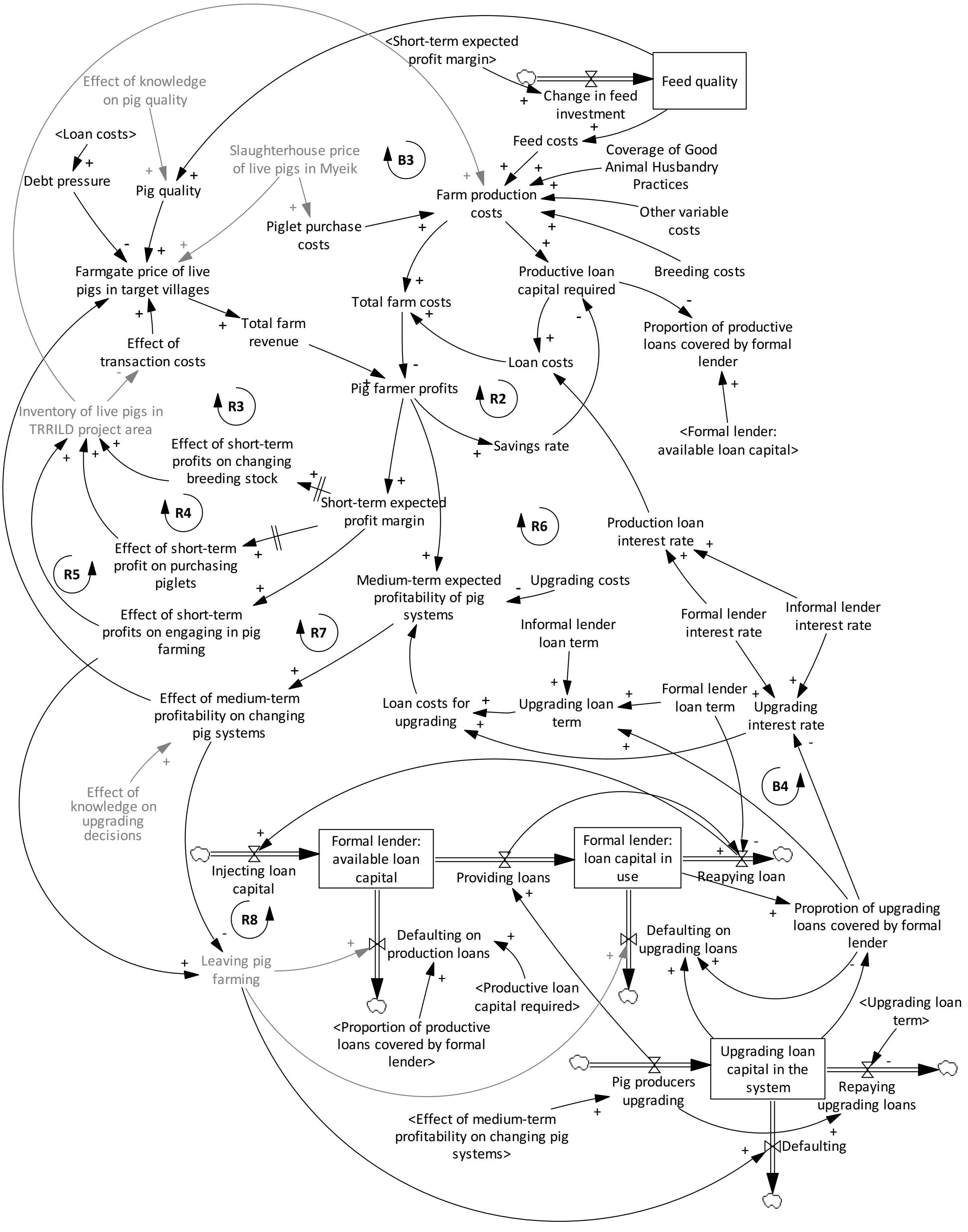

Figure 26: Farmer finance, credit, and investment modules

Note: Grey variables indicate structure from a different module.

Source: Developed by SGMB and RG participants and the Researcher

SGMB exercises noted that pig producers rely heavily on loans, primarily from informal moneylenders, to cover ongoing production costs. In the module, growth in *farm production costs* brings increases in the *productive loan capital required* to maintain cash flow. The model assumes that as profits increase, farmers save a greater portion of their profits for reinvestment, lowering the amount of p*roductive loan capital* required. The portion of profits saved is determined by the graphical function, s*avings rate.* This graph models a sigmoid curve to represent the behaviour of farmers using profits to first cover basic HH or primary livelihood requirements (such as paddy inputs) before reinvesting in pig farms. This was developed in conjunction with SGMB participants who explained that farm reinvestments increased after HHs used profits to cover HH essentials but then tapered off as profits were also invested in other livelihood sources. The cost of capital is dependent on the p*roductive loan interest rate* and is added into the *total farm costs*. The debt cycle loop described by SGMB participants is represented by the reinforcing feedback loop, R2: rising loan costs lower *pig farmer profits* which reduces the *savings rate* and requires producers to source further productive loan capital from informal moneylenders to remain in pig farming.

Farm revenue in the module is driven by the number and type of pigs sold as well as the f*armgate price of live pigs in target villages.* Derived from the production module, revenue comes from three categories of pigs: fatteners sold to slaughterhouses; piglets sold to WF farmers; and the culling of breeding stock. *The farmgate price of live pigs in the target villages* obtains its base value from the system pricing and marketing module and is conditioned by three variables represented by graphical functions. First, pig quality positively influences farmgate prices, with pig quality dependent upon *feed quality* and *farmer technical knowledge*. Investments in higher quality commercial feed enhance the physical condition of pigs and decrease fattening time. Second, the amount of outstanding *loan costs* creates pressure on producers to take lower prices from brokers to reduce debt that is accruing interest weekly, a phenomenon termed "*debt pressure"* by SGMB participants. As the amount of *loan costs* increase, *debt pressure* increases, which in turn lowers farmgate prices as producers have few alternative options to sell their fatteners. Lastly, the volume of fatteners ready for sale in the villages impacts on transaction costs incurred by brokers, especially search costs. As the *Inventory of live pigs in the TRRILD project area* increases, transaction costs decrease, which will in turn raise farmgate prices.

The pig farmer investment options elicited by the SGMB process and illustrated in Figure 26 are all reinforcing loops, "engines of growth or decline." In the module, all investment decisions are determined by expected profits which incur delays as producers take time to decipher market signals, following Lie et al. (2018). In R3 and R4, changes in short-term (26 weeks) profits cause producers to adjust production levels, by either increasing or decreasing the number of gilts allocated as breeding sows (R3) or altering the number of piglets purchased (R4). The resulting change in the number of pigs sold and transaction costs impacts pig farmer profits. If short-term profits fall to levels where pig farming is unsustainable, pig farmers cease to engage in the livelihood, lowering the number of pigs in villages, which lowers farmgate prices through increased transaction costs for brokers, depicted by the R5 reinforcing loop. Given pig farming's role in household savings, the graphical function governing the R5 loop, *effects of short-term profits on engaging in pig farming*, has a lower threshold for action than other profit related variables. Short-term profit margins also drive decisions around investments in pig feeding systems, shown by the reinforcing loop, R6. As profits increase, farmers have further savings to invest in production inputs, of which feed is the most significant. As described above, further investments in feed quality raise farmgate prices which increase farmer revenues.

Pig farmers can also upgrade their farming system, represented by the R7 feedback loop. Farmer decisions to upgrade are driven by technical knowledge and medium-term (52 weeks) profitability, which considers the expected profits of the upgrades and also the once-off upgrading costs. Upgrading costs include asset and animal purchases, such as piglets, sows, improved shelter, and equipment. The ongoing costs to service a loan to cover animal or asset purchases also determine the medium-term profitability of upgrading. Upgrading pig systems either increases the number or value of pigs in the village, which causes revenue to rise, driving further upgrading decisions.

The investment feedback loops also have reciprocal balancing loops, designated by B3 in Figure 26. While investments increase *total farm revenue*, they also raise *farm production costs*, which reduces farmer profits and balances investments. The R2 – debt loop – further curbs investment, as any increases in *farm production costs* further raise the amount of loan capital required. The B1 and B2 feedback loops from the system pricing and marketing module act as a further brake on producer investments, especially given the long production delays which prolong returns on investment strategies.

Two sources of credit are available to producers in the model: from informal moneylenders and from formal financial providers, such as MFIs and banks. The moneylender interest rate is set at 5% per month and 2.46%[17] per month from formal sources as reported by SGMB and RG participants and recent literature (Jefferies et al., 2018; Hein et al., 2016). Moneylenders are assumed to have an unlimited source of credit; however, loan capital from formal providers is limited by the initial value of the stock, *formal lender: available loan capital*. Two types of formal loans are available to farmers; loans to finance assets or animals needed for upgrading pig systems and loans to cover ongoing production costs, such as pig feed. The module prioritises loans for upgrading when it allocates the stock of *formal lender: available loan capital*. The remaining loan capital from formal lenders is made

[17] This is the interest rate of the TRRILD project's partner MFI.

available for production loans. The cost of loan capital is computed as weighted average of the interest rates charged by formal and informal lenders. As the proportion of loans from formal lenders increases, interest rates across the module move closer towards the floor level of 2.46% per month. The loan term for upgrading loans is computed in a similar manner, with formal lenders providing shorter term loans (52 weeks) compared to informal moneylenders (66 weeks).

The credit module also covers defaults by pig farmers. Recently upgraded pig producers default on loans when their new enterprises are unprofitable over a 52 week period. When the variable, medium-term *expected profitability of pig system* declines, the *number of new entrants leaving* rises and loan capital exits from the stock of *formal lender: loan capital in use* through the flow: *defaulting on upgrading loan*. Pig producers without upgrading loans but with production loans from the formal lender also exit from farming when short-term profits fall, and this causes reductions in the stock of *formal lender: available loan capital*.

Two main feedback loops are present in the credit module. Firstly, a balancing feedback loop, B4, exists given the finite nature of credit. When profits rise and pig producers make upgrades, they start to exhaust formal credit supplies. This increases the overall interest rate which in turn increases loan costs, thus lowering farming profits. Also acting to reduce loan capital, in R8, lower farmer profits cause higher default rates as farmers leave pig farming and are unable to meet their repayment obligations. This reduces the overall loan capital available, which raises system interest rates and negatively impacts farmer profits.

4.3.4 Farmer knowledge module

The farmer knowledge module determines changes to the stock of *farmer technical knowledge* and is illustrated in Figure 27. The stock of technical knowledge covers good GAHP like feed preparation, animal health, biosecurity, and appropriate shelter. The module assumes that, *ceteris paribus*, any increases in technical knowledge convert to improvements in farm practices. The technical knowledge of farmers has a positive relationship towards overall pig quality and increases the confidence of producers to upgrade their pig enterprises (as shown in Figures 26 and 27). The stock of *farmer technical knowledge has an inflow*, *acquiring knowledge*, and an outflow, *forgetting*, which is assumed as a fixed rate of 5% of capacity per annum. There are two pathways for acquiring knowledge in the module: through training events (based on the module structure presented by Lie et al., 2018) and peer-to-peer learning (based on the relationships identified by Reinker and Gralla, 2018).

Training structures represent training events[18] delivered by the TRRILD project, and LBVD and other civil society actors. For the baseline, SGMB participants estimated that 5% of the target population's farmers would participate in a training every year. The percentage of farmers acquiring knowledge from training positively influences the *learning rate* among farmers. The *learning rate* is also determined by the rate at which farmers absorb and apply knowledge, shown by the variable *knowledge absorption rate* (assumed at 50 % based on discussion with RG participants), as well as their *knowledge gap*. Farmer *knowledge gap* is the difference between the maximum knowledge a farmer can be expected to attain (i.e., a master or expert farmer) and their current level of knowledge. Herein lies the balancing feedback loop, B5; changes to the stock of *farmer technical knowledge* alters the *knowledge gap*, which determines the *learning rate*. As a balancing feedback loop, additional training events in the module produce diminishing rates of returns to the stock of *farmer technical knowledge*.

Farmers also increase their technical knowledge through regular interactions with peers, represented by the variable, p*roportion of farmers educated by peers*. As the stock of f*armer technical knowledge* rises there is increasing likelihood that farmers will encounter technically competent farmers when meeting with peers. Not all interactions between farmers result in education transfer and in the module, it is assumed that the *proportion of contacts resulting in education* is 50% as per advice from RG members. A reinforcing feedback loop, R9, operates within the peer-to-peer learning process. As farmers gain technical knowledge, the likelihood of learning from a technically competent farmer increases, which further increases the stock of knowledge among pig farmers. The peer-to-peer loop could, therefore, build on knowledge gains from a training event by multiplying it across the target village and offsetting the *forgetting* of technical knowledge. However, the strength of this multiplier effect depends upon the *number of contacts with peer farmers* and the *proportion of contacts resulting in education*. The *number of contacts with peer farmers* is positively influenced by the number of PG/PO members in the collective action module.

Learning curve principles adapted from the improvement process literature (Sterman, 2010; McGarvey & Hannon, 2004) determine the effect of knowledge changes on farmer upgrading decisions and pig quality. The learning rate is assumed at -0.05 for upgrading and -0.02 for quality following discussions with SGMB and RG participants. The module uses a learning rate formula (Sherman, p. 338, 2010) to calculate the effect of changes in knowledge. For example, the variable, *effect of knowledge on upgrading decisions*, is calculated in Stella Architect using the equation: (*farmer technical knowledge*/*Initial knowledge level*) ^ (LN (1-*Learning rate – upgrading*)/LN(2)).

[18] This includes events such as classroom training, learning from a mobile application, farmer field schools, and on-farm interactions with livestock extension workers.

When applying this calculation, the *effect of knowledge on upgrading decisions* increases by 5% every time *farmer technical knowledge* doubles compared with *initial knowledge levels.*

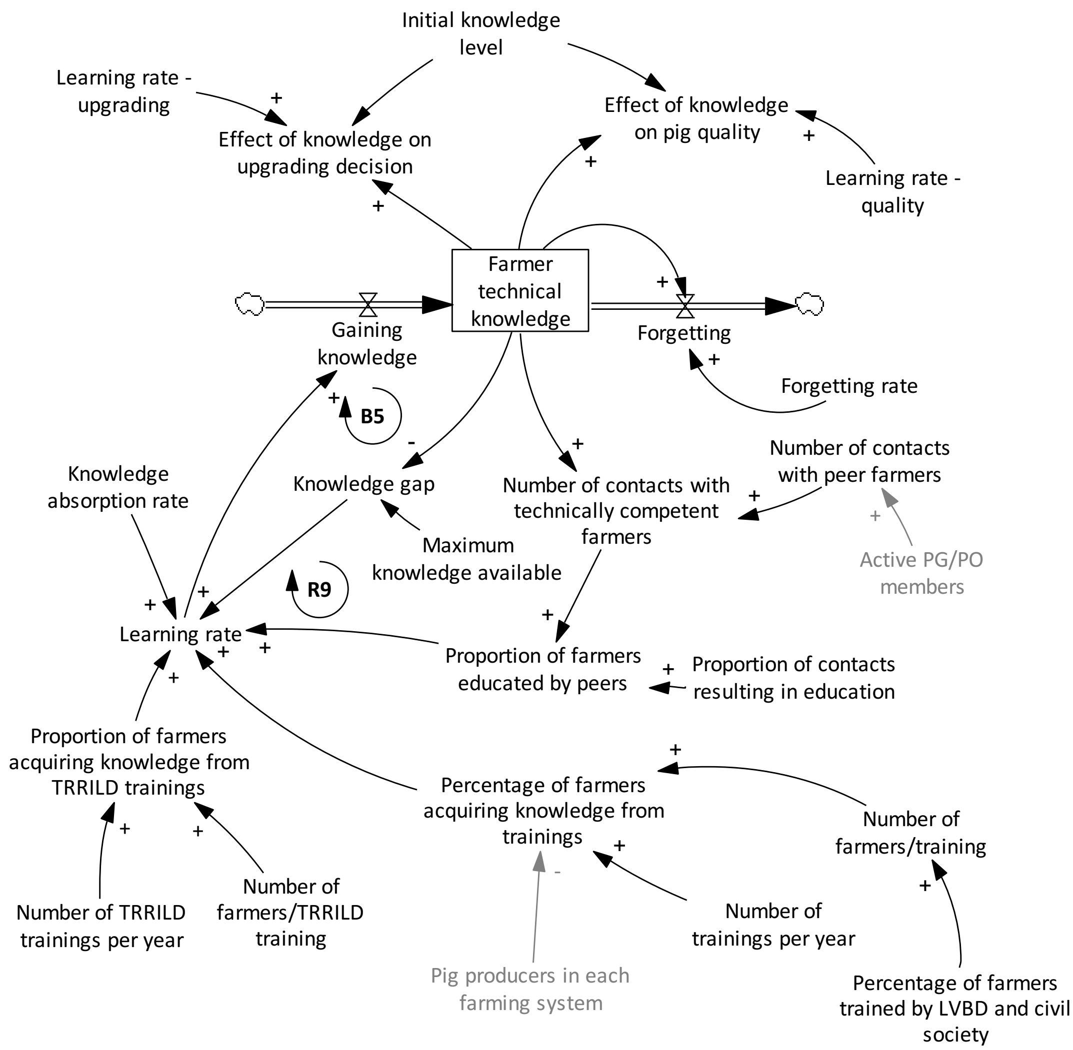

Figure 27: Farmer knowledge module
Note: Grey variables indicate structure from a different module.
Source: Adapted from Lie et al. (2019) by the Researcher

4.3.5 Collective action module

The collective action module in the pork VC SD model is based on the generic SFD developed in Section 3.5.2. In the pork VC, there is little to no collective action; hence, the collective action module operates as a potential intervention for scenario testing. The collective action module consists of two parts: (i) the PG module, shown in Figure 28; and (ii) the PO module, presented in Figure 29. In the pork VC SD model, pig PGs are established to transition to pig POs, hence the PG module structure is fully absorbed into the PO module. This is because PGs operate primarily at a transactional level in the model and POs extend their operations by investing in value-adding assets to capture a larger share of the consumer’s dollar. To achieve PO status, PGs adopt institutional arrangements that encourage investment and discourage side-selling, including tradable delivery rights and class B shares (Chaddad & Cook, 2004).

The PG module tracks membership in pig PGs, the financial position of pig PGs, and investments in pig PG services, as shown in Figure 28. The structure and equations used in this module are based on the cooperative decision and cashflow module developed by McRoberts et al. (2013), but with additional functionality around PG membership, institutional arrangements, and capacity investments. In this module, pig PG members are represented by two stocks, *active PG members* and *non-active PG members,* with two arrays to cover WF and FF farmers. Flows between the two stocks allow members to alter their engagement within the pig PG depending on circumstances. When working individually is more profitable than working through the PG, members stop patronising the PG, and when circumstances are reversed, they re-engage with the PG. This functionality represents the well-documented phenomenon of side-selling that negatively impacts collective action (Cook, 1995). Mirroring structure from other modules, pig PG members can leave pig farming permanently if profits fall sharply, and upgrade from WF to FF farms based on medium-term profitability.

The financial state of the PG is represented by the stock, *PG cashflow*, which has a revenue inflow, and outflows for savings (i.e., retained earnings to increase PG capital), costs, and price rebates. In the module, PGs establish a relationship with slaughterhouses to collectively market their pigs, with revenues collected from these sales increasing PG cashflow. PGs negotiate a modest premium (baseline value of 5% above farmgate prices was agreed by SGMB and RG members and confirmed during KIIs with slaughterhouse owners) to supply a consistent volume of high-quality hybrid pigs based on relational or formal contracts. On delivering pigs to the PG, members are paid the equivalent farmgate price which depletes *PG cashflow*. Covering the pig PG's operating costs also draws down *PG cashflow*; these costs include management fees (i.e., payments to Directors or PG Managers), technical fees (costs of technical training on hybrid pig production), and any ongoing costs to maintain the PG's capacity to provide services to its members. The level of cash reserves the pig PG needs to cover these regular costs is represented by the variable, *minimum desired balance*. The *minimum desired balance* is determined by multiplying *PG costs* by a *desired time coverage*, which is set for two weeks in the baseline model based on discussions with RG and TRRILD project staff. The *maximum flexible cash* that the PG has available to allocate for retained earnings or price rebates is then given by the equation: *PG cash flow - minimum desired balance.*

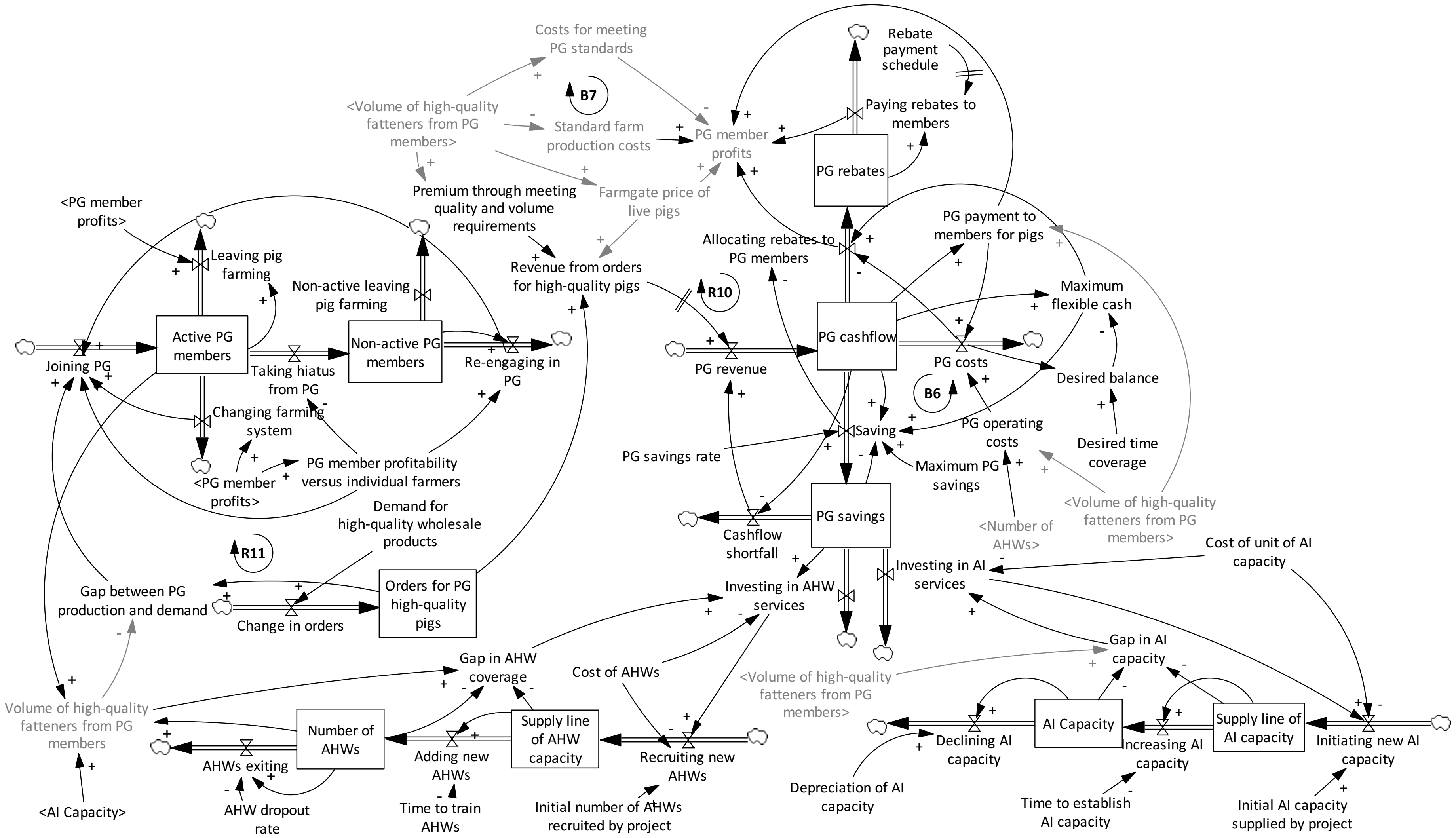

Figure 28: PG portion of the collective action module

Note: Grey variables indicate structure from a different module.

Source: Developed by the Researcher drawing on McRoberts et al. (2013)

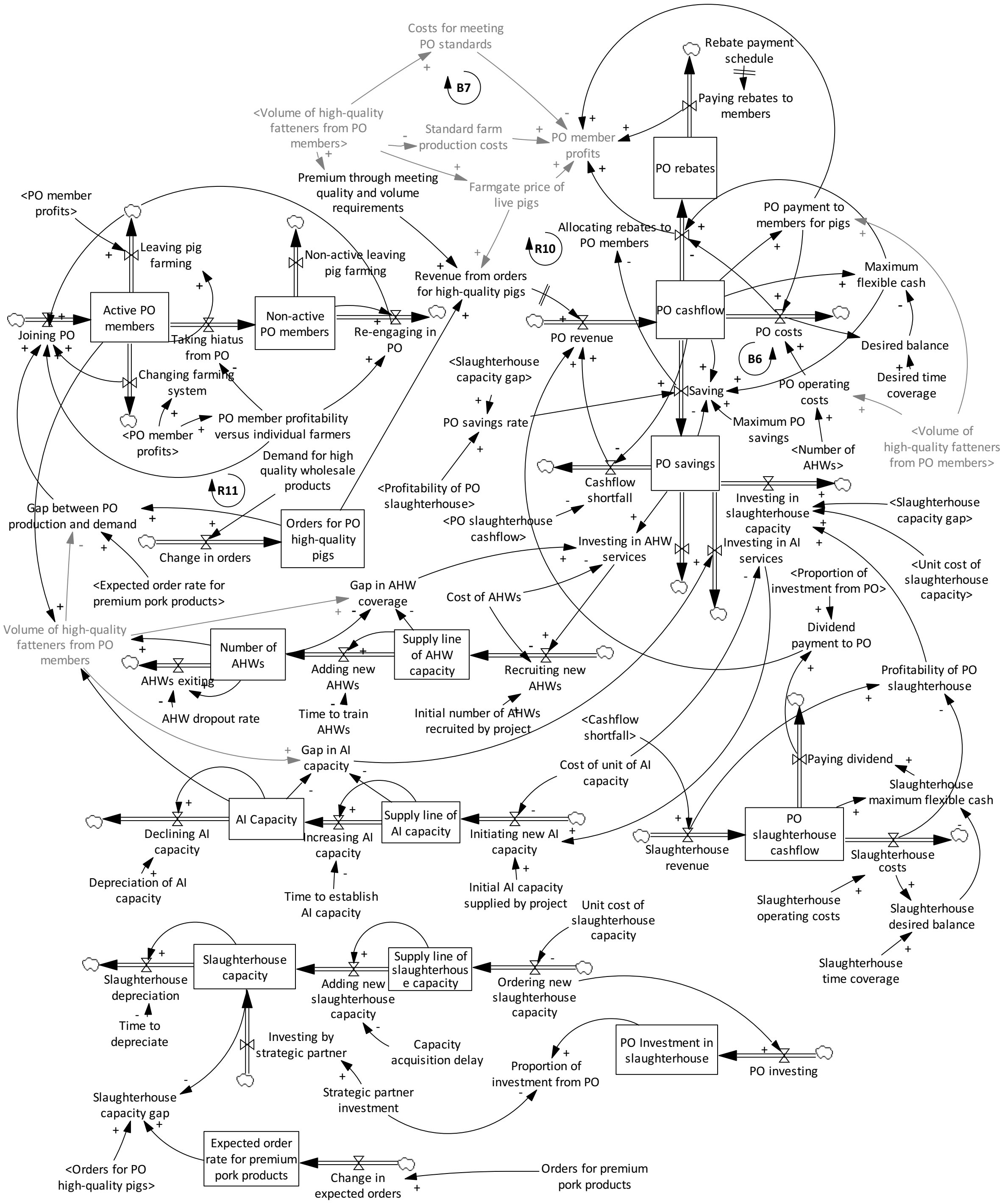

Figure 29: PO portion of the collective action module

Note: Grey variables indicate structure from a different module.

Source: Developed by the Researcher drawing on McRoberts et al. (2013)

The pig PG allocates cashflow to the stock of *PG savings* if there is sufficient cash to maintain the *minimum desired balance* and until the *maximum PG savings* level is attained (US$50,000 in the baseline). PG savings are used for *investing in PG capacity* to provide services to pig PG members. In the SD model, basic services include training for members, bulk purchasing of inputs (*decreasing standard farm production costs*), and collective marketing of products. Additionally, the pig PG continues to invest in TRRILD project-initiated services: Animal Health Workers (AHWs) and Artificial

Insemination (AI). The level of pig PG capacity determines the volume of high-quality fatteners that PG members can supply to the PG to meet orders. The module assumes that pig PGs aim to provide services to all members' pig enterprises, rather than limiting services to cover only the pigs required to meet contract orders. The pig PGs' capacity deficit (i.e., *gap in AHW coverage* and *gap in AI capacity*) is determined by the share of its members' pigs not serviced by the PG services. If savings allow, the PG continues to invest in the additional capacity needed to provide these services to its members. In the event of liquidity stress, the stock of *PG savings* is redirected to *revenue* inflows and *PG payments to members for pigs* are reduced to maintain positive cash flows in the PG.

The PG module contains multiple feedback loops, of which only the most significant will be explained. The success of the PG as an institution rests on its ability to maintain financial viability. In the reinforcing feedback loop, R10, revenue generated from meeting orders increases *PG savings* and investments in the capacity of the pig PG to service its members. Growth in services increases the volume and quality of members' pigs, which enables the PG to maintain and grow its orders for high-quality pigs. This revenue generating loop is counterbalanced by the B6 loop. In this balancing loop, PG investments in capacity to deliver services to members incur ongoing costs. These costs combine with payments to PG members in the form of immediate farmgate payments for pigs and delayed price rebates, decreasing *PG cashflow*, and its ability to save and make future investments in capacity.

The success of the PG also rests on its ability to maintain membership numbers that allow the PG to meet the *orders for PG high-quality pigs* and achieve economies of scale for its services. This feedback loop, R11, requires a critical mass of pig producers to join the PG to determine whether it operates in a state of growth or decline. In a state of growth, increases in profits earned by PG members relative to non-members encourages more pig farmers to join the PG, to re-engage with the PG, or to change their farming system from WF to FF, all of which grow the volume of high-quality fatteners produced by PG members. This grows PG member revenue as they can supply more high-quality fatteners at a premium to meet slaughterhouse orders, and fatteners sold outside of PG contracts also bring higher farmgate prices because of their improved quality. Both these revenue streams increase PG member profits, thus helping to maintain PG membership and attract new members when required. The balancing loop, B7, acts as a counter to the R11 loop, influencing whether the loop is in growth or decline. The B7 loops focuses on the costs associated with producing a quality product. If the costs of producing a quality product outweigh the price rebates that members receive over and above the farmgate price, then PG member profits decline relative to non-member profits and PG members begin to disengage from the PG and side-sell their products.

The institutional and PG member feedback loops in the PG module are interconnected and thus reinforce patterns of growth or decline. For example, in the B6 balancing loop, if the PG overinvests in its capacity, costs increase, decreasing its ability to pay price rebates to members. This causes a fall in PG member profits, which negatively affects both PG membership numbers and overall PG profitability (negatively effecting the R1, R2, R3, and R7 production and investment loops) and results in the R10 moving towards a state of decline. PG revenue is then decreased, limiting investments in capacity. If PG capacity drops to a point where it cannot supply the volume or quality determined by orders for high-quality pigs, then the R11 re-enforcing loop also moves into a state of decline, which lowers PG revenue and further decreases capacity and the ability to pay price rebates to members.

The PO module, shown in Figure 29, accommodates the scenario in which PGs convert to POs that invest in value-adding assets. In the pork VC SD model, POs invest in a hygienic slaughterhouse that produces premium pork products. Any remaining slaughterhouse capacity is allocated to producing a high-quality wholesale product for the wet market. The PO module replicates PG cashflow structure with a few notable exceptions. Firstly, investments by the POs in slaughterhouse capacity are determined by the gap between production capacity and orders as well as the long-term profitability of the slaughterhouse. As shown in Figure 29, changes to long-term profitability of the slaughterhouse determine both *PO savings rates* and the rate of investment in the PO's slaughterhouse. Additionally, the slaughterhouse capacity stock and flow structures provide the opportunity for a strategic partner to inject an initial capital investment in the slaughterhouse. As a result, dividends paid out from the slaughterhouse through to the POs are determined by the variable, *Proportion of slaughterhouse investment from PO*. As the slaughterhouse's profitability increases, and the POs continue to investment in this asset, the POs' share of the dividend payments increase.

Chapter 5

Results of the *ex-ante* impact evaluations of pro-poor interventions to upgrade the pork value chain

This chapter presents and analyses the results of the *ex-ante* impact evaluation of pro-poor interventions to upgrade the pork VC. First, the process to validate the model is outlined in Section 5.1 followed by an overview of the indicators used to analyse the results of scenario-testing in Section 5.2. Findings from the baseline model of the pork VC are then described in Section 5.3. Next, Section 5.4 provides an overview of the institutional scenarios and technical upgrading activities used for scenario-testing. Sections 5.5 and 5.6 present and analyse the results from the *ex-ante* evaluation of these pro-poor upgrading scenarios. The chapter concludes with the sensitivity analysis of the pork VC model's findings in Section 5.7, including alternative scenarios and a multi-variate parameter analysis.

5.1 Model validation

Model validation outlined by Forrester and Senge (1980) and Sterman (2010) was undertaken to establish confidence in the SD model and its ability to guide decision-making in the TRRILD project. During the fifth SGMB session, the quantitative SD model was shared with the original SGMB and RG participants and the evolution of the concept model's structure was examined and verified by them. This sharing served as a structure-verification test, helping to ensure that only structure that had real world meaning was included in the model (Sterman, 2010). Throughout the model-building process, the Researcher performed intuitive sensitivity analyses to verify the accuracy of critical parameters. This was particularly important for parameters that could not be triangulated with secondary data and for the graphical functions that drive the model's dynamic behaviour (Sterman, 2010). Extreme condition testing was applied to the model to analyse and confirm its ability to respond plausibly when using extreme ranges of parameters. Critical parameters and graphical functions were also selected for more intensive sensitivity analysis. The results of these analyses are reported in Section 5.7.

The model was also validated by checking its ability to replicate historical behaviour (Forrester & Senge, 1980; Sterman, 2010). Owing to the lack of historical secondary data, the model's behaviour was compared to historical trends described in reference modes established by SGMB and RG participants. The baseline model was able to recreate notable historical trends and patterns including (i) live pig prices which oscillate seasonally, continue to rise, and have peaks and troughs following disease shocks; (ii) the migration of pig producers to FF systems; (iii) disease outbreaks; and (iv) the growth in importation of pigs from outside the region. These behaviour reproduction tests were reviewed and confirmed by SGMB and RG participants in workshop five to further build confidence in the model's results.

5.2 Model indicators

Indicators were identified to analyse the results of scenario testing and to guide the selection of upgrading strategies for the TRRILD project. Originally suggested by workshop participants in SGMB and RG four, indicators were iteratively modified by TRRILD project partners as further information to guide project decision-making was required. Given the large number of indicators and scenarios for testing,[19] two were chosen as outcome-level indicators: (i) the aggregate profits of all pig producers in the project's target villages was selected to assess the size of the project's economic impact; and (ii) the number of pig producers in highly profitable systems was selected to assess the project's pro-poor impacts by examining the distribution of economic benefits across producers. These two aggregate indicators were chosen to understand both the project's economic and pro-poor impacts within the system under enquiry – pig producers in the 32 target villages. To further strengthen the project's pro-poor impacts, the focus of the remaining indicators was weighted towards small- and medium-scale producers in the target area, with per capita indicators used to understand differences in timelines and between farming systems. However, several meso-level indicators were also included to measure the impacts of upgrading on other key chain actors, such as slaughterhouses and brokers. Where possible each indicator was delineated by pig breed (local or hybrid); farming system (FF or WF); and participation in a farmer organisation (individual or PG/PO member). The final set of seventeen indicators is presented in Table 6. The model produced data using a time step of weeks; typically, indicators were compared across short- (260 weeks), medium- (520 weeks), and long-term (780 weeks) horizons.

Table 6: Indicators for the pork VC model

Indicator	*Unit*	*Indicator definition*
Slaughterhouse price of live pigs	US$/kg	Price of live pigs purchased by slaughterhouses in Myeik and Palaw
Proportion of pigs slaughtered in Myeik and Palaw originating in Myeik and Palaw	Percent	The proportion of all pigs slaughtered in Myeik and Palaw slaughterhouses that were produced by farmers in Myeik and Palaw
Cumulative profits for slaughterhouses	US$	Total profits for slaughterhouses in Myeik and Palaw servicing the 32 villages targeted by the project
Cumulative profits for brokers	US$	Total profits for all brokers servicing the 32 villages targeted by the project

[19] Analysing seventeen indicators over three different time horizons across the baseline and three scenarios containing five upgrading activities equated to 1,020 unique data points for comparison.

Table 6: Indicators for the pork VC model (continued)

Indicator	*Unit*	*Indicator definition*
Number of weeks worked in pig-related off-farm activities	Weeks	The number of weeks worked by people employed as animal health workers (AHWs), artificial insemination (AI) workers, brokers, and slaughterhouse labourers that are directly attributable to the supply of live pigs from target villages
Number of pig producers in each farming system	Pig producers	The number of pig producers active in each of the six farming systems: (i) individual local breed FF; (ii) individual local breed WF; (iii) individual hybrid breed FF; (iv) individual hybrid breed WF; (v) PG member hybrid breed FF; and (vi) PG member hybrid breed WF
Number of pig producers in highly profitable systems	Pig producers	The number of pig producers that earn more than US$153[a] per year from pig sales.
Weekly cashflow for individual producers in each farming system	US$/week	Weekly cashflow for an individual producer in each of the six types of farming systems
Aggregate profits[b] for individual producers in each farming system	US$/producer	Total profits for an individual producer in each of the six types of farming systems
Annual profits for individual producers in each farming system	US$/producer/year	Annual profits for an individual producer in each of the six types of farming systems
Aggregate profits of all pig producers in target villages	US$	Total profits from pig farming for all pig producers in all 32 target villages
Cumulative number of fatteners sold	Fatteners	Cumulative number of fatteners sold at full weight by each of the six type of farming systems
Number of active PG members	PG members	Number of farmers who belong to a PG and are actively working through the PG to sell their fatteners
PG cashflow	US$/week	Weekly cash balance of the PG
PO slaughterhouse cashflow	US$/week	Weekly cash balance of the PO's upgraded slaughterhouse
Aggregate profits for slaughterhouse strategic partner	US$	Total profits of the strategic partner from their investment in the PO slaughterhouse

Note: [a] The figure of US$153 is selected as this is approximately 50% more than the average (MMK153,000) revenue of sales from livestock recorded in the TRRILD's baseline survey (Lyne & Snoxell. 2018). [b] Profit refers to economic returns to a pig producer's labour, management, and land used in pig production.
Source: Developed by SGMB and RG participants, TRRILD project partners, and the Researcher

5.3 Model baseline

5.3.1 Baseline description

The baseline model represented the farming enterprises of 1,280 pig producers in the TRRILD project's target area of 32 villages in Myeik and Palaw and established a benchmark against which to compare the results of pro-poor upgrading scenarios. The model was parameterised with data provided by SGMB and RG workshop participants and, when appropriate, secondary sources. The complete list of baseline parameters and their sources are presented in Appendix C. The TRRILD project's PG survey of December 2019 provided baseline information about the initial distribution of pig producers across farm enterprises: 15% individual local breed FF farmers; 60% individual local breed WF farmers; 12.5% individual hybrid breed FF farmers, and 12.5% individual hybrid breed WF farmers.

The baseline scenario included a significant disease outbreak every four years that lasts for 26 weeks. This represented another covariate risk to the target population over and above the typical losses from disease which are embedded in the model (10% during gestation, 13% for piglets, and 10% for growers as reported by RG members). The significant disease shock was assumed to cause mortality rates of 15% per week across all pigs (pregnant sows, breeding sows, piglets, and fatteners) and induced panic selling, represented by increasing the selling rate of under-weight (40% of optimal weight) fatteners by 5% per week for ten weeks. Four weeks after disease is detected, consumer demand for pork falls by 30% and returns to pre-disease level after 26 weeks. The disease outbreak parameters in the baseline reflect historical events as described by SGMB and RG participants, such as the hog cholera epidemic in 2015/16 and the porcine reproductive and respiratory syndrome (PRRS) outbreak of 2011.

5.3.2 Baseline results

In the model's baseline, the nominal slaughterhouse price of live pigs in Myeik and Palaw rose steadily, albeit with regular price oscillations. Smaller annual price fluctuations of up to 4% reflect increased demand during the Chinese New Year festival and increased local supply when producers sell prior to the monsoon season. As shown in Figure 30, significant outbreaks of swine disease caused more substantial price fluctuations. At the initial stages of a disease outbreak, live pig prices fell for thirteen weeks due to panic selling by pig producers and reduced consumption owing to food-safety concerns following widespread pig deaths. Prices then rebounded sharply, peaking 18 weeks after the disease outbreak finishes. Price peaks were 10% higher than pre-disease prices because of the fall in overall pig supplies and consumer demand returning near to pre-disease levels. These large spikes in price induced small-scale pig producers to increase production capacity or to upgrade their pig enterprises. Once farmer investments in production capacity were realised, higher volumes of fatteners became available, and prices fell steadily over a twelve-month period to slightly higher than pre-disease levels. The baseline model showed that these price reductions grew in magnitude over time. As a result, price troughs caused by disease and oversupply reached levels later in the model that caused recently upgraded pig farmers, particularly those that used debt capital for investment purchases, to operate at losses.

Figure 30: Slaughterhouse price of live pigs in baseline model
Note: The letter "D" denotes disease events occurring at weeks 72, 280, 488, and 696.
Source: Pork VC model simulation

In the baseline model, FF farming systems were much more profitable than WF farming systems, with hybrid breeds more profitable than local breeds. As Table 7 shows, WF pig systems generated minimal cash profits; for example, over the long-term local breed WF farmers earned a cash income of US$2 per year that increased to US$13 per year for Hybrid WF farmers. This supports SGMB findings and the literature (Ebata et al., 2018; Smith et al., 2019) which suggest that small-scale producers in Myanmar and other Southeast Asian countries raise pigs primarily as a "livestock bank" used for household savings. For villages without access to formal banking and with limited space and capital, pig farming enables poorer households to use available resources – such as kitchen scraps, rice by-products, and household land – to maintain an asset that is easy to sell when cash is required. This is aligned with the findings of Jefferies et al. (2018) that in Myanmar livestock is the second highest non-cash form of savings. By contrast, hybrid FF farmers earned US$907 annually, compared to US$209 for local breed FF farmers. This is a more than four-fold increase in profits and provided a strong incentive for farmers to upgrade from local to hybrid breeds as well as from WF to FF systems; this also tracked with reference modes developed during SGMB workshops. When comparing the model's annual earnings with the TRRILD's baseline study (which showed an average household gross income of US$950 from farming) there is evidence that hybrid pig farming could become a primary livelihood opportunity while local breed pig farming will remain a supporting, or secondary, livelihood.

Table 7: Annual profits for individual producers in each farming system in the baseline model

Farming System	*Short-term* US$	*Medium-term* US$	*Long-term* US$
Individual local breed FF	194	204	209
Individual local breed WF	1	2	2
Individual hybrid breed FF	800	867	907
Individual hybrid breed WF	7	9	13

Source: Pork VC model simulation

The baseline model showed that the profitability gains of hybrid breeds and FF farming systems were offset by the higher risks inherent within these systems. As illustrated in a Figure 31, FF farming systems experienced more significant periods of negative cashflow during disease outbreaks than WF farmers. These negative cashflows were a result of pig mortality and panic selling at lower prices as well as the obligation to continue making repayments on loans taken to finance upgrading investments and regular production costs. Hybrid pig farming was associated with greater risks given the higher susceptibility of hybrid breeds to disease and the substantial loan payments to moneylenders. These higher loans occur from one-off upgrading costs (in the model upgrading costs for hybrid FF are US$1,000 compared with US$240 for local breed FF as confirmed by SGMB and RG participants) and ongoing production costs, particularly feeding practices (RG and SGMB members reported that hybrid feed costs are twice as high as that of local breeds). The model projected that FF farmers experience negative cashflow for 18 weeks following a disease outbreak. Debt totalled US$182 per hybrid FF farmer compared with US$19 per local breed WF farmer. These negative cashflows make upgrading from WF to FF and from local breeds to hybrid pigs a risky endeavour unless farmers have significant cash reserves or lines of credit to cope with these liquidity problems.

The number of pig producers in highly profitable systems showed a small increase of 2.1% per annum in the baseline model. As Table 8 below illustrates, pig farmers upgraded steadily from local breed WF to local breed FF farming systems but were unable to upgrade at a similar rate to the hybrid FF system. The prolonged periods of negative cashflow and high entry costs combined with high interest rates from moneylenders prohibited upgrading to the highly profitable hybrid FF system. Though less risky than hybrid FF systems, the baseline model forecasted that just over a third of farmers who upgraded to the local breed FF system would drop out at some point because of disease shocks and return to the less risky local WF system. This contributed to the overall dropout rate from pig farming of 9.3% predicted by the model which suggests a moderately stable livelihood over the long-term. In the baseline model, only 14 producers successfully upgraded to hybrid FF systems; hence, the dropout rates of this system remain low. This inability of a large portion of producers in the baseline model to upgrade to hybrid and local breed FF farming combined with the growing demand for pork in Myeik led to a decline in the proportion of locally produced pigs purchased by slaughterhouses. This share fell from 48% to 32% over fifteen years, tracking with the trend reported in SGMB workshops.

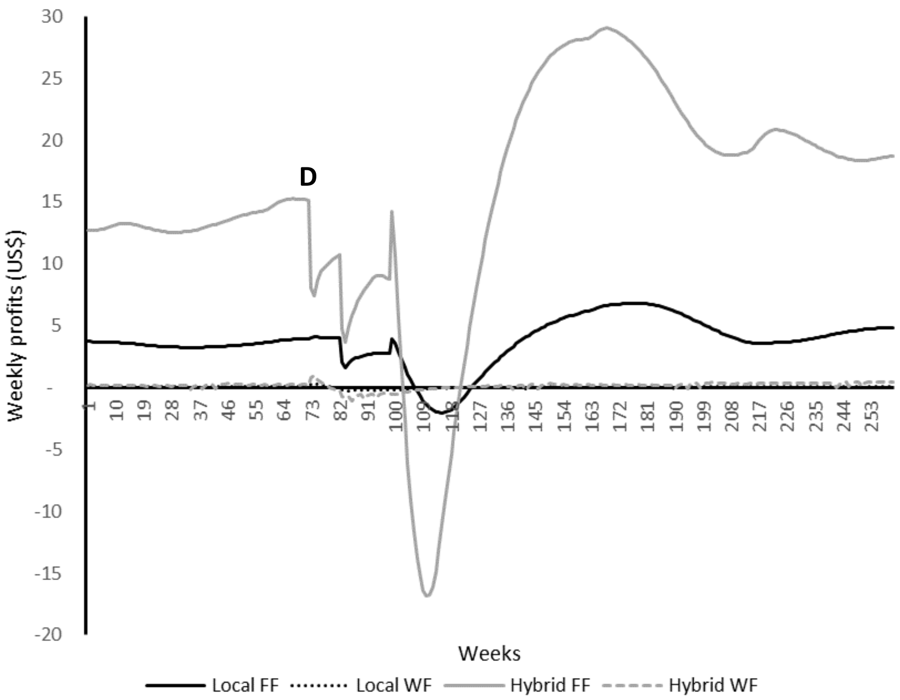

Figure 31: Weekly profits for individual farmers in each farming system in the baseline model (up to week 260)

Note: The letter "D" denotes disease events occurring at weeks 72.

Source: Pork VC model simulation

Table 8: Number of pig producers in each farming system in the baseline model

Farming system	*Model start*	*Short-term*	*Medium-term*	*Long-term*
Local FF	192	220	280	290
Local WF	768	727	656	550
Hybrid FF	160	160	161	174
Hybrid WF	160	157	154	147
Total number of pig farmers	1,280	1,264	1,251	1,161
Number of pig farmers in highly profitable systems	352	380	441	464

Source: Pork VC model simulation

The baseline model shed light on the skewed distribution of profits amongst small-scale pig producers towards hybrid and FF systems across all time horizons. Accounting for only 15% of pig farmers in the baseline model, hybrid FF producers recorded 68% of the total producer profits in the system. This is followed by local FF producers who accounted for 25% of pig farmers and 31% of the producer profits in the target villages.

The baseline model showed that slaughterhouses generated the largest profits among VC actors upstream of the retail market. Of the total profits generated over fifteen years, slaughterhouses received 56% (US$4,481,533), pig producers 38% (US$3,043,266), and brokers 5% (US$393,564). The portion of profits to local producers slowly decreased over the model's timeline as the proportion of pigs sourced from Myeik and Palaw continued to decrease. Pig farming also generated off-farm employment (AHWs, artificial insemination workers, brokers, and slaughterhouse labourers) equating to US$499,137 in wages over fifteen years[20].

5.4 Pro-poor upgrading scenarios

Three institutional scenarios were developed for testing and comparison with the baseline scenario of no project interventions. In addition, five technical upgrading activities were tested within each of these institutional scenarios. The scenarios and activities were originally developed in the SGMB and RG workshops and then shared with TRRILD partners for refinement to ensure that they aligned with the project's donor-approved design document, workplan, and budget. This section outlines each of the scenarios and activities.

5.4.1 Institutional upgrading scenarios

Scenario one (S1): Individual pig farmers

In S1, the TRRILD project implements five technical activities across all 1,280 pig producers in the 32 target villages. These activities include introducing microcredit, training for pig farmers on GAHP, establishing and training animal health workers (AHWs), setting up artificial insemination (AI) units, and a combination of all technical activities. The scale and scope of these activities align with the TRRILD project's workplan and budget and are further described in Section 5.4.2.

Scenario two (S2): Producer groups

In S2, the TRRILD project establishes a producer group (PG) in each of the 32 target villages with 20 members per PG (i.e., half of all pig farmers join PGs for a total of 640 members). The technical activities in S2 are the same scale and scope as for S1; however, they focus solely on the 640 PG members. The model assumes that PGs are established in the first year of the model and that it takes 52 weeks for all members to join. PGs focus on hybrid pig production and draw new members from each of the four pig enterprises. Village pig producers become PG members at a ratio of one hybrid FF farmer to six hybrid WF farmers[21] and then upgrade from WF to FF systems based on expected profitability.

The PG's adopt institutional arrangements similar to those that characterise a new generation cooperative (Chaddad & Cook, 2004). These arrangements discourage members from side-selling their pigs and from extracting all PG profits as short-term price rebates, allowing the PGs to retain

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[20] On-farm and off-farm employment SD model structure is found in Appendix B with related data in Appendix C. The model used US$5 per day as the off-farm wage as reported by SGMB and RG participants and VC studies in the target region (ACCESS Advisory, 2019; Rich, 2018).

[21] This ratio is based on an FF producer with two sows producing around 48 piglets per year. If 50% of piglets are kept for fattening, then the remaining 24 piglets can be purchased by six WF farmers to ensure they have two piglets for fattening at a time.

and accumulate profits to finance long-term investments in PG capacity. Price rebates are paid to members every 26 weeks in proportion to patronage, and only after the PG's savings and investment goals are achieved. The PG incurs operational expenses, including management, technical support, and training costs, and engages in collective purchasing of pig feed to receive a 5% bulk purchasing discount for members (as proposed by input suppliers during KIIs). Savings from the PGs are first used to cover any cashflow shortfalls after which they finance increases in AHW and AI capacity. These operational and capacity costs are covered by the TRRILD project for the first three years and, following the project's exit, are fully funded by the PG. The model restricts PG membership changes for the first three years, after which the PG recruits new members to meet capacity shortfalls. PG members can exit or reduce their delivery obligations to the PG, based on comparisons of profitability with non-members.

PGs enter into a contract with a local slaughterhouse to supply high-quality fatteners for the wholesale market in Myeik and Palaw. As a contract condition, PGs receive a 5% premium above the farmgate price of live pigs. Slaughterhouses sell this high-quality pork to local restaurants and other customers for a 10% premium over current wholesale prices. These premiums for high-quality fatteners were derived from KIIs with restaurants and slaughterhouse owners. On delivery PG members are paid the equivalent farmgate price for their high-quality live pigs, with the 5% premium retained to cover PG operational costs and capacity investments. Once capacity needs are meet, PG profits are paid out as price rebates every six months to members proportional to their supply of high-quality fatteners. The demand for high-quality fatteners in the wholesale market starts at 511 kgs per week (i.e., 1% of all pork sold in the target area) and grows by 2%[22] per year, which reflects market patterns as informed by SGMB and RG participants. PG members' pigs that are surplus to the orders for high-quality fatteners are sold at farmgate prices. All members' pigs, however, are covered by PG services, such as training, AHWs, and AI.

Scenario three (S3): Producer organisations

In S3, after three years of operations, the PGs upgrade into POs that co-invest in a modern, hygienic slaughterhouse with the capacity to produce premium pork cuts that meet the quality standards required by domestic supermarkets, restaurants, and premium wholesalers. The initial capital for the slaughterhouse comes from a strategic partner who invests US$25,025[23] to establish a facility with the capacity to slaughter and butcher 35 pigs/week. Subsequent investments in slaughterhouse capacity come from PO savings, equivalent to US$750 per additional carcass of capacity per week. The strategic partner is paid a six-monthly dividend from slaughterhouse profits proportional to their

[22] This is equivalent to demand of nine high-quality fatteners per week in year one growing to 30 in year fifteen of the model.
[23] This is based on costings by Handlos (2015) on the feasibility of upgrading slaughterhouses in Uganda.

original investment, with the remaining profits flowing into the PO's revenue to cover operational costs, future investments in slaughterhouse capacity, and PO management and technical costs. Once operational and capacity needs are met, any remaining profits are paid to PO members proportional to the number of high-quality fatteners they supplied to the PO.

The establishment of a modern slaughterhouse enables the PO to sell pork through four market channels. The priority channel is the premium pork market in Yangon which covers premium wholesalers that supply high-quality restaurants and hotels, and domestic supermarkets. KIIs in Yangon revealed a strong demand for locally produced premium pork cuts, suggesting a conservative value of 1000 kgs per week of premium cuts[24] which would increase by 6% per year. Preparing a premium product for the Yangon market incurs additional costs for marketing, butchering, packaging, and transport through a cold chain, but also attracts a 35% premium (confirmed by KIIs in Yangon) over the Myeik wholesale market price. The modern slaughterhouse also provides premium pork cuts to restaurants in Myeik based on the assumption that quality is equivalent to products currently sourced from Thailand. According to RG feedback, the demand for premium pork cuts in Myeik is 255 kgs per week (i.e., 0.5% of total pork demand), and this is expected to increase by 2% per year. The slaughterhouse also provides pork from high-quality fatteners for the Myeik wholesale market as in S2, with the remaining slaughterhouse capacity used to supply the undifferentiated wholesale pork market. The POs continue to invest in slaughterhouse capacity based on profitability and when there is sufficient supply from members. When the supply of high-quality fatteners falls below the production capacity of the slaughterhouse, the PO actively recruits members to fill supply gaps.

5.4.2 Technical upgrading activities

Unlike the upgrading institutional scenarios which implement macro-level initiatives, technical upgrading activities affect change at the individual farm level.

Upgrading activity one (A1): Microcredit

In A1, an initial stock of microcredit amounting to US$150,000[25] is made available to targeted individual pig producers for the life of the model.[26] The microcredit products modelled are standard amortised loans[27] which charge interest at 2.46% per month and have a loan term of 12 months. As per the partner MFI's policies, microcredit clients are required to save 5% of the loan amount. In the

[24] According to KIIs, 30% of a pig carcass is suitable for premium cuts demanded in Yangon.
[25] The figure of US$150,000 was selected as this was the approximate amount of VC funding in use by the TRRILD project at the time of conducting scenario tests.
[26] The microfinance partner's strategy is to retain a presence in the target area following the project's exit.
[27] The partner MFI loan terms reflect the Government of Myanmar's microfinance laws and regulations. The standard amortised loan charges equal monthly repayments across the loan term with the interest calculated on the outstanding loan balance.

model, the stock of available microcredit is first prioritised for upgrading costs (e.g., purchasing of shelters, equipment, and breeding sows) that enable pig producers to move up through the hierarchy of pig enterprises as outlined in Figure 25. The remaining loan capital is made available for seasonal production loans for inputs, such as feed and piglets. Any shortfalls in formal credit are filled by loans taken from informal moneylenders at an interest rate of 5% per month with a loan term of 1.25 years. As per the model's structure, the stock of microcredit reduces permanently when producers default on loans following farm failure.

A second microcredit upgrading activity (referred to as A1.2) that increased the stock of available microcredit to US$300,000 was also considered. This was included to better understand the impact of microcredit on the pork VC and to guide the project's allocation of budget between VC lending and other lending opportunities in the target area. Further exploration of the impacts of loan terms and product types on the profitability of pig producers is reported in Section 5.7.1: Alternative scenarios.

Upgrading activity two (A2): Training

Upgrading activity two (A2) covered technical training provided by the project to pig producers. Training workshops increased the technical knowledge of pig farmers, leading to improvements in biosecurity and hygiene measures, increased confidence to upgrade, and improvements in overall pig quality. Training is conducted for three years by the TRRILD project, which has the capacity to educate 650 farmers per year. In S1, training opportunities are provided to all pig producers but in S2 and S3 they are limited to PG and PO members. In S2 and S3, the PGs/POs employ a technical officer who provides training to members to ensure that PG/PO fatteners consistently meet minimum quality standards for premium pork markets. Technical knowledge also increases through peer-to-peer contacts in which learning takes place.

Upgrading activity three (A3): Animal health workers

Within A3, one AHW per village is trained and equipped by the project to service the target population. RG members reported that an AHW had the capacity to cover 140 pigs (including piglets, breeding sows, and fatteners) and this reduces the disease mortality rate by up to 60%[28] through the provision of vaccinations, advice, and basic veterinary services. The effectiveness of AHW on mortality rates depends on the proportion of pigs in the target area covered by AHWs and the AHW's technical knowledge. Changes to the AHWs technical knowledge is modelled using the same structure as per farmer technical knowledge, outlined in Section 4.3.4. In S2 and S3, PGs/POs hire a

[28] In A2, mortality from disease is reduced by up to 20% simulating the effects of GAHP, as such the total mortality reduction possible (A2 and A3) is 80%.

technical officer to provide refresher trainings to AHWs and the PGs/POs continue to recruit and train AHWs with the goal that all their members' pigs are covered by their services.

Upgrading activity four (A4): Artificial insemination

In A4, an AI unit is established to service the target population. From the RG and TRRILD project staff's experience, an AI unit costs US$3,000 to establish (including equipment and boars to produce semen to service 20 sows per week) and depreciates over thirty years. The AI unit is subsidised by the TRRILD project for three years to keep its service fee below the standard hybrid boar charges of US$30 per service. Following the project's exit, the AI unit's service fee is determined by covering its costs and adding a 20% profit margin (as per guidance from TRRILD staff). Costs include maintenance fees, veterinary services, boar feed, transport, labour, and boar replacement costs. In S2 and S3, the PGs/PO continue to invest in AI capacity to cover fertilisation of member sows to ensure high-quality piglets.

Upgrading activity five (A5): Combination of microcredit, training, AHWs, and AI

In A5, all four interventions are implemented jointly across the target populations.

5.5 Results of *ex-ante* evaluation of technical upgrading activities.

The five upgrading activities were simulated within each of the three institutional scenarios, with results analysed across the pork VC indicators outlined in Table 6. Preliminary results were shared with TRRILD partners at roundtable discussions in Yangon and Christchurch. During this time, a decision was made to emphasise two outcome indicators from the model and include non-model indicators to compare and prioritise upgrading institutional scenarios and technical activities. This narrowing of indicators was undertaken to help simplify results and ease decision-making considering the large volume of numerical data generated by the model. The final categories incorporate quantitative measures from the pork VC model on financial impact (represented by the outcome indicator: aggregate profits of all pig producers), pro-poor orientation (represented by outcome indicator: number of pig producers in highly profitable systems) and benefit-to-cost analysis[29] (comparing each activity's financial impact with its costs[30]). Alongside model-derived information, qualitative judgements on risks and the implementing INGO's experience levels in each of the technical activities were also included to guide decision-making and recommendations. Following these discussions, the upgrading activities were given a priority score (high, medium, low) across the selected categories to establish a clear rank order. The rationale behind allocating priority

[29] Benefit-to-cost analysis used a discount rate of 5% as recommended by Sequeros et al. (2020) in a study on agricultural impacts and returns in Myanmar.

[30] Costs for the activities were obtained from the TRRILD project's budget and information from the TRRILD project team.

scores was to provide a clear ranking of interventions in relation to each other, leading to improved decision-making. The rank order of the individual technical upgrading activities is presented in Table 9. The results of each technical upgrading activity and the combination of activities are analysed and discussed in this section.

Table 9: Rank order of technical upgrading activities

Upgrading Activity	*Financial Impact*	*Pro-poor Impact*	*Benefit-to-Cost Ratio*	*Risks*	*Organisational Experience*	*Overall Priority*
A3. Animal Health Workers	High	Medium	High	Medium	Medium	High
A1. Microcredit	Medium	High	Low/ Medium	High	High	High
A2. Training	Medium	Medium	Medium	Low	High	Medium
A4. Artificial Insemination	Low	Low	Low	High	Low	Low

Source: Pork VC model simulation and TRRILD project partners

5.5.1 Animal health workers: High priority

The establishment of AHWs in target villages ranked as the highest priority activity, with the financial and pro-poor impact greater in S2 (PGs) and S3 (POs) than S1 (individuals). In the model, the key benefit of establishing an AHW network was a decreased pig mortality rate which protected farmers from sustained periods of negative cashflow and defaulting on loans. This had strong positive flow-on effects to farm profitability, allowing for further farm investment and the activation of the feedback loops R2: production capacity; R3: purchasing piglets; and R7: upgrading. As shown in Table 10, the AHW activity (A3) ranked first or second for raising aggregate profits of all pig producers across almost all upgrading scenarios and timeframes. Across the three scenarios, establishing AHWs consistently delivered the highest profit gains across the six different farming systems. WF producers had the highest proportional gains because the loss of one or two fatteners from disease can completely nullify yearly earnings. For example, in S1(individual producers), WF aggregate profits rose by 22% (local) and 47% (hybrid) compared with FF producer gains of 8.7% (local) and 11% (hybrid). However, in terms of overall cash income, the larger FF farmers benefited substantially more than smaller WF farmers. For example, in S3(POs), establishing a healthy AHW network drew in additional cumulative income of US$1,631 for PG hybrid FF farmers and US$135 for PG hybrid WF farmers compared to the next highest upgrading activity.

Table 10: Results from scenario testing on aggregate profits of all pig producers

Scenario	*Short-term*			*Medium-term*			*Long-term*		
	US$	Change (%[a])	Rank[b]	US$	Change (%)	Rank	US$	Change (%)	Rank
Baseline	842,295			1,866,956			3,043,266		
Scenario One: Individual Producers									
S1.A1: Microcredit $150K	1,087,576	+29	1	2,380,011	+27	1	3,940,949	+29	1
S1.A1.2: Microcredit $300K	1,261,361	+50	(1)[c]	2,877,423	+54	(1)	4,897,681	+61	(1)
S1.A2: Training	945,149	+12	3	2,089,817	+12	3	3,452,985	+13	2
S1.A3: AHWs	975,574	+16	2	2,139,809	+15	2	3,420,022	+12	3
S1.A4: AI	919,824	+9	4	2,027,026	+9	4	3,353,877	+10	4
S1.A5: Combination[d]	*1,382,303*	*+64*	*1*	*3,214,879*	*+72*	*2*	*5,441,792*	*+79*	*3*
Scenario Two: Producer groups									
S2.A1: Microcredit $150K	830,903	-1	1	2,171,795	+16	2	4,021,996	+32	3
S2.A1.2: Microcredit $300K	917,148	+9	(1)	2,475,852	+33	(1)	4,692,074	+54	(1)
S2.A2: Training	800,067	-5	3	2,141,964	+15	3	4,062,055	+33	2
S2.A3: AHWs	819,634	-3	2	2,210,552	+18	1	4,103,582	+35	1
S2.A4: AI	769,025	-9	4	2,044,762	+10	4	3,812,834	+25	4
S2.A5: Combination	*1,022,314*	*+21*	*3*	*3,199,340*	*+71*	*3*	*7,063,532*	*+132*	*2*
Scenario Three: Producer organisations									
S3.A1: Microcredit $150K	835,051	-1	1	2,754,206	+48	2	6,835,205	+125	4
S3.A1.2: Microcredit $300K	921,469	+9	(1)	3,145,440	+68	(1)	7,730,822	+154	(2)
S3.A2: Training	804,249	-5	3	2,754,454	+48	3	7,153,488	+135	2
S3.A3: AHWs	823,966	-2	2	2,955,368	+58	1	8,166,828	+168	1
S3.A4: AI	773,044	-8	4	2,658,302	+42	4	6,890,234	+126	3
S3.A5: Combination	*1,026,296*	*+22*	*2*	*4,033,651*	*+116*	*1*	*11,205,559*	*+268*	*1*

Note: [a] Percentage change from the baseline. [b] Rank for the combined activities compares S1, S2, and S3. [c] Value in parentheses denotes that ranking of the sub activity A1.2. [d] Combination refers to A1 + A2 + A3 + A4, where A1 is microcredit capped at $150K.
Source: Pork VC model simulation

The introduction of AHWs decreased the length and depth of negative cashflow experienced during disease outbreak, as shown by the example of hybrid FF farmer cashflow across the baseline, S1(individuals), and S2(PGs) in Figure 32. The ability to maintain higher pig stocks during disease outbreaks not only reduced financial losses from pig mortality and panic selling but also enabled pig producers to rapidly scale-up production to take advantage of favourable post-disease prices. With fewer pig losses, the introduction of AHWs resulted in the number of FF farmers dropping out of pig farming reducing by over 50% in comparison with the next highest activity.

There are two underlying reasons for the higher financial impacts of AHWs in S2(PGs) and S3(POs) compared with S1(individuals). Firstly, the structure of PGs/POs allowed them to maintain investments in AHWs after the project exited to work towards covering the entire pig population of members with AHW services. By contrast, once the project exited in S1(individuals), AHWs services slowly depleted as the government and civil society were unable to maintain the project's investment. After fifteen years, 22.1% of the pig population was covered by AHW services in S1(individuals) compared with 96.8% in S2(PGs) and 97.6% in S3(POs). This is further illustrated in

Figure 32, that shows negative cashflows for hybrid FF farmers in S1(individuals) returned after five years and approached baseline values by the end of the model.

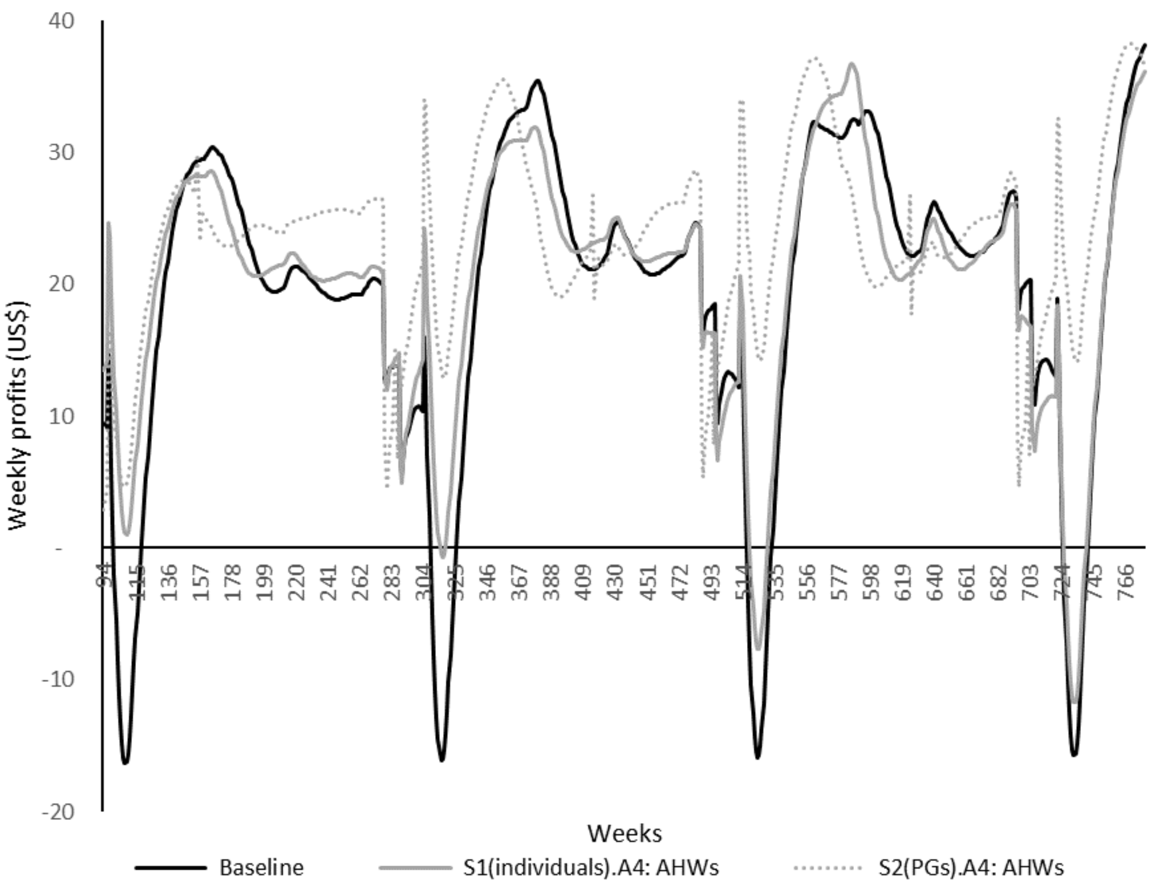

Figure 32: Comparison of weekly profits of hybrid FF producers in baseline, S1, and S2
Source: Pork VC model simulation

Secondly, in S2 and S3, PGs/POs made increased on-farm investments, such as improved shelter, bio-security measures, and commercial feed, to produce a high-quality hybrid fattener. When these substantial upfront investments and associated higher-value loans are combined with the premiums lost from a high-quality fattener's death or discounted panic sale, the consequences of pig mortality and morbidity were more significant in S2(PGs) and S3(POs). AHWs, therefore, helped offset the higher risks of producing a premium product by enabling PGs/POs to maintain livestock numbers to consistently meet the orders from Yangon and Myeik. PGs/POs also sold fatteners that were surplus to orders from premium buyers in Yangon and Myeik and could therefore take advantage of the price rises in the local wholesale market that invariably follow a disease outbreak.

At the macro-level, as shown in Table 11, the AHW activity had little impact on the number of pig producers in highly profitable systems in S1(individuals) and S2(PGs), in contrast to S3(POs) where it had the largest impact out of all activities. Analysis at the farm enterprise level shows that AHWs enabled PG and PO members to continually transition to the highly profitable FF system; however, this scale of upgrading did not take place in S1(individuals). By the end of the model simulation period, there were 292 (S2[PGs]) and 633 (S3[POs]) hybrid FF farmers compared with 173 in S1(individuals). The greater number of farmers in FF systems and the higher price of PG and PO high-quality fatteners is an important reason why AHWs had a larger impact on overall system profitability compared to microcredit in S2(PGs) and S3(POs) but had a smaller impact in S1(individuals). In the model, microcredit had a larger impact in enabling farmers to quickly upgrade while AHWs reduced the risks of the high-quality pig enterprise, allowing producers to extract more value from these systems and continue farming during disease and price shocks.

Table 11: Results from scenario testing on the number of pig producers in highly profitable systems

Scenario	*Short-term*			*Medium-term*			*Long-term*		
	Number	Change (%)[a]	Rank[b]	Number	Change (%)	Rank	Number	Change (%)	Rank
Baseline	379			441			464		
Scenario 1: Individual producers									
S1.A1: Microcredit $150K	420	+11	1	539	+22	1	550	+18	1
S1.A1.2: Microcredit $300K	477	+26	(1)[c]	635	+44	(1)	636	+37	(1)
S1.A2: Training	399	+5	2	495	+12	2	522	+12	2
S1.A3: AHWs	389	+3	3	457	+3	3	507	+9	3
S1.A4: AI	380	+0	4	449	+2	4	483	+4	4
S1.A5: Combination[d]	*480*	*+26*	*1*	*639*	*+45*	*2*	*710*	*+53*	*2*
Scenario 2: Producer groups									
S2.A1: Microcredit $150K	343	-10	2	394	-11	2	453	-2	2
S2.A1.2: Microcredit $300K	363	-4	(1)	435	-2	(1)	512	+10	(1)
S2.A2: Training	343	-10	1	498	-10	1	474	+2	1
S2.A3: AHWs	343	-10	2	378	-14	4	449	-3	4
S2.A4: AI	343	-10	2	387	-12	3	451	-3	3
S2.A5: Combination	*397*	*+5*	*3*	*542*	*+23*	*3*	*704*	*+52*	*3*
Scenario 3: Producer organisations									
S3.A1: Microcredit $150K	343	-10	1	534	+21	4	699	+51	4
S3.A1.2: Microcredit $300K	363	-4	(1)	575	+30	(1)	853	+84	(2)
S3.A2: Training	343	-10	1	550	+25	2	751	+62	2
S3.A3: AHWs	343	-10	1	556	+26	1	882	+90	1
S3.A4: AI	343	-10	1	540	+22	3	722	+55	3
S3.A5: Combination	*399*	*+5*	*2*	*684*	*+55*	*1*	*877*	*+89*	*1*

Note: [a] Percentage change from the baseline. [b] Rank for the combined activities compares S1, S2, and S3.
[c] Value in parentheses denotes that ranking of the sub activity A1.2. [d] Combination refers to A1 + A2 + A3 + A4, where A1 is microcredit capped at $150K.
Source: Pork VC model simulation

The ability of AHWs to help individual farmers and PG/PO members maintain pig stocks in the region resulted in positive flow-on effects across other chain actors. The introduction of AHWs was the most effective measure for improving off-farm employment (by a factor of eight compared with other activities) and strengthening the supply of locally produced pigs for brokers, slaughterhouses, and consumers. This continuous supply led to increased local slaughterhouse profits as they had multiple supply channels to choose from, thereby reducing the price of live pigs they purchased. Moreover, while not directly modelled, non-PG members and nearby villages would likely access AHW services, thus increasing overall pig health in both target and non-target villages in all three scenarios.

There are some risks involved with establishing AWHs which were not accounted for completely in the model but will affect the implementation and impact of this activity. Firstly, AHW dropout rates of 10% per annum (as reported within previous WV Myanmar projects) were used in the SD model, but this could vary based on the relative profitability of this livelihood compared with other semi-skilled occupations. Secondly, there is a risk that AHWs will not always be able to provide quality, low-cost services given periodic shortages of vaccinations and medicines and the occasional monopolisations of vaccines by the local LBVD department who then charge a premium for access.

Despite these risks, the AHW activity had the highest BCR out of all the interventions. In the medium-term, the BCRs were S1(individuals), 1.65; S2(PGs), 1.63; and S3(POs), 5.39. These continued to rise in the long-term with S2(PGs).A3: AHWs posting an equivalent BCR to S2(PGs).A5: Combination of activities (4.54 versus 4.72) and the BCR for S3(POs).A3: AHWs (21.77) over twice as strong as S3(POs).A5: Combination of activities (9.36). This provides a strong rationale for the project to invest its resources in mitigation strategies to prevent AHW service failure, such as providing ongoing fees-free training for AHWs, gifting start-up vaccination kits to AHWs, and importing vaccines and medicines from outside of Myeik when required to ensure a consistent supply for AHWs before PGs have sufficient capacity to take on this role.

5.5.2 Microcredit: High priority

The provision of microcredit loans to pig farmers is another high priority intervention. Across all three institutional scenarios, providing microcredit with a total capital stock of US$150,000 significantly improved the aggregate profitability of all pig producers in the target villages, as shown in Table 10. However, given the risks of potential negative impacts for poorer producers, it ranks below establishing and training AHWs. Microcredit consistently ranked first or second for overall financial and pro-poor impacts in the short- and medium-term. Because the majority of PG and PO members upgraded to highly profitable systems in the short- and medium-term, the financial and pro-poor impact of microcredit lessened in the long-term in S2(PGs) and S3(POs). However, when the larger capital stock of US$300,000 was modelled (A1.2) in S2(PGs) and S3(POs), microcredit retained first or second priority because it covered larger portions of pig producers' regular production loans (for example, in S2(PGs).A1, US$150,000 of loan capital covered 35% of production loans, while in S2(PGs).A1.2, US$300,000 covered 64%). Having a larger amount of loan capital available reduced producers' interest payments and enabled further savings, which in turn encouraged smaller loan sizes and enabled more PG members to access the lower interest microcredit loans.

A key impact of microcredit was the reduction in entry costs for upgrading, allowing more farmers to migrate to highly profitable pig systems, as shown in Table 11. The model showed that compared to other project activities, microcredit enabled more producers to upgrade to the most profitable system – hybrid FF – rather than only upgrading to the local breed FF system. For example, in S1(individual).A1 the number of farmers practicing local and hybrid FF enterprises increased by 26% and 22%, respectively, almost twice the change of the next highest activity.

As a stand-alone intervention, introducing microcredit resulted in higher numbers of farmers exiting FF pig farming as it exacerbated the negative consequences of disease shocks. In the model, microcredit alone was unable to materially decrease the length or depth of negative cashflows during times of disease. In the baseline model, an average of 8 farmers exited FF systems annually. When microcredit was made available to producers, annual dropout numbers increased to an average of 16 farmers in S1(individuals).A1, 14 farmers in S2(PGs).A1, and 20 farmers in S3(POs).A1. Doubling the stock of microcredit available (A1.2) increased dropout rates in S1(individuals) and S2(PGs) but decreased dropout numbers in S3(POs) because cheaper production loans helped offset negative cashflow during disease. Without other activities to support recently upgraded FF farmers, the risks of upgrading were not sufficiently reduced, leading to negative impacts for some farmers. If the TRRILD project pursued a singular focus on microcredit, poorer farmers, in particular, could face difficulty servicing their loans because of disease and price shocks and may need to liquidate farm and other household assets to pay back the lending MFI. In the model, loan defaults resulted in a steady reduction in the stock of microfinance capital in the system. For example, in S3(POs).A1, microfinance capital declined from US$150,000 to US$77,377 over fifteen years. This large fall explains the declining influence of microcredit on producer profits in S3(POs) and shows that the medium- to long-term sustainability of the partner MFI's operations could be threatened by a singular focus on delivering microcredit to pig farmers.

When pro-rating MFI and TRRILD project costs across the loan capital of US$150,000 the BCRs over the medium-term were 1.43 for S1(individual).A1, 0.66 for S2(PGs).A1, and 2.04 for S3(POs).A1. When the larger capital amount of US$300,000 was modelled In A1.2, the BCR remained steady for S1(individuals), rose for S2(PGs) to 1.05, and dropped for S3(POs). This is related to the increased volatility that higher stocks of microcredit bring to the system. While A1.2 increased dropout numbers in S1(individuals) and S2(PGs), it also encouraged more farmers to transition to hybrid FF systems and experience profit gains, albeit for a short period of time. This resulted in higher profits in A1.2 compared to A1 and a stronger BCR.

5.5.3 Training: Medium priority

Training delivered moderate to high impacts on overall farmer profits and the number of farmers in highly profitable enterprises. In comparison to high-priority activities, training delivered around two-thirds the gains on both outcome indicators. As highlighted in Table 11, short-term training did not enable farmers to upgrade in large numbers to more profitable systems. Rather, training helped farmers extract further profits from current enterprises through improved farm practices that lessen the impact of seasonal diseases and produce a higher quality fattener. As a result, apart from AHWs, training had the highest impact on increasing individual farmer profit. However, with limited impact on upgrading farm enterprises, the effect of training on overall profitability remained low compared with microcredit. When the transition to hybrid pig farming takes place within a PG/PO, the impact of training on overall profits were negative in the short-term (see Table 10) because gains in sale prices did not overcome the repayment costs of high-interest loans from informal moneylenders. This was reflected in training BCRs which were less than one in the short-term for S2(PGs) and S3(POs) but were greater than one in the medium-term: S1(individual).A2, 1.27; S1(PGs).A2, 1.18; and S3(POs).A2, 4.19. Because of the low-cost of training, BCRs were higher in S2(PGs) and S3(POs) than a higher impact activity like microcredit. The model further suggested that training had the highest potential for negative impacts on slaughterhouses, as it equipped producers with further knowledge on the quality of their product, reducing the gap between the slaughterhouse price and the farmgate sale price, and thus reducing slaughterhouse profit margins.

5.5.4 Artificial insemination: Low priority

AI was the lowest priority for the project because of its relatively small financial and pro-poor impacts and the high risks involved. AI is a new technology in Myanmar and practised only by the larger, internationally backed pig farms near Yangon. In the model, AI reduced costs for the fertilisation of hybrid sows, from US$30 to around US$6.67. While this was a large cost reduction, it is only a small percentage (<4%) of the overall costs of producing a hybrid fattener, and therefore did not bring material gains to the system. In S2(PGs).A4 and S3(POs).A4, the introduction of an AI unit at early stages resulted in the largest negative financial impacts to farmers. This is because the small reduction in production costs were unable to offset the large upgrading costs of PG/PO members and the burdens of disease shocks. Additionally, AI only benefited FF systems – that made up a small portion of farmers at early stages of the intervention. However, as the number of FF farmers grow in S2(PGs).A4 and S3(POs).A4, the cost of insemination services reduced, and the impacts of AI were experienced to a wider degree and by more farmers.

Project partners noted the high risks involved with introducing a new technology into the target locations. While the training and maintenance service for AI could be contracted to a third-party, this would also increase the costs by a factor of two to three according to RG members. The idea of PGs/POs managing the AI unit was also considered, as the model shows this enterprise grows in profitability given the large volume of insemination events required once the PGs are well established. However, local capacity to manage an AI unit from among PG/PO members was considered weak and basic infrastructure requirements to ensure a cold chain would require substantial capital investments from the project team and later PG/PO members. The risks of AI are further exacerbated by the low BCR in the medium-term: S1(individual).A4, 0.74; S2(PGs).A4, 0.53; and S3(POs).A4, 2.95. Across all time horizons, these BCRs are among the lowest ratios out of the five technical upgrading activities.

5.5.5 Combination of technical activities: Highest priority

Combining the four upgrading activities (A1, A2, A3, and A4) resulted in a healthy interaction effect that provides strong evidence that multiple interventions are a strategic priority for the TRRILD project. As Figure 33 and Table 10 illustrate, combining interventions delivered between two to three times more aggregate profits for all pig producers than the highest single intervention over the long-term. This combinatorial impact was particularly important in the early stage of S2(PGs).A5 and S3(POs).A5 to prevent the negative financial returns of solo activities and allow mutually reinforcing feedback loops to deliver strongly positive short-term financial benefits compared to the baseline. As shown in Table 10, in S3(POs), adding percentage effects from isolated activities in the short-term showed a combined change of -18% from the baseline in terms of producer profits, but a well-sequenced combination of upgrading activities ensured short-term positive outcomes (i.e., S3.A1+A2+A3+A4 = +21%). Standalone interventions reduced the number of highly profitable pig producers in the short- and medium-term in S2(PGs) and short-run in S3(POs). However, as illustrated in Table 11, combining technical activities reversed this trend; for example, in S3(POs), isolated upgrading activities resulted in ten fewer producers in highly profitable systems which shifted to five more producers in S3(POs).A5.

Jointly implementing technical activities also discouraged PGs/POs from dissipating in the early stages when revenue is low due to small production rates, and costs are high because of repayments for upgrading loans. Combining activities also helped ensure that the project’s impacts were further spread among community members. Compared to the highest single activity, the interaction effect brought in an extra 160 farmers in S1(individuals).A5 and 194 farmers in S2(PGs).A5 into highly profitable systems. In S3 the interaction effect worked strongest in the short- and medium-term, but after fifteen years the establishment of an AHW network and the combination of activities had similar impacts on the number of pig producers in highly profitable systems (882 in A3 and 877 in A5). However, when activities were combined in S3(POs), 95% of PO members remained in the most profitable hybrid FF system by the end of the model simulation period, compared with only 86% when AHWs were solely introduced.

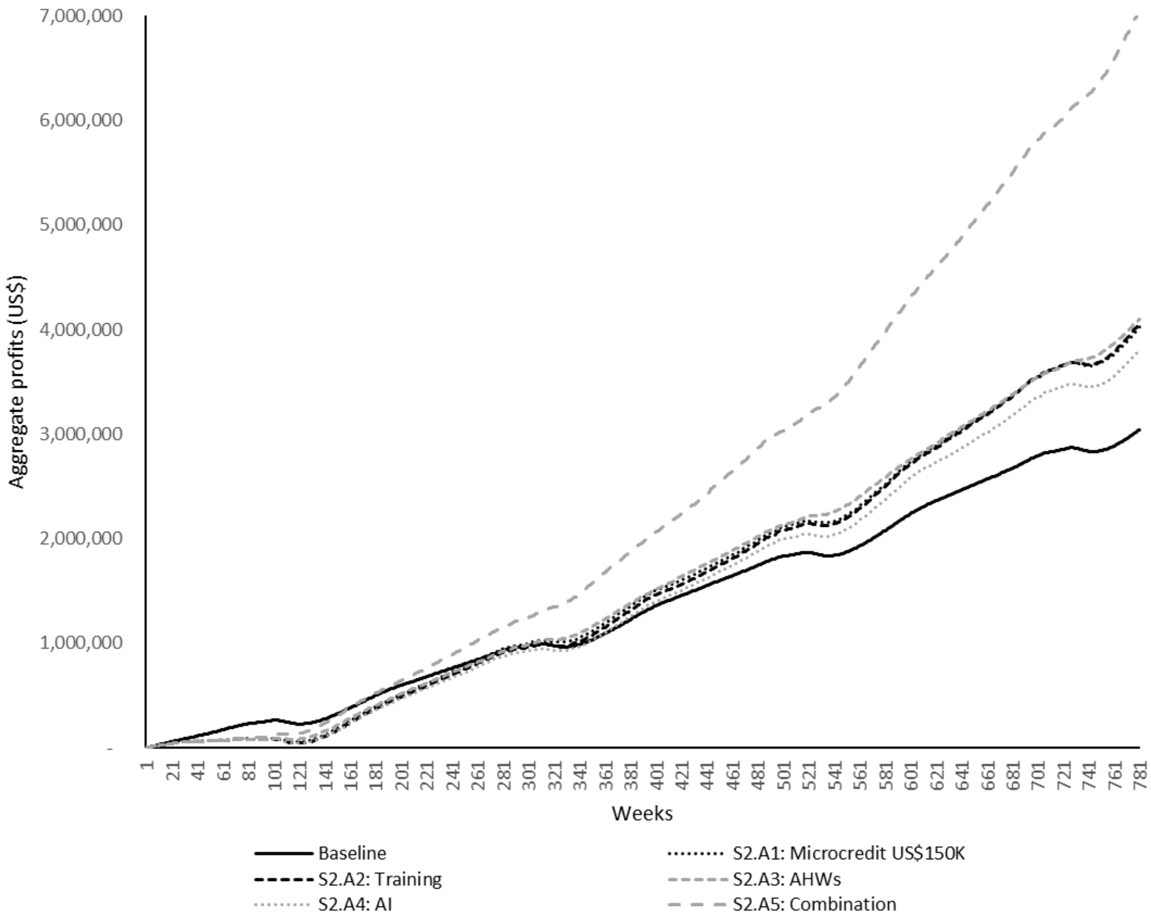

Figure 33: Comparison of technical upgrading activities on aggregate profits of all pig producers in S2(PGs)
Source: Pork VC model simulation

Model results showed that implementing isolated interventions within S2(PGs) and S3(POs) could bring significant risks to the project. Stand-alone activities that promote rapid upgrading did not fully overcome liquidity problems of PG/PO members and therefore could lead to a failure of collective action. In contrast, a strategy of multiple activities prevented PGs/POs from dissipating early on when member profits and PG/PO rebates and services were low (due to biological production delays and loan repayments) and continued to provide ongoing protection from negative cashflows and subsequent dropouts. This allowed PG/PO members to rapidly transition from moderately profitable WF to highly profitable FF systems and prevented farmers leaving the industry during disease outbreaks. This is highlighted in Figure 34 that shows a steady increase in the number of PO hybrid FF farmers in S3.A5: Combination, compared to fluctuations in S3.A1: Microcredit which delivered the next highest financial returns. Moreover, with a combination of activities, PG/PO FF members generated 16% (S2.A5) and 18% (S3.A5) more income and WF members 26% (S2.A5) and 102% (S3.A5) more income than the next highest intervention.

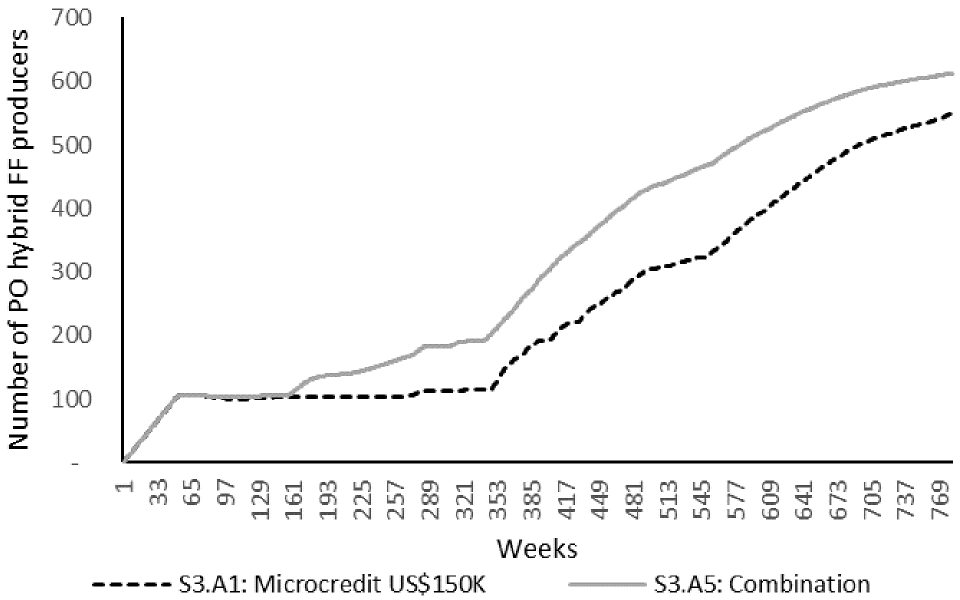

Figure 34: Number of PO members engaged in hybrid FF systems in S3.A1 and S3.A5
Source: Pork VC model simulation

Implementing activities in tandem unlocked the reinforcing feedback loops in the pork VC system, particularly in S3(POs). Increases in the number and profitability of PO hybrid FF farmers improved the efficiencies of investments in AI and AHWs. This enabled POs to invest more heavily in slaughterhouse capacity, delivering increased revenue to POs, and allowing further investments that lowered the risks of price and disease shocks and increased rebates to PO members. The number of PO dropouts also fell from 8.6 farmers per annum in the S3.A1: Microcredit to zero in S3.A5: Combination. This had a positive effect on keeping MFI loan capital in the system and resulted in retaining 99% of total loan capital in S3.A5 compared to 52% when microcredit was a stand-alone intervention (S3.A1). This additional MFI loan capital helped lower the cost of transitioning to FF systems and increased pig production rates. Ensuring a multipronged approach to support pig farmers rather than relying purely on microcredit, therefore, protects the project's partner MFI's long-term sustainability and profits because its operation costs can be further covered by the interest earned on the larger loan portfolio.

Implementing all four activities in tandem generated the highest BCR across all timeframes in S1(individuals) and S2(PGs) and remained strongly positive in S3(POs). This means that as well as the highest overall gains for producers, combining activities also generated cost efficiencies for the TRRILD project. In the medium term, a project strategy of combined activities delivered BCRs of 2.06 (S1[individuals].A5), 1.84 (S2[PGs].A5), and 2.94 (S3[POs].A5) for financial gains for small-scale producers. BCRs for S2(PGs).A5 and S3(POs).A5, more than doubled in the long-term; however, they remained below 1 in the short-term. This suggested that measures of the project's cost effectiveness would remain negative over the project's lifetime of five years if the project's strategy focused on establishing PGs and POs in the short-run. As such, further consideration should be given to understanding the relative strength of institutional arrangements in the project's evaluation as these will underpin the medium- and long-term measurements of value for money in the project.

Different combinations of technical upgrading activities were also run to determine their relative contributions to outcome level changes. Given the low priority of A4: AI, combinations of A1: Microcredit $150K, A2: Training, and A3: AHWs were simulated, with the results provided in Tables 13 and 14. In S2(PGs) and S3(POs), the results show that A3: AHWs provided the greatest contributions to financial and pro-poor outcomes. Combining A3: AHWs with A1: Microcredit $150K, had the strongest short- and medium-term impacts, generating around 50% of the effects of the full combination of technical activities in S2(PGs).A5 and S3(POs).A5. However, combining A3: AHWs and A2: Training was preferrable in the long-term, capturing 52% (S2) and 77% (S3) of the financial impacts and 70% (S2) and 100% (S3) of the pro-poor impacts of all the technical activities combined. In contrast, in S1, A1: Microcredit $150K had the largest contribution to financial and pro-poor impacts. When combining A1: Microcredit $150K and A3: AHWs, one-half to two-thirds of the effects of the full combination of technical interventions were generated in S1(individuals).

The results in Tables 13 and 14 further highlight the strong interaction effect between the technical activities, particularly in the early stages of S2(PGs) and S3(POs). The highest performing combination of two technical interventions (A1: Microcredit $150K and A3: AHWs), raises short-term profits by 9% (S2[PGs]) and 10% (S3[POs]) above the baseline, respectively; however, adding one further technical activity (A2: Training) close on doubles the financial impacts of the project to 18% gains. A similar pattern follows in relation to the number of pig producers in highly profitable systems: combining two technical interventions still results in negative project impacts, while implementing three technical interventions shows little change from the baseline value. While the interaction effect reduces over time, the results show there are still substantial financial gains to be found by reducing pig production costs through means other than establishing an AI unit. On average, introducing an AI unit reduced input costs by less than 4%, but Table 12 shows that even this small reduction could increase income from pig farming in the target villages by an additional 22% (US$917,236) in S2(PGs) and 10% in S3(POs) (US$850,841), compared with jointly implementing three technical activities.

Table 12: Results of different technical activity combinations on aggregate profits of all pig producers

Scenario		*Short-term*			*Medium-term*			*Long-term*	
	US$	Change from baseline[a] (%)	Proportion of A5[b] (%)	US$	Change from baseline (%)	Proportion of A5 (%)	US$	Change from baseline (%)	Proportion of A5 (%)
Baseline	842,965			1,866,956			3,043,266		
Scenario 1: Individual producers									
S1.A5: Combination[c]	*1,382,303*	*+64*	*+100*	*3,214,879*	*+72*	*+100*	*5,441,792*	*+79*	*+100*
S1.A1+A2: Microcredit + Training	1,169,143	+39	+60	2,650,862	+42	+58	4,476,380	+47	+60
S1.A1+A3: Microcredit + AHWs	1,218,094	+45	+70	2,679,858	+44	+60	4,385,983	+44	+56
S1.A2+A3: Training + AHWs	1,094,007	+30	+47	2,411,612	+29	+40	3,901,729	+28	+36
S1.A1+A2+A3: Microcredit + Training + AHWs	1,317,033	+56	+88	2,995,532	+60	+84	4,994,627	+64	+81
Scenario 2: Producer groups									
S2.A5: Combination	*1,022,314*	*+21*	*+100*	*3,199,340*	*+71*	*+100*	*7,063,532*	*+132*	*+100*
S2.A1+A2: Microcredit + Training	890,179	+6	+26	2,443,168	+31	+43	4,727,772	+55	+42
S2.A1+A3: Microcredit + AHWs	922,794	+9	+45	2,516,805	+35	+49	4,877,684	+60	+46
S2.A2+A3: Training + AHWs	897,333	+6	+30	2,525,335	+35	+49	5,148,729	+69	+52
S2.A1+A2+A3: Microcredit + Training + AHWs	90,628	+18	+82	2,940,691	+58	+81	6,164,296	+103	+78
Scenario 3: Producer organisations									
S3.A5: Combination	*1,026,296*	*+21*	*+100*	*4,033,651*	*+116*	*+100*	*11,205,559*	*+268*	*+100*
S3.A1+A2: Microcredit + Training	894,510	+6	+28	3,083,050	+65	+56	7,762,565	+155	+58
S3.A1+A3: Microcredit + AHWs	926,321	+10	+45	3,242,479	+74	+63	8,807,806	+189	+71
S3.A2+A3: Training + AHWs	900,805	+7	+32	3,254,083	+74	+64	9,351,578	+207	+77
S3.A1+A2+A3: Microcredit + Training + AHWs	994,389	+18	+83	3,760,327	+101	+87	10,354,718	+240	+90

Note: [a] Percentage change from the baseline. [b] Column represents the proportion of the change from the baseline value of A.5: Combination captured by the various technical activity combinations. For example, 60% indicates that this combination captures 60% of the impacts of implementing all technical activities jointly (A5). [c] Combination refers to A1 + A2 + A3 + A4, where A1 is microcredit capped at $150K.

Source: Pork VC model simulation

Table 13: Results of different technical activity combinations on number of pig producers in highly profitable systems

Scenario	Short-term			Medium-term			Long-term		
	Number	Change from baseline[a] (%)	Proportion of A5[b] (%)	Number	Change from baseline (%)	Proportion of A5 (%)	Number	Change from baseline (%)	Proportion of A5 (%)
Baseline	379			441			464		
Scenario 1: Individual producers									
S1.A5: Combination[c]	*480*	*+26*	*+100*	*639*	*+45*	*+100*	*710*	*+53*	*+100*
S1.A1+A2: Microcredit + Training	453	+19	+73	597	+35	+79	612	+32	+60
S1.A1+A3: Microcredit + AHWs	433	+14	+53	561	+27	+61	626	+35	+66
S1.A2+A3: Training + AHWs	415	+9	+35	519	+18	+39	584	+26	+49
S1.A1+A2+A3: Microcredit + Training + AHWs	470	+24	+90	626	+42	+94	700	+51	+96
Scenario 2: Producer groups									
S2.A5: Combination	*397*	*+5*	*+100*	*542*	*23*	*+100*	*704*	*+52*	*+100*
S2.A1+A2: Microcredit + Training	360	-5	n.a	436	-1	n.a	527	+13	+26
S2.A1+A3: Microcredit + AHWs	352	-7	n.a	417	-6	n.a	516	+11	+22
S2.A2+A3: Training + AHWs	354	-7	n.a	433	-2	n.a	568	+22	+43
S2.A1+A2+A3: Microcredit + Training + AHWs	378	-1	n.a	459	4	+18	633	+36	+70
Scenario 3: Producer organisations									
S3.A5: Combination	*399*	*+5*	*+100*	*684*	*+55*	*+100*	*877*	*+89*	*+100*
S3.A1+A2: Microcredit + Training	360	-5	n.a	585	+32	+59	858	+85	+95
S3.A1+A3: Microcredit + AHWs	353	-7	n.a	577	+31	+56	880	+90	+100
S3.A2+A3: Training + AHWs	355	-6	n.a	607	+37	+68	880	+90	+100
S3.A1+A2+A3: Microcredit + Training + AHWs	379	0	n.a	640	+45	+82	878	+89	+100

Note: [a] Percentage change from the baseline. [b] Column represents the proportion of the change from the baseline value of A.5: Combination captured by the various technical activity combinations. For example, 60% indicates that this combination captures 60% of the impacts of implementing all technical activities jointly (A5). [c] Combination refers to A1 + A2 + A3 + A4, where A1 is microcredit capped at $150K.

Source: Pork VC model simulation

5.6 Results of *ex-ante* evaluation of institutional upgrading scenarios

A comparison of the three institutional upgrading scenarios (with all technical upgrading activities jointly implemented, i.e., A5: Combination) showed differences in impact and trade-offs across temporal horizons and between pig producers and VC actors. As Table 10 and Figure 35 demonstrate, S1(individuals) delivered the highest short-term aggregate profits for all pig producers, delivering triple the financial impact of S2(PGs) and S3(POs) (+64% change from baseline for S1.A5 compared with +21% for S2.A5 and +22% for S3.A5). However, financial impacts in S1 from broadly targeting 1,280 individual farmers plateaued after the project exited, registering a +72% change from the baseline in the medium-term and +79% change in the long-term. This contrasts with S2 and S3's focused investments in 640 PG and PO members that produced accelerating financial gains that outperform S1(individual) in the medium- to long-term. While investing in PGs (S2) yields similar financial impact as targeting individual producers (S1) after ten years, PGs delivered close to twice the economic benefits by year 15. Further investments in institutions like POs (S3) that manage value-adding assets, such as the slaughterhouse, had by a large measure the highest impact in the system. The model showed that over fifteen years, S3(POs).A5 increased incomes in target villages by three times that of S1(individuals).A5 and twice that of S2(PGs).A5. This meant S3(POs) delivered an additional US$818,772 in the medium-term and US$4,412,027 in the long-term to target village members compared with the next highest institutional scenario.

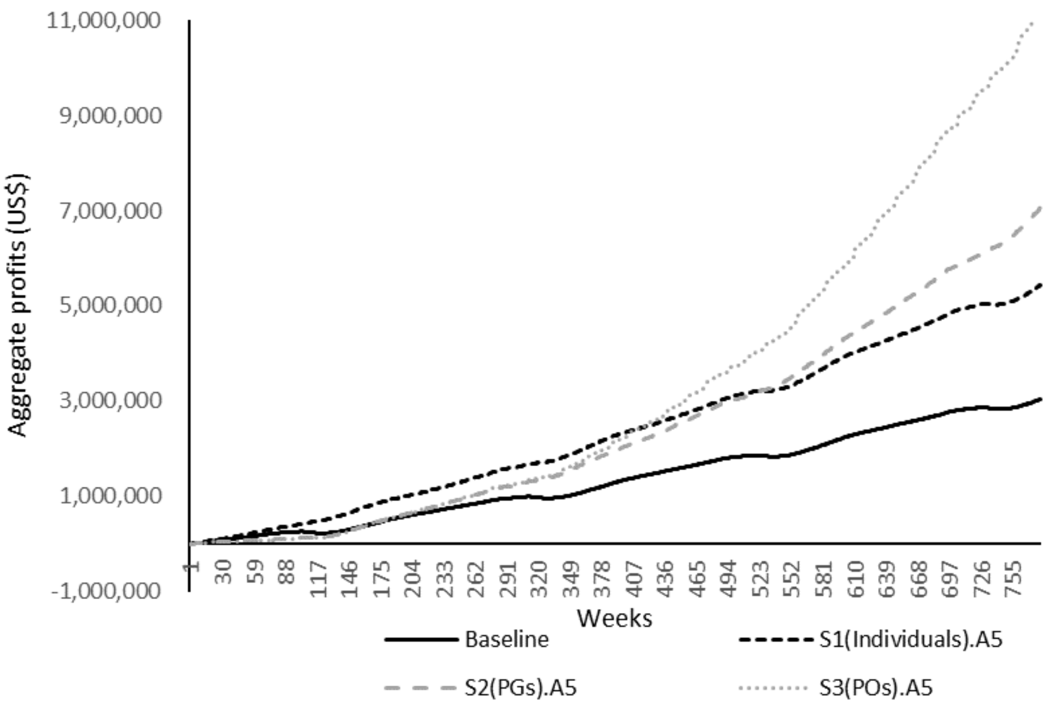

Figure 35: Comparison of aggregate profits of all producers in baseline, S1, S2, and S3
Source: Pork VC model simulation

All three institutional scenarios markedly increased the number of farmers engaged in highly profitable systems compared with the baseline. As highlighted in Table 11, the short-run number of highly profitable farmers was higher in S1(individuals).A5 (480) than S2(PGs).A5 (397) and S3(POs).A5 (399). This is because in S1(individuals) project activities were applied across all 1280 producers, causing most farmers (59%) to upgrade to local breed FF systems and thereby missing out on the substantially larger financial gains from hybrid FF farming. In S2 and S3, PGs/POs concentrated on hybrid pig production. This led to an initially lower number of farmers transitioning to highly profitable systems because of the high entry costs surrounding a hybrid FF system that aims to produce pork for a premium market. In S2, PGs were unable to capture a significant portion of the value added for their fatteners as they received premiums for only a small portion (19.4%) of their stock that supplied Myeik restaurants. This meant that price rebates from the PGs in S2 are less than POs in S3, slowing down further investment and transitions to the FF system. As a result, S2(PGs) and S1(individuals) had a similar number of producers engaged in highly profitable systems by the end of the model. By contrast, PO farmers in S3 had access to a larger market for high-quality pork and received higher premiums, which encouraged members to scale-up production and quickly upgrade to FF systems. By the model's midpoint, S3(POs) had the highest pro-poor impact and by the end of the model S3(POs) had 24% more farmers in highly profitable systems than S1(individuals) and S2(PGs) as highlighted in Table 11. Importantly, as illustrated in Table 14, in S2(PGs) and S3(POs) the number of hybrid FF farmers was considerably larger, reaching 548 and 693 farmers, respectively, by the end of the model compared with 298 in S1(individuals).

Table 14: Results from scenario testing on the number of hybrid pig producers

Scenario	*Short-term*			*Medium-term*			*Long-term*		
	Number	Change (%)[a]	Rank	Number	Change (%)	Rank	Number	Change (%)	Rank
Number of hybrid FF pig producers									
Baseline	160			161			174		
S1(Individual).A5: Combination	195	+22	3	242	+51	3	298	+86	3
S2(PGs).A5: Combination	242	+51	2	385	+141	2	548	+243	2
S3(POs).A5: Combination	243	+52	1	528	+230	1	693	+333	1
Number of hybrid WF pig producers									
Baseline	157			154			147		
S1(Individual).A5: Combination	146	-7	3	135	-14	3	120	-24	3
S2(PGs).A5: Combination	558	+255	1	413	+163	1	250	+59	1
S3(POs).A5: Combination	556	+254	2	270	+72	2	104	-34	2

Note: [a] Percentage change from the baseline.
Source: Pork VC model simulation

S2(PGs) and S3(POs) created a third pro-poor option for generating substantial income from pig farming: the hybrid WF system. In S1(individuals), though hybrid WF incomes increased by over 200% compared with the baseline, they were still low averaging around US$49 per year. With a focus on quality hybrid pigs and access to market channels that pay premiums, PG/PO hybrid WF members had substantial income gains compared with non-PG counterparts. As presented in Figure 36, in S2(PGs).A5 and S3(POs).A5, PG/PO members with hybrid WF farms had annual incomes reaching US$103 and US$411 in the long-term. In S3(POs), incomes were considerably larger because of the rebates afforded by investments in the slaughterhouse. The profits from PO hybrid WF pig farming in S3 compared favourably to local breed FF farms (US$252 per annum) albeit with a significantly lower environmental cost[31] and resource (financial, physical, and human) requirements. S3(POs), and to a lesser extent S2(PGs), therefore, created a pathway through hybrid WF farming for pig producers with less capital and risk tolerance to engage in a moderately profitable livelihood. These hybrid WF pig farmers could remain in the WF system if their circumstances require or readily upgrade to the more profitable hybrid FF systems with the advantage of the technical experience and capital gained. Model data revealed that after paying off upgrading loan costs, it would take on average five years for PG/PO hybrid WF pig farmers to upgrade to the FF system without needing to take on any additional external debt.

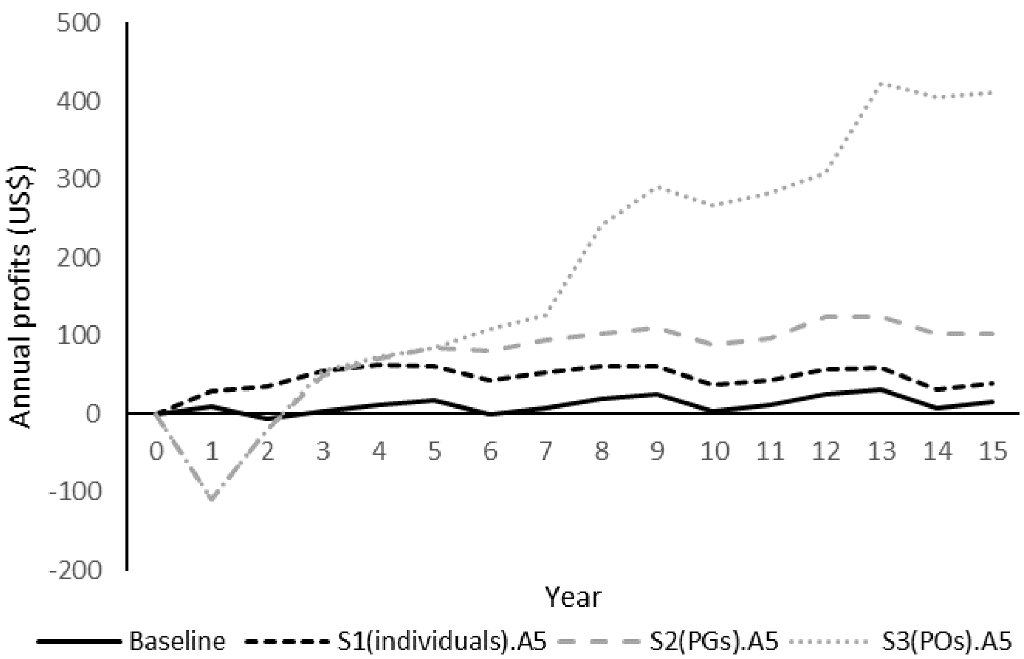

Figure 36: Comparison of annual profits for hybrid WF producers in baseline, S1, S2, and S3
Source: Pork VC model simulation

All three scenarios increased the incomes of hybrid FF farmers compared with the baseline as shown in Figure 37. Annual incomes by the end of the model were US$2,573 in S3(POs).A5, US$1,810 in S2.(PGs)A5, and US$1,040 in S1(individuals).A5. This level of income would enable pig farming to become a primary livelihood that brings cash income above the average household levels of US$950 in the target region (Snoxell & Lyne, 2019) without diverting substantial amounts of land, capital, and

[31] For example, a local breed FF farmer raised three to four times more fatteners than a hybrid WF farmer in S3.

human resources from other enterprises. The large upfront upgrading costs and the requirements for PG/POs to withhold rebates to initially invest in PG/POs capacity meant short-term profits are lower for PG/PO members compared with existing hybrid FF farmers. Once members and the PG/POs were well established by the midpoint of the model, there was little difference in the annual incomes of hybrid FF farmers between the three scenarios. Moreover, in the long-term PG and PO member annual profits exceeded non-members by 75% and 147%, respectively. By contrast, in S1(individual).A5, the difference in hybrid FF producer profits from the baseline slowly decreased because project interventions brought short-lived production efficiencies and protection against disease shocks; however, essentially the market channel and price for live pigs remained unchanged.

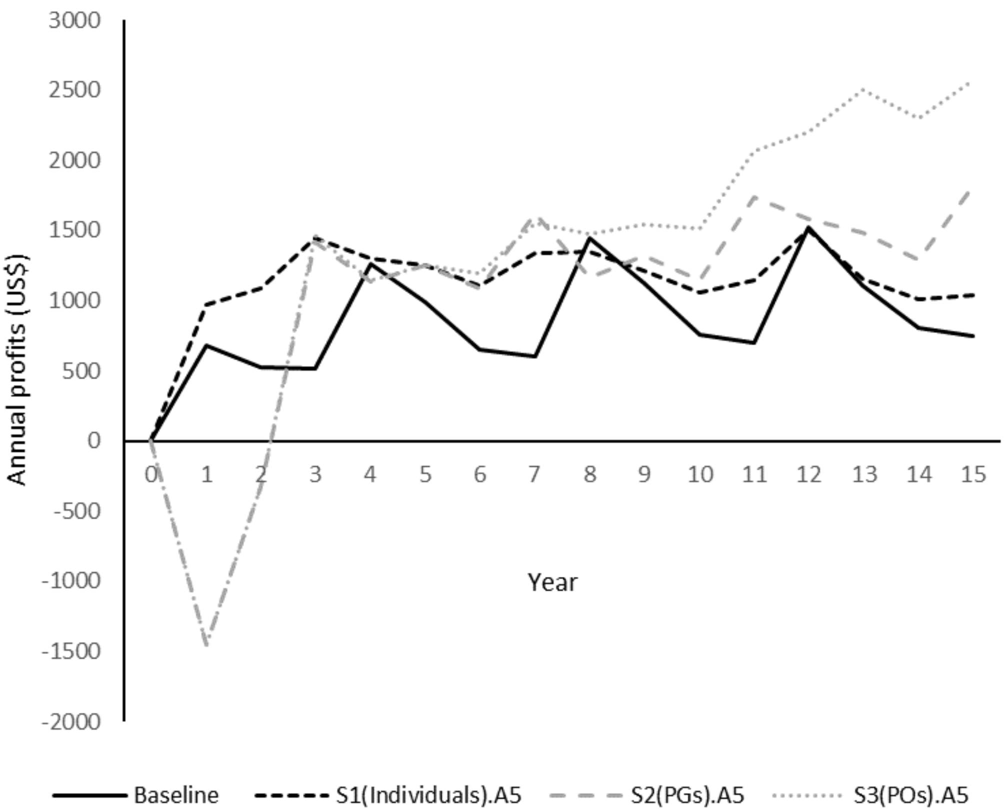

Figure 37: Comparison of annual profits for hybrid FF producers in baseline, S1, S2, and S3
Source: Pork VC model simulation

The model's results pointed towards two areas of concern regarding liquidity problems for farmers in the more profitable hybrid FF and PG/PO WF enterprises. First, as shown in Figure 32, in S1(individuals), soon after the project exits, hybrid FF farmers faced periods of negative cashflow following disease outbreaks. This increased risk to recently upgraded farmers who had taken out loans for investments and seasonal production costs. In S2 and S3, PG/PO members did not experience similar liquidity problems once loans were repaid, as they were able to maintain investments in biosecurity and AHWs. The second area of concern was the prolonged period of negative cashflow experienced by PG/PO members in S2 and S3 when they take on microfinance loans to upgrade farms to hybrid FF or WF systems. These negative cashflows are shown in Figures 36 and 37. In S2.A5 and S3.A5, it took PG/PO members around 90 weeks for their enterprises to break even, with debt peaking at US$1,951 for FF farmers and US$134 for WF farmers. The model assumed that PG members brought no existing capital or assets into their high-quality hybrid FF/WF farming enterprise and that microcredit loans operated on an amortised payment schedule. While these assumptions presented a worst-case scenario, it draws attention to the need for the TRRILD project to design institutional arrangements and loan products that enable poorer households to upgrade their farming systems while reducing risks from prolonged liquidity problems and disease outbreaks. Further analysis on the impact of microcredit loan terms and types is conducted in Section 5.7.1: Alternative scenarios.

S3 provided the largest pro-poor impacts by enabling PO members to further capture value from high-quality fatteners through the addition of a hygienic, safe slaughtering facility. The unlocking of market channels for high-quality pork enabled the PO to increase the number of FF members by 24% compared with S2(PGs). The PO delivered substantially higher returns for members from additional price rebates, resulting in a 28% increase in total profits for FF members and a 164% increase for WF members compared with S2(PGs). Along with individual financial returns in S3, PO members invested on average US$292 each in the expansion of the slaughterhouse. The model suggested that the slaughterhouse is a sound investment for a strategic partner. The initial cash investment of a partner of US$25,000 delivered annualised returns of around 53%. The start-up investment established a 35 fattener/week slaughtering facility which expanded to 262 fatteners/week by the end of the model. PO cashflows remained positive throughout S3, even when a standard two-year MFI loan was taken to finance slaughterhouse investments in the absence of a strategic partner. These findings suggest that if a strategic partner is not forthcoming, the project should consider providing start-up capital through either a grant or loan facility to unlock the gains from a hygienic slaughtering facility.

Each institutional scenario had a different impact on downstream actors in the pork VC as shown in Table 14. S1(individuals) magnified the current system because it introduced higher volumes of low-quality hybrid and local breed pigs. The higher volumes led to annual profit increases for brokers (92%) and slaughterhouses (41%) as well as increases in off-farm employment (117%) by the end of the model. In S2 and S3, PGs and POs establish a collective supply agreement with a slaughterhouse, causing annual profits for brokers to fall by 57% in the long-term. In S2, the ongoing relationship between PGs and an existing slaughterhouse delivered a small (6%) annual decrease in total slaughterhouse profits. While purchasing high-quality fatteners for a premium wholesale market is profitable for local slaughterhouses, the model revealed that slaughterhouse profit margins were slightly lower than when purchasing low-quality fatteners for the standard wholesale market. This finding shows that it may prove difficult to engage with established slaughterhouses to switch part of their system to focus on high-quality wholesale pork, given the strong financial incentive to continue in a high volume, low-quality system. S3(POs) decreased slaughterhouse annual profits by a more significant margin (34%), as local slaughterhouses needed to substitute fatteners previously supplied by PO members with higher priced fatteners from Mawlymine. All three institutional scenarios substantially increased off-farm employment by 95% to 154% in the short-run. After five years, employment gains in S2 and S3 outpaced S1(individuals) as PG and POs became debt-free and invested in farm and organisational capacity that brought additional employment to the VC. S3's further investments in value-adding assets brought the highest employment gains. By the end of the model, these were equivalent to an additional US$174,462 in yearly wages to the local community compared with US$109,437 from S2(PGs) and US$37,327 from S1(individuals). As highlighted in Table 15, increases in off-farm wages in S2(PGs) and S3(POs) offset any losses in the system experienced by brokers and slaughterhouses by the model's midpoint.

Table 15: Financial impacts of scenario tests on downstream actors in the pork value chain

Downstream Actors	*Short-term*			*Medium-term*			*Long-term*		
	US$	Change (%)[a]	Rank	US$	Change (%)	Rank	US$	Change (%)	Rank
Broker annual profits									
Baseline	27,163			24,178			25,065		
S1.A5: Combination	37,976	+40	1	42,738	+43	1	48,220	+92	1
S2.A5: Combination	13,301	-51	2	11,137	-31	2	10833	-57	2
S3.A5: Combination	13,407	-51	3	10,950	-31	3	10,389	-57	3
Slaughterhouse annual profits									
Baseline	255,570			294,657			327,663		
S1.A5: Combination	296,506	+16	1	402,055	+36	1	460,712	+41	1
S2.A5: Combination	203,382	-20	2	235,470	-20	2	307,652	-6	2
S3.A5: Combination	188,478	-26	3	237,229	-19	3	215,597	-34	3
Off-farm employment (wages earned annually)									
Baseline	34,338			31,155			31,791		
S1.A5: Combination	87,202	+154	1	75,064	+141	3	69,118	+117	3
S2.A5: Combination	66,892	+95	3	97,212	+212	2	141,228	+344	2
S3.A5: Combination	70,856	+106	2	138,437	+344	1	206,253	+549	1
Total earnings for downstream actors									
Baseline	317,071			349,990			384,519		
S1.A5: Combination	421,684	+33	1	519,857	+49	1	578,050	+50	1
S2.A5: Combination	283,575	-11	2	343,819	-2	2	459,713	+20	2
S3.A5: Combination	272,741	-14	3	386,616	+10	3	432,239	+12	3

Note: [a] Percentage change from the baseline.
Source: Pork VC model simulation

All institutional scenarios resulted in changes in the share of overall revenues generated among pork VC actors, as shown in Figure 38. S1(individuals) brought the smallest movement, with brokers retaining 8% of total revenue but slaughterhouse and producer proportions switching ranking compared to the baseline. In S2(PGs) and S3(POs), broker proportions fell to small amounts (1% to 2%) and producers gradually gained three-quarters or more of the revenues from pig production in the target villages. The model overestimated these gains as it did not take into consideration pig producers from outside of the target villages, from whom local slaughterhouses could purchase live pigs from at discounted rates. There were sufficient declines in the revenues of the current lead VC actors, slaughterhouses, suggesting that power shifts along the chain will be noted and potentially resisted by this group.

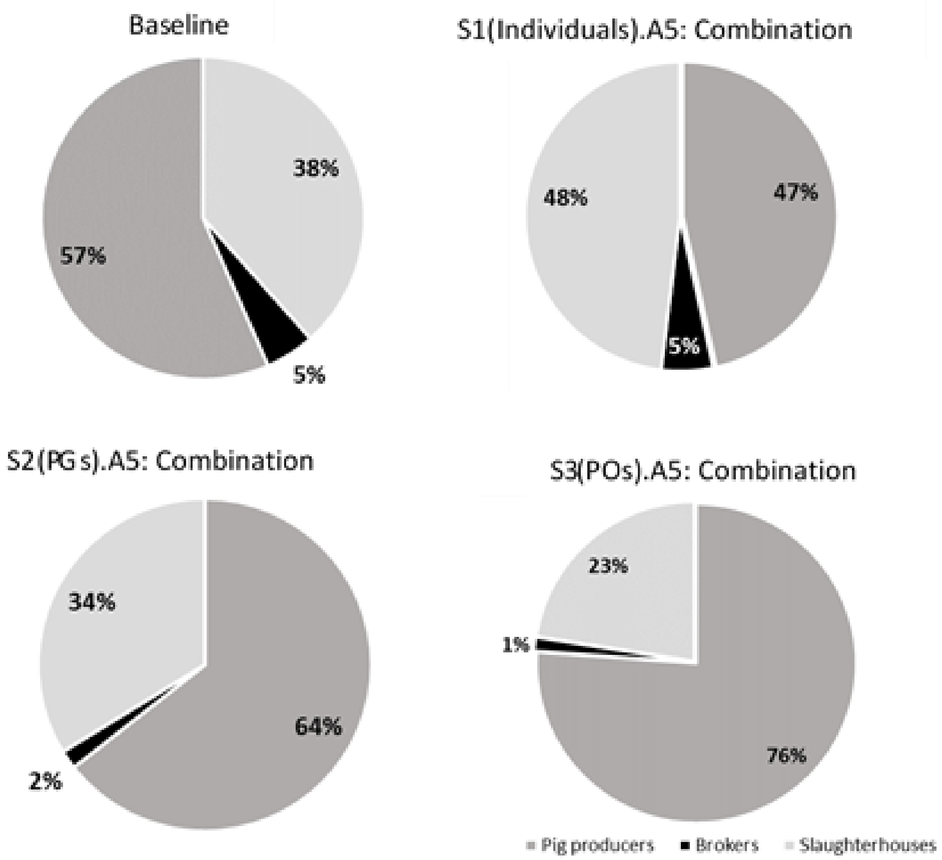

Figure 38: Share of revenue captured by pork value chain actors
Source: Pork VC model simulation

Of the total pork consumed in the region, producers in the target area provided on average 7.4% (S1[individuals]), 9.9% (S2[PGs]), and 10.4% (S3[POs]), respectively. While these values are higher than the baseline of 5.6%, the increases were insufficient to significantly alter the live pig price in Myeik and Palaw. As shown in Figure 39, impacts on pricing equated to an average movement of between -1% (S1.A5) to -1.7% (S3.A5). Pricing shifts were the highest in S3(POs) because it produced the highest number of fatteners (103% increase from the baseline) of which between 70% to 85% entered the local wholesale pork market. Even with the highest number of additional fatteners, S3(POs) was still not able to reverse the baseline trend of increasing importations of live pigs from outside Myeik.

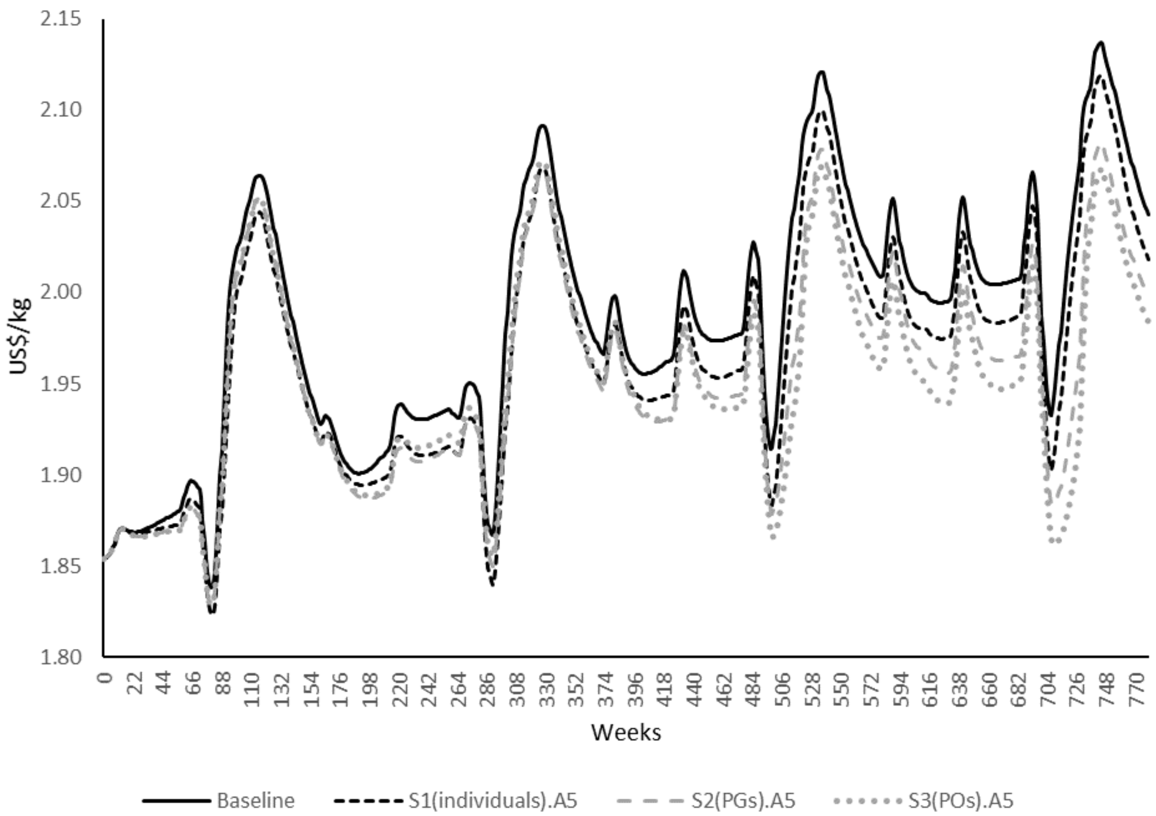

Figure 39: Comparison of slaughterhouse price of live pigs across baseline, S1, S2, and S3
Source: Pork VC model simulation

5.7 Sensitivity analysis

The process of developing the pork VC SD model involved critical assumptions around structures, behaviours, and parameters. This is not unique to this research given that all models are approximations of reality and SD modellers strive for the "least wrong" or "most useful" model (Sterman, 2000). In this research, sensitivity analysis (SA) was performed to test whether conclusions from the model remained valid when assumptions were altered over a plausible range of uncertainty (Sterman, 2010, p.883). This section outlines the SA undertaken by altering both model structure, and parameters and then comparing results to the findings from the original scenario tests (i.e., the findings described in Sections 5.5 and 5.6).

5.7.1 Alternative scenarios

Based on assumption choices and discussions with project team members, alternative scenarios were created to examine the sensitivity of the model's results to plausible alternative scenarios. Beyond building confidence in the model's results, alternative scenarios also served to further shape pro-poor upgrading recommendations for the TRRILD project team.

5.7.1.1 Alternative disease scenarios

Two alternative disease scenarios were developed for SA. In the first alternative scenario, there is no significant disease outbreak and in the second, the government imposes and successfully enforces a ban on pigs imported from outside Myeik and Palaw following a significant disease outbreak. The second alternative disease scenario is based on SGMB and RG participants recollections of two importation bans in the past decade, instigated by the government to control wholesale pork prices, and reduce the spread of disease between regions and townships within Tanintharyi. In this alternative scenario, the importation ban took place four weeks after the disease outbreak, and slaughterhouses were only able to source locally grown fatteners. These two alternative disease scenarios were selected because using them helped strengthen the TRRILD project team's ability to select interventions that deliver on short-term contractual obligations[32] under three plausible external short-term circumstances: no disease, significant disease (i.e., the model baseline), and significant disease with an importation ban.

The negative impacts of disease outbreaks on the target villages are clear when comparing the two alternative disease scenarios and the standard model baseline.[33] As shown in Table 16 and Table 17, compared with a scenario where no disease outbreaks occur, a disease outbreak (i.e., the model baseline) reduced the aggregate profits of all pig producers by 14% and resulted in 14 fewer producers entering highly profitable systems. Pig producers in Myeik and Palaw benefited positively from the enforcement of an importation ban as it encouraged slaughterhouses to purchase locally resulting in the highest profits for pig producers (19% above the baseline), and an extra 57 producers in highly profitable systems. The model showed that impacts of disease particularly affected smaller (and typically less wealthy) WF pig producers whose profits fell by 109% (hybrid) and 209% (local breed) compared to the alternative scenario of no disease outbreaks. Meanwhile, FF farmer profits fell by 18% (local breed) and 15% (hybrid) when there is a significant disease outbreak. Among VC actors only slaughterhouses fared worse (3% decrease in aggregate profits) during an importation ban because they were unable to access the Mawlymine market and were forced to purchase locally to maintain production. This increased the price of locally produced pigs, increasing operating costs and reducing profit margins in slaughterhouses.

The two alternative disease scenarios had opposite impacts on the slaughterhouse price of live pigs in the region, as illustrated in Figure 40. When there are no significant disease outbreaks the price of live pigs stabilises with only small annual oscillations associated with Chinese New Year (demand)

[32] The TRRILD project had three years to implement upgrading interventions following the model's recommendations.
[33] The standard model baseline refers to the baseline of the pork SD model outlined in Section 4.3 and 5.3. In graphs and tables this is referred to as "Baseline: Disease."

and pre-monsoon (supply) shocks. Meanwhile, the introduction of an importation ban caused steeper and larger price rises of between 32% and 43% above panic selling lows. These large price fluctuations cause significantly more investment in production capacity and upgrades to higher value pig enterprises. Once the importation ban is lifted, prices then drop to below pre-disease levels for a period of 70 weeks, which causes more farmers to exit from pig farming.

Table 16: Comparison of alternative disease scenarios and standard model baseline on aggregate profits of all pig producers

Scenario	*Short-term*			*Medium-term*			*Long-term*		
	US$	Change (%)[a]	Rank	US$	Change (%)	Rank	US$	Change (%)	Rank
Baseline: Disease	842,965		3	1,866,956		3	3,043,266		3
Alternative scenario: No Disease	916,551	+9	1	2,085,929	+12	2	3,481,062	+14	2
Alternative scenario: Disease and Importation Ban	911,040	+8	2	2,089,426	+12	1	3,624,170	+19	1

Note: [a] Percentage change from the baseline.
Source: Pork VC model simulation

Table 17: Comparison of alternative disease scenarios and standard model baseline on number of pig producers in highly profitable systems

Scenario	*Short-term*			*Medium-term*			*Long-term*		
	Number	Change (%)[a]	Rank	Number	Change (%)	Rank	Number	Change (%)	Rank
Baseline: Disease	379		1	441		2	464		3
Alternative scenario: No Disease	353	-7	2	401	-9	3	488	+5	2
Alternative scenario: Disease and Importation Ban	375	+6	3	443	+10	1	521	+7	1

Note: [a] Percentage change from the baseline.
Source: Pork VC model simulation

The institutional scenarios and technical upgrading activities were simulated using these two alternative disease scenarios and compared with the model's original results. These comparisons on pro-poor and financial indicators are found in Appendix D, Tables D.1, D.2, D.3, and D.4. When running the model with no disease outbreaks there was a minor rank order change in the impact of project interventions on aggregate profits of pig producers: S2(PGs).A5 surpassed S1(individuals).A5 in the medium-term. There was also a minor change in the rank order when considering pro-poor impacts: S1(individuals).A5 consistently outperformed S2(PGs).A5 in increasing the number of pig producers in highly profitable systems. Investing in POs (S3.A5), however, still delivered the highest pro-poor benefits in the medium- and long-term. In the baseline model, live pig price fluctuations reduced the number of producers who can weather disease and economic shocks and remain in the recently upgraded systems. When these fluctuations are minimised by prolonged periods without disease shocks, the project's activities had less impact on reducing risk below an acceptable level for upgrading. As a result, in the no disease alternative scenario, increasing the number of farmers which engage in the project (i.e., S1[individuals]) enabled more farmers to upgrade into profitable systems.

Because S3(POs) brings increased value to hybrid WF farmers, S3 still outperformed S1(individuals) in pro-poor impacts even when these risks are reduced. In terms of the rank order of technical activities, without disease shocks A2: Microcredit strengthened its position to consistently have the highest financial and pro-poor impacts in S1(individuals) and in the short- and medium-term for S2(PGs) and S3(POs). As expected, this resulted in a reduced impact for A3: AHWs which dropped to the third priority activity, above A4: AI but below A2: Training. The exception, however, was S3 (and the long-term for S2), in which A3: AHWs still had the highest impact on aggregate pig producer profits and the number of highly profitable pig producers because the premium pork market afforded considerable extra value to fatteners. This confirmed the value of AHWs in S3 even when their impacts are scaled down to limiting pig mortality from regular seasonal diseases.

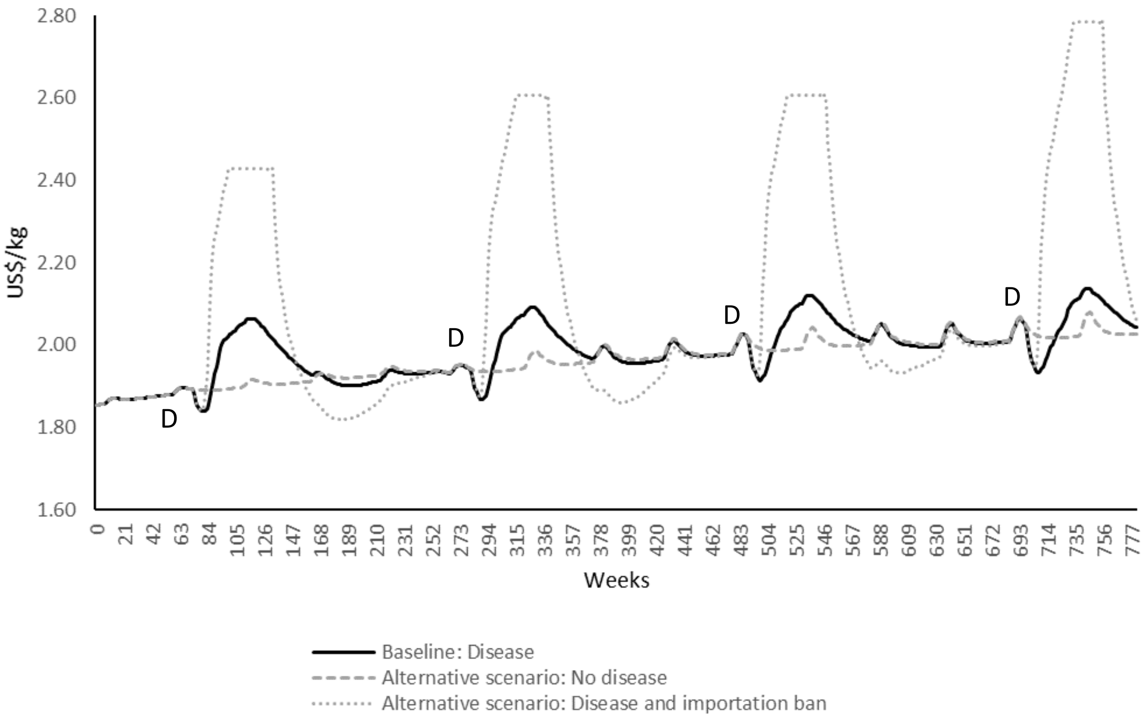

Figure 40: Slaughterhouse price of live pigs in Myeik and Palaw in alternative baselines and standard model baseline
Note: The letter “D” denotes disease events occurring at weeks 72, 280, 488, and 696.
Source: Pork VC model simulation

The alternative scenario: disease and importation ban resulted in larger oscillations of the live pig price in Myeik, as highlighted in Figure 40. This works to the overall advantage of local producers who are protected from competing with imported pigs and can take advantage of higher live pig prices following disease outbreaks. In this alternative scenario, slaughterhouse income was reduced because of the loss of their alternative supply channels and bargaining power with small-scale farmers. The high live pig prices post-disease created further advantage for those producers who could safely bring fatteners and sows through periods of disease. Fatteners could be sold for peak prices when consumer demand returned, and FF farmers could produce piglets to take advantage of high prices due to piglet scarcity. As a result, in the disease and importation ban scenario, the A3: AHW improves its ranking to become the highest priority across S2(PGs) and S3(POs) for financial and pro-poor outcomes, and consistently second highest priority for S1(individuals) in terms of financial benefits for producers. The increased impact of AHWs and the ability of PGs to continue to invest in services for their members propelled S2(PGs).A5 above S1.(individuals)A5 in the medium-term for financial impact and increased the impacts of the TRRILD project. For example, in S2(PGs).A5 the changes in long-term incomes for all pig producers shifted from +132% in the standard model run to +169% in this alternative scenario.

5.7.1.2 Temporal changes to disease outbreaks

The standard model (i.e., baseline: disease) consisted of a regular disease outbreak (every four years and starting at week 72 to coincide with start of the monsoon season) with a static length (26 weeks). To understand the impacts of temporal changes to disease outbreaks on the system, the standard model was simulated with the disease outbreak starting a quarter of a year later (i.e., 13 weeks) and randomly assigning four disease start times[34] across the fifteen-year model timeframe as well as randomly assigning the length of the disease outbreak to between 10 and 52 weeks. The results in Tables 18 and 19 show that temporal changes to disease outbreaks had only a minor impact on financial and pro-poor outcomes.

As illustrated in Tables 18 and 19, randomly assigning the timing and length of the disease outbreak had the largest change from the baseline, hence, this was selected as an alternative baseline for *ex-ante* testing of the project's institutional scenarios and technical upgrading activities. The complete financial and pro-poor results of this scenario testing are found in Appendix D, Tables D5 and D6. In terms of technical activities, the only change was a minor improvement in the rank order of A3: AHW which is related to the short- and medium-term increased severity of the disease outbreak in this alternative scenario. When testing institutional scenarios, S2(PGs) improved its ranking on financial impact compared to S1(individuals), and S1(individuals) had more pig producers in highly profitable systems than S2(PGs) in the long-term. These improvements in S1(individuals) were related to the increased risks to pig producers from randomising disease outbreaks. These risks result in larger profits for farmers in the Hybrid FF system. However, in S2(PGs) with a smaller market for premium products, PG hybrid WF farmers, were unable to fully take advantage of post-disease price rises and are outperformed by non-PG local breed FF farmers. As a result, there are less pig producers in highly profitable systems in S2(PGs) than S1(individuals).

[34] This was achieved by randomly assigning a disease start time within four portions on the fifteen-year model timeframe.

Table 18: Comparison of changes to timing and length of disease outbreaks on aggregate profits of all pig producers in model baseline

Scenario	*Short-term*		*Medium-term*		*Long-term*	
	US$	Change (%)[a]	US$	Change (%)	US$	Change (%)
Baseline: Disease	842,965		1,866,956		3,043,266	
Baseline + 13-week delay	793,013	-6	1,836,010	-2	3,020,267	-1
Baseline + 26-week delay	791,820	-6	1,866,547	0	2,998,024	-1
Baseline + 39-week delay	791,912	-6	1,875,050	0	3,010,675	-1
Baseline + random assignment	852,195	+1	1,782,994	-4	3,132,999	3

Note: [a] Percentage change from the baseline.
Source: Pork VC model simulation

Table 19: Comparison of changes to timing and length of disease outbreaks on number of pig producers in highly profitable systems in model baseline

Scenario	*Short-term*		*Medium-term*		*Long-term*	
	Number	Change (%)[a]	Number	Change (%)	Number	Change (%)
Baseline: Disease	379		441		464	
Baseline + 13-week delay	376	-1	425	-4	491	6
Baseline + 26-week delay	378	0	429	-3	498	8
Baseline + 39-week delay	375	-1	432	-2	514	11
Baseline + random assignment	362	-4	372	-16	484	4

Note: [a] Percentage change from the baseline.
Source: Pork VC model simulation

5.7.1.3 Temporal delays to technical upgrading activities

The baseline model assumed no delays occurred in the implementation of the project's technical activities to the target population. However, implementation setbacks in development projects are common, often resulting from delays in contracting, procurement, hiring of staff, and natural disasters (Ashan & Gunawan, 2010). To investigate the effect of project delays, the A5: Combination scenario was simulated with a one-year delay to each of the four technical activities as well as to the formation of the PGs and POs. As highlighted in Tables 20 and 21, delays to A2: Training and the formation of PGs and POs have the highest negative impacts for the project. Delaying training by a year reduces the financial impact in S2(PGs).A5 and S3(POs).A5 by between 5% to 10%. In S2(PGs) and S3(POs), training on high quality pig production by the TRRILD project builds up the knowledge of PG/PO members, which is further increased as they interact with one-another. When the initial stock of knowledge is lower (i.e., through delayed training events by the project) the effect of peer-to-peer learning is decreased for the model's lifetime, leading to higher disease burdens and lower confidence to upgrade to more profitable systems. When training is delayed in S2(PGs).A5 and S3(POs).A5, the combination of technical activities results in a negative short-term impact in terms of the number of pig producers in highly profitable systems.

Table 20: Results of implementation delays of technical upgrading activities on aggregate profits of all pig producers

Scenario	*Short-term*			*Medium-term*			*Long-term*		
	US$	Change from baseline[a] (%)	Proportion of A5[b] (%)	US$	Change from baseline (%)	Proportion of A5 (%)	US$	Change from baseline (%)	Proportion of A5 (%)
Baseline	842,965			1,866,956			3,043,266		
Scenario 1: Individual producers									
S1.A5: Combination[c]	*1,382,303*	*+64*	*+100*	*3,214,879*	*+72*	*+100*	*5,441,792*	*+79*	*+100*
S1.A5: Microcredit delay	1,304,901	+55	+94	3,110,210	+67	+97	5,319,503	+75	+98
S1.A5: Training delay	1,328,246	+58	+96	3,043,649	+63	+95	5,105,735	+68	+94
S1.A5: AHW delay	1,328,450	+58	+96	3,073,897	+65	+96	5,221,731	+72	+96
S1.A5: AI Delay	1,365,600	+62	+99	3,195,151	+71	+99	5,422,364	+78	+100
Scenario 2: Producer groups									
S2.A5: Combination	*1,022,314*	*+21*	*+100*	*3,199,340*	*+71*	*+100*	*7,063,532*	*+132*	*+100*
S2.A5: Microcredit delay	1,013,077	+20	+99	3,184,677	+71	+100	7,042,612	+131	+100
S2.A5: Training delay	955,084	+13	+93	2,895,031	+55	+90	6,435,701	+111	+91
S2.A5: AHW delay	961,868	+14	+94	3,169,358	+70	+99	7,050,572	+132	+100
S2.A5: AI Delay	1,007,438	+20	+99	3,164,684	+70	+99	7,007,462	+130	+99
S2.A5: PG delay	956,536	+13	+94	3,054,271	+64	+95	6,827,084	+124	+97
Scenario 3: Producer organisations									
S3.A5: Combination	*1,026,296*	*+21*	*+100*	*4,033,651*	*+116*	*+100*	*11,205,559*	*+268*	*+100*
S3.A5: Microcredit delay	1,017,040	+21	+99	4,021,298	+115	+100	11,110,442	+265	+99
S3.A5: Training delay	958,729	+14	+93	3,737,865	100	+93	10,614,487	249	+95
S3.A5: AHW delay	949,594	+13	+93	3,984,025	113	+99	11,209,927	268	+100
S3.A5: AI Delay	1,011,375	+20	+99	3,996,411	114	+99	11,151,500	266	+100
S3.A5: PO Delay	957,207	+14	+93	3,627,232	94	+90	10,381,056	241	+93

Note: [a] Percentage change from the baseline. [b] Column represents the proportion of the change from the baseline value of A.5: Combination captured by the various technical activity combinations. For example, 60% indicates that this combination captures 60% of the impacts of implementing all technical activities with no delays. [c] Combination refers to A1 + A2 + A3 + A4, where A1 is microcredit capped at $150K.

Source: Pork VC model simulation

Table 21: Results of implementation delays of technical upgrading activities on number of pig producers in highly profitable systems

Scenario	*Short-term*			*Medium-term*			*Long-term*		
	Number	Change from baseline[a] (%)	Proportion of A5[b] (%)	Number	Change from baseline (%)	Proportion of A5 (%)	Number	Change from baseline (%)	Proportion of A5 (%)
Baseline	379			441			464		
Scenario 1: Individual producers									
S1.A5: Combination[c]	*480*	*+26*	*+100*	*639*	*+45*	*+100*	*710*	*+53*	*+100*
S1.A5: Microcredit delay	472	+25	+98	631	+43	+99	703	+51	+99
S1.A5: Training delay	461	+22	+96	606	+37	+95	674	+45	+95
S1.A5: AHW delay	470	+24	+98	623	+41	+98	679	+46	+96
S1.A5: AI Delay	479	+27	+100	639	+45	+100	710	+53	+100
Scenario 2: Producer groups									
S2.A5: Combination	*397*	*+5*	*+100*	*542*	*23*	*+100*	*704*	*+52*	*+100*
S2.A5: Microcredit delay	396	+5	+100	541	23	+100	703	+52	+100
S2.A5: Training delay	372	-2	+94	504	14	+93	676	+46	+96
S2.A5: AHW delay	398	+5	+100	544	23	+100	705	+52	+100
S2.A5: AI Delay	394	+4	+99	539	22	+99	702	+51	+100
S2.A5: PG Delay	356	-6	+90	526	19	+97	698	+50	+99
Scenario 3: Producer organisations									
S3.A5: Combination	*399*	*+5*	*+100*	*684*	*+55*	*+100*	*877*	*+89*	*+100*
S3.A5: Microcredit delay	398	+5	+100	682	+55	+100	878	+89	+100
S3.A5: Training delay	373	-2	+93	659	+49	+96	879	+89	+100
S3.A5: AHW delay	397	+5	+100	686	+56	+100	878	+89	+100
S3.A5: AI Delay	396	+4	+99	681	+54	+100	878	+89	+100
S3.A5: PO Delay	356	-6%	+89	639	+45	+93	879	+89	+100

Note: [a] Percentage change from the baseline. [b] Column represents the proportion of the change from the baseline value of A.5: Combination captured by the various technical activity combinations. For example, 60% indicates that this combination captures 60% of the impacts of implementing all technical activities with no delays. [c] Combination refers to A1 + A2 + A3 + A4, where A1 is microcredit capped at $150K.

Source: Pork VC model simulation

Delays in the formation of PGs and POs also bring ongoing reduced financial impacts in S2.A5 and S3.A5 in the range of 5% to 10%; however, the impacts to the number of producers in highly profitable systems is largely overcome by the end of the model run.

5.7.1.4 Alternative PG and PO arrangements

The literature suggests that different forms of institutional arrangements impact the financial performance of collective action (Chaddad & Cook, 2004). To understand the impact of alternative forms of collective action, institutional upgrading scenarios were simulated with the following alternative institutional arrangements: (i) no savings – PGs and POs are unable to collect fees (or withhold premiums) from members for savings and investment in shared assets and services; (ii) 50% less savings – PGs prioritise rebates for members over savings, resulting in 50% less savings; iii) 50% more savings – PGs and POs prioritise savings over member rebates, resulting in 50% more savings; iv) no rebates – PGs and POs do not pay rebates proportional to patronage in order to maximise their saving and investment capacity. The results of these alterative arrangements are presented in Table 22 and show that institutional arrangements had an impact on the financial position of PG and PO members, particularly in the long-term.

In the short term, these altered institutional arrangements had little effect on the financial position of PG and PO members. This is explained by the support of the project to cover technical and management costs for the PGs and POs over the first three years of their lifetime. However, medium- and long-term results strongly point to the importance of institutional arrangements that encourage collective savings and rebates proportional to patronage as a mechanism to increase the financial position of its members. Without arrangements that encourage collective savings allowing investments in value-adding assets and technical services, member profits fell by 14% for PGs and 49% for POs. The large reduction in PO member profits shows the critical nature of institutional arrangements when investments in value-adding assets are required, such as the slaughterhouse. PGs and POs were also less inclusive when collective savings were reduced by 50%; the number of members in the highly profitable hybrid FF system fell by 31% in S3(POs) and 15% in S2(PGs) relative to the standard model run and total membership fell by 19 producers in S3(POs) and 15 producers in S2(PGs). The ability to deliver rebates to members was also important in encouraging investments in individual farms, which in turn brought further cashflow and investment to the PGs and POs. Institutions that provided a financial rebate to members outperformed those that only pay market rates for fatteners in order to maximise collective savings. The overall financial position of PGs was reduced by 1.5% (S2) and 15% (S3) relative to the standard model run when rebates were held back entirely from members. Between the extremes of no savings (full rebate payment) and no rebates (full savings) the model showed that in POs, where investments in value-adding assets are required, erring on the side of saving (i.e., 50% more savings) was the more profitable option.

Table 22: Financial position of PG and PO members under alternative institutional arrangements

Scenario	*Short-term*		*Medium-term*		*Long-term*	
	US$	Change (%)[a]	US$	Change (%)	US$	Change (%)
Scenario 2: Producer Groups						
S2.A5: Standard model	464,522		2,144,077		5,462,947	
S2.A5: PGs 50% less savings	464,583	+0	2,145,230	-0.1	5,453,094	-0.2
S2.A5: PGs 50% more savings	463,342	+0	2,141,207	-1	5,451,744	-0.2
S2.A5: PGs no rebates	463,342	-0.3	2,123,087	-1.0	5,380,764	-1.5
S2.A5: PGs no savings	464,643	+0	2,074,945	-3.2	4,704,143	-14
Scenario 3: Producer Organisations						
S3.A5: Standard model	515,629		3,128,648		9,948,502	
S3.A5: POs 50% less savings	513,197	-0.3	2,889,062	-7.7	9,397,306	-5.5
S3.A5: POs 50% more savings	507,197	-1.6	3,250,668	+3.9	10,160,539	+2.1
S3.A5: POs no rebates	501,551	-2.7	3,170,966	+1	8,479,973	-15
S3.A5: POs no savings	512,571	-0.6	2,235,547	-29	5,105,785	-49

Note: [a] Percentage change from the standard model.
Source: Pork VC model simulation

5.7.1.5 Changes in responsiveness of pig producers to market signals

Upgrading between farming systems and changes in production capacity in the model were driven by profitability and the time taken for producers to determine market signals on price. These decisions were governed by graphical functions embedded in the model that were developed through interactions with SGMB and RG members. Because these graphical functions were based on perceptions of behaviour rather than publicly available or survey data (such as sale weight of live pigs, feed prices, etc.) SA was performed by increasing or decreasing pig producers' responsiveness to market signals by 25%[35] compared with the original model. The full results of this alternative scenario are found in Appendix B: Tables B.7, B.8, B.9, and B.10.

The alternative scenario in which producers are more responsive to market signals brought increased volatility in the transition of pig producers between farming systems. This is illustrated in Figure 41, that shows the number of highly profitable pig producers oscillated significantly in this alternative scenario compared to the standard model. This is because higher numbers of producers initially upgraded but then a substantial portion failed and exited as prices fell and disease outbreaks occurred in the target area. Comparing baselines, the overall financial benefits of the rapid upgrading in pig systems outweighed the costs of a higher portion dropping out, shown by the 34% increase in the aggregate profits of pig producers when they are more responsive to market signals. In this alternative scenario there was only one minor change in the rank order of institutional scenarios: in the medium term, S2(PGs) outperformed S1(individuals) on financial impact (+78% change from baseline for S2.A5 compared with +72% for S1.A5). S2(PGs) and S3(POs) also showed larger financial

[35] To model this, the time taken to adjust to market signals was reduced by 25% and the effect of change, i.e., the increase in production or number of producers upgrading, was increased by 25% for a scenario of increasing responsiveness. For a scenario of decreasing producer responsiveness, time was increased by 25% and the effect of change was decreased by 25%.

gains compared to S1(individuals) than in the baseline model. This can be explained by the increased pace at which producers within PGs/POs transitioned to the most profitable system, hybrid FF, as well as the dropout rates, which were lower for PG and PO members. For example, when the responsiveness of producers to market signals is increased, in S3(POs) there were 568 producers in the PG hybrid FF system in the mid-point of the model compared with 447 in the baseline model simulation. Furthermore, in this alternative scenario, in S1(individuals) the number of hybrid FF producers reached 445 with a dropout rate of 20% per annum; by contrast, the dropout rate of hybrid FF producers in S3(POs) in the alternative scenario was 1.3%.

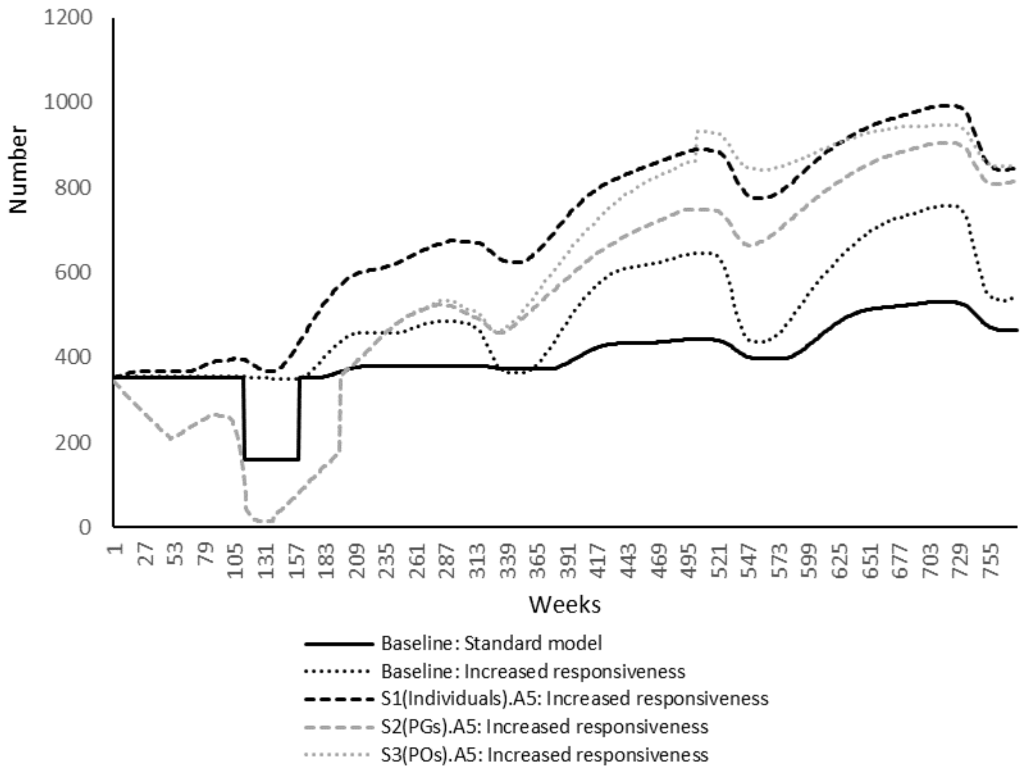

Figure 41: Comparison of number of pig producers in highly profitable systems in standard model and increased responsiveness alternative scenario
Source: Pork VC model simulation

In terms of the rank order of technical upgrading activities, increasing responsiveness to markets signals had one main consequence: the relative impact of microcredit across both outcome indicators dropped one or two priority levels. In the baseline model simulation, microcredit encouraged faster upgrading because it lowered the entry costs of engagement in higher value pig enterprises. As a result, when producers naturally respond faster and at a higher magnitude to perceived profitability, the effect of microcredit is reduced. Volatility was also responsible for the diminished effect of microcredit because increasing the number of failed upgrades reduced the available loan capital, lessening the systematic impact of microcredit. For example, in the standard simulation, in S1(individuals).A1 the available loan credit is US$133,000 by the end of fifteen years; however, this falls to US$82,300 in S1(individuals).A1 in this alternative scenario.

Reducing the rate of producer responsiveness to market signals did not alter the results of the model in terms of the rank order of the financial impact of the three scenarios. From the standpoint of the number of producers in highly profitable systems the rank order was slightly changed in that S2(PGs) and S3(POs) had greater impacts on producer numbers than S1(individuals) in the short-term. This is owing to the 640 producers that enter the PG and PO, out of which 109 upgraded to the hybrid FF system after five years. Regarding technical upgrading activities, decreasing the responsiveness rate increased the impacts of microcredit, which moved up the priority ranking in all scenarios and timelines by at least one place. This is understandable when considering the results of the increased responsiveness scenario, as essentially the opposite reaction is in effect, namely, the ability of microcredit to improve the system is higher when starting from a base of lower responsiveness.

5.7.1.6 African swine fever outbreak

The presence of African swine fever (ASF) in the TRRILD project's target region was considered a high likelihood given the ASF outbreak across Southeast Asia and Myanmar in 2019 (FAO, 2020). At the time of developing the model, a small ASF outbreak was present in northern Myanmar and yet to impact the target villages. As a result, an *ex-ante* ASF scenario was simulated in the model, using parameters provided by livestock specialists within the RG, to determine the potential impacts on the TRRILD target villages and possible changes to the rank order of institutional scenarios and technical upgrading activities. In the ASF scenario, the training and AHW activities were merged into a comprehensive biosecurity intervention (A2). This modelled the training of pig producers in biosecurity practices by the TRRILD project team and the coordination and implementation of biosecurity measures by village AHWs and pig producers. The model assumed biosecurity practises were adopted as per the VietGAHP[36] 2016 guidelines (Nguyen et al., 2019) and FAO criteria (2010), with full implementation reducing pig losses from ASF by up to 80%. These biosecurity interventions ensured:

I. Swill feed does not contain pork and is boiled for 30 minutes prior to feeding.

II. Perimeter double fencing is established for pig sties and minimum contact occurs between pigs.

[36] The 2016 VietGAHP guidelines were adapted by the TRRILD project for pig production trainings and as minimum quality standards for PG/PO members.

III. Equipment is cleaned and disinfected at least three times per week. All incoming vehicles and pigs are washed and disinfected outside of the perimeter fence.

IV. Entry to pig farms is controlled. Vehicles and personnel, including AHWs, are disinfected on entering and leaving farms. Footbaths are installed at the entrance and exit of farms. Pig-loading and off-loading is done outside perimeter fences. All replacement breeding stock comes from trusted sources.

V. All dead animals, effluent, and discarded pig parts are burned and buried away from perimeter fences.

VI. Animals showing signs of illness are isolated immediately and the AHW and LBVD office informed.

VII. Mites are controlled through cutting back any vegetation from around pig houses.

The RG provided the additional model parameters for the ASF scenario based on their estimates of a worst-case ASF scenario in the target villages. The costs of biosecurity measures are estimated as a one-off cost of US$34 per WF Unit and US$34 per Sow per FF Unit, and an ongoing cost of US$0.66 (MMK1,000) per grower. The ongoing costs are similar to Ouma et al.'s (2018) estimation of 2625 Uganda Shillings (equivalent to MMK942). In this simulation, the ASF outbreak caused a four-fold increase in mortality (60%) and panic selling (20%) of fatteners per week compared with the baseline disease scenario. The ASF outbreak began after three years of project implementation (week 156) and lasted for six months with the government imposing a strict importation ban. Consumer demand for local and premium pork dropped by 70% during this period. Taking into consideration the fear associated with ASF, producers are 25% more responsive to market signals during the ASF outbreak. The regular disease outbreaks that were part of the standard model run continued in the ASF scenario with a second ASF outbreak occurring seven years after the first outbreak (i.e., at week 560).

As shown in Tables 23 and 24 ASF outbreaks could have a large impact in the target area without any project interventions. In comparison with data from the standard model baseline, two years following the first ASF outbreak (i.e., in the short-term) the target community lost 52% of their earnings from pig farming. These losses were slowly reclaimed by pig producers, but aggregate profits were still 29% lower than the baseline model prior to the second ASF outbreak. The number of highly profitable pig farmers also fell by 63% post-outbreak and did not fully recover (-25%) before the next outbreak occurred or by the end of the model (-41%). Correspondingly, the total number of pig farmers fell to 680 by the end of the ASF outbreak scenario compared with 1,161 in the baseline model. Other pork VC actors (slaughterhouses, brokers, and employees) lost around a third of their income as a result of ASF.

Table 23: Results of ASF alternative scenarios on aggregate profits of all pig producers

Scenario	*Short-term*			*Medium-term*			*Long-term*		
	US$	Change (%)[a]	Rank[b]	US$	Change (%)	Rank	US$	Change (%)	Rank
Baseline: Disease	842,295			1,866,956			3,043,266		
Baseline: ASF outbreak	401,177	-52		1,325,393	-29		1,862,715	-39	
Scenario One: Individual Producers and ASF									
S1.A1: Microcredit $150K	573,486	+43	3	1,150,238	-13	3	1,458,516	-22	3
S1.A1.2: Microcredit $300K	672,217	+68	(4)[c]	999,860	-25	(4)	1,251,237	-33	(4)
S1.A2: Biosecurity	976,952	+144	1	2,163,755	+61	1	3,143,634	+56	1
S1.A4: AI	463,054	+15	2	1,356,512	+2	2	1,936,144	+4	2
S1.A5: Combination[d]	*1,198,247*	*+199*	*1*	*2,503,514*	*+89*	*3*	*3,770,806*	*+102*	*3*
Scenario Two: Producer groups and ASF									
S2.A1: Microcredit $150K	295,378	-26	2	1,535,276	+16	2	2,224,667	+19	2
S2.A1.2: Microcredit $300K	360,194	-10	(2)	1,752,904	+32	(2)	2,759,177	+48	(2)
S2.A2: Biosecurity	565,780	+41	1	2,241,898	+69	1	4,664,053	+150	1
S2.A4: AI	248,049	-38	3	1,363,685	+3	3	2,145,941	+15	3
S2.A5: Combination	*738,431*	*+84*	*3*	*2,044,762*	*+114*	*2*	*6,299,043*	*+238*	*2*
Scenario Three: Producer organisations and ASF									
S3.A1: Microcredit $150K	309,509	-23	2	2,000,210	+51	1	3,199,039	+72	2
S3.A1.2: Microcredit $300K	375,956	-6	(2)	2,267,309	+71	(2)	3,484,176	+87	(2)
S3.A2: Biosecurity	568,575	+42	1	3,009,714	+127	1	8,558,098	+359	1
S3.A4: AI	250,426	-38	3	1,743,761	+32	3	2,813,527	+51	3
S3.A5: Combination	745,336	+86	2	3,716,863	+180	1	10,174,486	+446	1

Note: [a] Percentage change from the baseline. [b] Rank for the combined activities compares S1, S2, and S3. [c] Value in parentheses denotes that ranking of the sub activity A1.2. [d] Combination refers to A1 + A2 + A3 + A4, where A1 is microcredit capped at $150K.

Source: Pork VC model simulation

In the ASF alternative scenario, there were no substantial changes to the rank order of intervention scenarios for the project's impacts on aggregate profits of all pig producers. In terms of differences from the baseline model, the combination of the project's interventions had a more robust impact when there was an ASF outbreak. This was particularly evident in S2(PG) and S3(POs), in which the financial impacts of the project during an ASF outbreak were 80% (S2) and 67% (S3) higher than the baseline model run, compared with 30% for S1(individuals). This adds further support to earlier findings that PGs and POs can act as a safety net by helping small-scale producers maintain pig stocks to take advantage of price rebounds post-disease. When there is an ASF outbreak, collective action enabled the number of producers in highly profitable systems in S2(PGs) and S3(POs) to remain higher than in S1.A5. This was a change from the baseline model run where S1(individuals) outperformed S2(PGs) across all timelines and S3(POs) in the short-term.

Table 24: Results of ASF alternative scenarios on the number of pig producers in highly profitable systems

Scenario	*Short-term*			*Medium-term*			*Long-term*		
	Number	Change (%)[a]	Rank[b]	Number	Change (%)	Rank	Number	Change (%)	Rank
Baseline: Disease	379			441			464		
Baseline: ASF outbreak	138	-63		330	-25		274	-41	
Scenario One: Individual Producers and ASF									
S1.A1: Microcredit $150K	74	-46	3	79	-76	3	51	-81	3
S1.A1.2: Microcredit $300K	11	-92	(4)[c]	67	-80	(4)	44	-81	(4)
S1.A2: Biosecurity	244	+76	1	338	+2	1	251	-8	1
S1.A4: AI	143	+3	2	146	-56	2	109	-60	2
S1.A5: Combination[d]	227	+64	3	374	+13	2	276	+1	3
Scenario Two: Producer groups and ASF									
S2.A1: Microcredit $150K	70	-50	2	277	-16	2	140	-49	3
S2.A1.2: Microcredit $300K	69	-69	(4)	255	-23	(4)	196	-28	(2)
S2.A2: Biosecurity	210	+51	1	283	-14	1	400	+46	1
S2.A4: AI	71	-58	3	263	-20	3	166	-39	2
S1.A5: Combination	249	+80	2	370	+12	3	495	+81	2
Scenario Three: Producer organisations and ASF									
S3.A1: Microcredit $150K	70	-50	3	391	+18	2	261	-5	2
S3.A1.2: Microcredit $300K	69	-50	(4)	384	+16	(3)	252	-8	(3)
S3.A2: Biosecurity	211	+52	1	442	+34	1	593	+117	1
S3.A4: AI	71	-48	2	372	+13	3	243	-11	4
S3.A5: Combination	250	+80	1	504	+53	1	671	+145	1

Note: [a] Percentage change from the baseline. [b] Rank for the combined activities compares S1, S2, and S3. [c] Value in parentheses denotes that ranking of the sub activity A1.2. [d] Combination refers to A1 + A2 + A3 + A4, where A1 is microcredit capped at $150K.

Source: Pork VC model simulation

Implementing biosecurity protocols had a considerably stronger impact than other technical activities regardless of the scenario or time horizon. In the ASF outbreak scenario, a singular focus on providing microcredit to individual pig farmers resulted in long-term negative impacts. In S1(individuals).A1 increasing access to microcredit encouraged more pig producers to upgrade to higher profit but higher risk systems. When ASF outbreaks occurred, these producers were forced to abandon pig farming as a livelihood and default on loans given their high debt levels. After the first ASF outbreak, available loan capital plummeted from US$150,000 to US$15,997, and thus kneecapped further recovery. The greater the stock of microcredit the larger the negative impacts, as more pig producers were encouraged to upgrade and, subsequently, became susceptible to farm failure.

In S2(PGs).A1 and S3(POs).A1, microcredit delivered negative short-term but positive medium- and long-term financial benefits. However, it had associated negative consequences on the number of farmers in highly profitable systems. Microcredit in S2(PGs).A1 and S3(POs).A1 enabled farmers to upgrade to the highly profitable hybrid FF systems, though ASF and other disease outbreaks meant they regularly failed and consequently returned to WF systems. Even when biosecurity, microcredit, and AI were jointly implemented (i.e., A5), ASF still brought noticeable disruption to PGs and POs. In

S2(PGs).A5, 13% of PG members left the PG for a year or more after ASF occurred, with the number reducing to 7% of PO members in S3(POs).A5. If biosecurity protocols were not implemented by PG/PO members and premiums for high-quality fatteners were not forthcoming, these dropout rates further increased to 46% (S2) and 40% (S3) for hybrid FF farmers and 20% for hybrid WF (S2 and S3), which would seriously compromise PG and PO sustainability.

The ASF scenario contained a static outbreak start time and fixed length. To understand the impacts of temporal variations to an ASF outbreak, the ASF scenario was re-simulated with the outbreak starting one year earlier, one year later, and two years later, randomly assigning the ASF start times as well as randomly assigning the length of the outbreak to between 10 and 52 weeks. In general, altering the timing and length of the ASF outbreak brought slightly stronger negative financial and pro-poor impacts to pig producers, as illustrated in Tables 25 and 26. The scenario with a two-year delay had the largest shift and was selected as an alternative ASF scenario to understand temporal impacts on the project's institutional and technical upgrading activities. The results comparing the ASF outbreak and delaying the outbreak by two years on the rank order of upgrading interventions are found in Appendix D, Tables D.11 and D.12. These results reinforce the key findings of the ASF scenario: biosecurity activities have a strongly positive impact that is magnified when combined with other technical interventions. However, delaying the start time of the ASF outbreak brought some changes to the rank order of institutional scenarios. In the short-term, S2(PGs) outperformed S3(POs) in financial and pro-poor outcomes. This is because the ASF outbreak occurs at year five (i.e., when the short-term values are extracted from the model) and therefore investments in additional biosecurity measures for PO members have not been realised yet. The delay in the ASF outbreak allows higher numbers of pig producers to successfully pay back upgrading loans in S1(individual).A1 and leads to improved performance for microcredit. In S2(PGs).A1 and S3(POs).A1, microcredit encourages PG and PO members to continually upgrade from WF to FF systems and hence they are susceptible to ASF shocks and as such microcredit's rank order drops in these two institutional scenarios.

Table 25: Comparison of changing ASF outbreak timing and length on aggregate profits of all pig producers

Scenario	*Short-term*		*Medium-term*		*Long-term*	
	US$	Change (%)[a]	US$	Change (%)	US$	Change (%)
Baseline: Disease	842,965		1,866,956		3,043,266	
Baseline: ASF outbreak	401,177	-52	1,325,393	-29	1,862,715	-39
Baseline: - 52 weeks	298,446	-65	992,571	-47	1,630,635	-46
Baseline: + 52 weeks	678,346	-20	1,223,025	-34	1,791,792	-41
Baseline: + 104 week	842,965	0	1,203,111	-36	1,575,269	-48
Baseline: + random assignment	323,953	-62	970,912	-48	1,592,240	-48

Note: [a] Percentage change from the baseline.

Source: Pork VC model simulation

Table 26: Comparison of changing ASF outbreak timing and length on number of pig producers in highly profitable systems

Scenario	*Short-term*		*Medium-term*		*Long-term*	
	Number	Change (%)[a]	Number	Change (%)	Number	Change (%)
Baseline: Disease	379		441		464	
Baseline: ASF outbreak	138	-64	330	-25	274	-43
Baseline: - 52 weeks	110	-71	110	-75	233	-52
Baseline: + 52 weeks	347	-8	294	-33	187	-63
Baseline: + 104 week	379	0	105	-76	112	-80
Baseline: + random assignment	99	-74	99	-78	239	-51

Note: [a] Percentage change from the baseline.
Source: Pork VC model simulation

5.7.1.7 Alternative microcredit products

The lending parameters of the TRRILD project's partner MFI are derived from both internal company rules and external regulations governed by the Government of Myanmar's (GoM) microfinance law. While interest rate terms are capped at 2.46% per month by the GoM, the lending term of six to 24 months is applied at the discretion of the MFI. RG and SGMB participants reported that the partner MFI's loan officers routinely offer short loan cycles to new clients to establish credit histories before lengthening the loan term in subsequent loan cycles. The model was simulated with a range of loan conditions within the bounds of the partner MFI's and the GoM's rules and regulations to determine the extent of their financial and pro-poor impacts on the system.

As shown in Tables 27 and 28 extending the terms for loans provided greater financial and pro-poor impact across all scenarios and timelines. While longer loan terms for amortised loans resulted in higher total interest payments, this was offset by increasing the medium-term profitability of higher-risk enterprises, which encouraged more producers to upgrade and as such increased the overall profits in the system. From the worst- (six-months) to best-case (24 months) scenario for loan terms, system profits doubled. Interestingly, the shortest loan term of six-months performed worse in pro-poor impact than the baseline of no microcredit in S1(individuals) and S2(PGs). In these scenarios, the higher interest/longer loan terms of informal moneylenders proved superior to the lower interest/shorter loan term from the partner MFI in enabling farmers to upgrade to the local FF system. This is because production cycles of local breed fatteners (one production cycle per year) exceeded the MFI's six-month loan term.

Findings from the baseline model simulation showed prolonged periods of negative cashflow and profitability when pig producers take on microcredit loans to upgrade to more profitable pig enterprises. This was most visible in the early stages of S2(PGs) and S3(POs) because all PG and PO members accessed microcredit loans to upgrade to high-quality systems at one time.

Table 27: Comparison of the aggregate profits of all pig producers under different microcredit loan terms

Scenario	*Short-term*		*Medium-term*		*Long-term*	
	US$	Change (%)[a]	US$	Change (%)	US$	Change (%)
Baseline	842,965		1,866,956		3,043,266	
Scenario 1: Individual producers						
Scenario 1.A5: 6 months	1,459,331	+51	3,128,003	+68	4,818,710	+58
Scenario 1.A5: 12 months (standard)	1,382,303	+64	3,214,879	+72	5,441,792	+79
Scenario 1.A5: 24 months	1,344,872	+60	3,628,301	+94	6,851,573	+125
Scenario 2: Producer Groups						
Scenario 2.A5: 6 months	924,485	+10	2,782,685	+49	4,930,938	+62
Scenario 2.A5: 12 months (standard)	1,022,314	+21	3,199,340	+71	7,063,532	+132
Scenario 2.A5: 24 months	1,018,533	+21	3,801,911	+104	9,028,524	+197
Scenario 3: Producer Organisations						
Scenario 3.A5: 6 months	929,135	+10	3,353,464	+80	7,379,768	+142
Scenario 3.A5: 12 months (standard)	1,026,598	+21	4,033,651	+116	11,205,559	+268
Scenario 3.A5: 24 months	1,023,598	+21	4,983,556	+167	13,260,683	+336

Note: [a] Percentage change from the baseline.
Source: Pork VC model simulation

Table 28: Comparison of the number of producers in highly profitable systems under different microcredit loan terms

Scenario	*Short-term*		*Medium-term*		*Long-term*	
	Number	Change (%)[a]	Number	Change (%)	Number	Change (%)
Baseline	379		441		464	
Scenario 1: Individual producers						
Scenario 1.5: 6 months	352	-7	352	-20	352	-24
Scenario 1.5: 12 months (standard)	480	+26	639	+45	710	+53
Scenario 1.5: 24 months	692	+82	972	+120	1,037	+123
Scenario 2: Producer groups						
Scenario 2.5: 6 months	343	-10	378	-14	449	-3
Scenario 2.5: 12 months (standard)	397	+5	542	+23	704	+52
Scenario 2.5: 24 months	483	+5	732	+66	848	+83
Scenario 3: Producer Organisations						
Scenario 3.5: 6 months	343	-10	399	-9	882	+90
Scenario 3.5: 12 months (standard)	399	+27	684	+55	874	+89
Scenario 3.5: 24 months	484	+5	794	+80	877	+88

Note: [a] Percentage change from the baseline.
Source: Pork VC model simulation

However, the same negative cashflows occurred throughout S1(individuals) and in later stages of S2(PGs) and S3(POs) but are masked due to the aggregate nature of the model's data. To test the effect of loan terms and interest payment schedules on profitability and cashflows, a simple model of an individual hybrid FF producer was constructed in Stella Architect using static parameters derived from averages across the first three years of the pork VC SD model. In the individual model, the hybrid FF producer purchases two breeding sows and constructs improved shelter using a loan from the partner MFI. As per the baseline model, 50% of piglets are sold and the rest raised as fatteners for market. The TRRILD partner MFI had three possible loan products available: (i) amortised; (ii) balloon; and (iii) deferred payment loan. The amortised loan product consisted of equal payments across the lifetime of the loan period. The balloon loan on offer required regular interest payments on the outstanding principal which is paid at the end of the loan period. In the deferred payment loan both principal and accrued interest are paid at the end of the loan period. These loans can be applied to fund assets (in this case the initial establishment of the hybrid FF unit) or for working capital (i.e., a production loan to fund ongoing costs, such as feed, vaccinations, maintenance, etc.). The loan terms were six to 24 months for asset loans and four to 18 months for working capital loans. Different types of loan products have been shown to impact liquidity and overall profitability of farm enterprises (Finnemore et al., 2010). To test this, the three loan products[37] were introduced to the individual hybrid FF model through an asset loan of US$1,279 for 24 months to purchase two high-quality sows and related equipment and two back-to-back working capital loans[38] of US$1,333 for 18 months.

The three microcredit products had different impacts on hybrid FF farm profitability as shown in Figure 42. Reflecting findings from the baseline model, the amortised loan resulted in liquidity stress for the individual hybrid FF pig producer. This stress lasted for 67 weeks, with the pig producer requiring US$1,315 of additional capital to cover loan repayments and ongoing costs. If these periods of negative cashflow can be managed, amortised loans offered pig farmers the greatest profit after three years of US$2,349. In comparison, the balloon loan reduced periods of negative cashflow to around five weeks during the first year of operation, though cash requirements were still significant with a peak of US$368. The deferred payment loan was able to fully insulate pig producers from liquidity stress, showing a minimum available balance of US$250. Both the balloon and deferred loan lowered the profitability of the farm enterprise to US$1,410 and US$1,429 which was 40% less than the amortised loan.

Further options were simulated in the individual hybrid FF model to ascertain their ability to limit liquidity stress. Selling a higher rate of piglets brought revenue sooner into the business at the cost of lower and delayed profits. With an amortised loan, increasing the piglet selling rate to 80% relieved liquidity stress by around 50% (US$714 of additional capital was still required) but dampened short-term profits by 3% after three years (US$2,445). For the balloon loan, increasing piglet sales to 80% fully alleviated liquidity stress but with a subsequent 5% drop in profits. The other option modelled was to take out a higher amount for the working capital loan. If the working capital loan amount is increased to the maximum rate of US$2,000, it worsened the liquidity stress for amortised loans but fully alleviated negative cashflows for balloon loan recipients. However, the larger balloon loan amounts impinge on profits, reducing three-year income to US$944, a drop of 38%.

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[37] Parameters for three loan products is based on the TRRILD partner MFI's lending practices.
[38] Maximum working capital amount is US$2,000 for the first cycle of the loan as per MFI rules.

Altering the duration of loan terms also changed the liquidity stress of individual FF pig producers. When loan terms for asset and working capital were reduced to 52 weeks, cashflow problems are greatly magnified. Deficits peaked at US$2,177 for amortised loans, US$1,230 for balloon loans, and US$1,227 for the deferred loan. Altering the piglet selling rate to 80% does not alter the liquidity stress with such a short loan term, regardless of loan type.

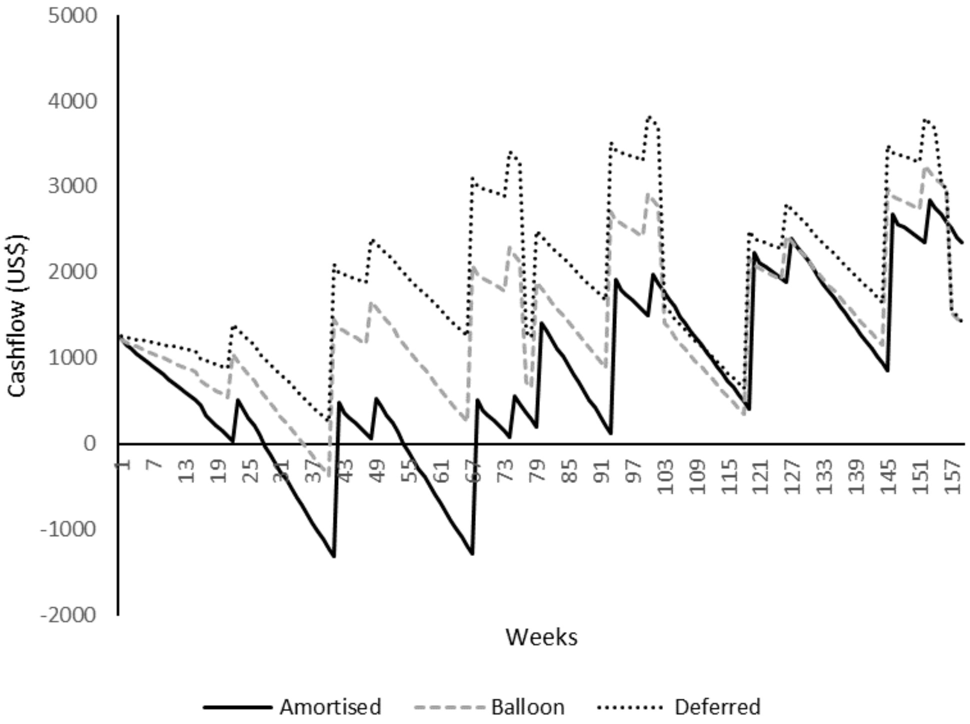


Figure 42: Aggregate profits of an individual hybrid FF producer in the first three years of operations
Source: Individual hybrid FF model simulation

5.7.2 Parameter sensitivity analysis

A multi-variate parameter SA was performed to understand whether conclusions from the model were valid when assumptions were altered over a plausible range of uncertainty (Sterman, 2010, p.883). The first step in the process was undertaken by SGMB, RG, and PAC members who selected exogenous model parameters that were both highly uncertain and had a strong likelihood of influencing the model's results (Sterman, 2010, p.884). SGMB, RG, and PAC members then helped determined the plausible range of these values. In this set of SA tests, a triangular distribution was selected for parameters where RG and SGMB could recall historical minimum and maximum values which were used for the lower and upper bounds, with the value used in scenario testing remaining as the mean. Triangular distributions are recommended for use within SA of SD models by Ford (2010) and are of particular value when the mean and upper and lower limits are known but there is data scarcity on the shape of the distribution (Thomopoulos, 2017). When historical data indicated equally likely values, a uniform distribution was used with the upper and lower values decided by

SGMB, RG, and PAC (Green, 2018). Uniform distributions are commonly used within SA of agri-food SD models (see Dizyee et al., 2017 and Ouma et al., 2018). For parameters without real-world equivalency, such as price elasticity for demand, ±50% from the original value were used as bounds for the uniform distribution. As illustrated in Table 29, bounds for parameter SA were weighted towards a worst-case scenario given the desire to "bullet proof" project upgrading strategies against potential negative events and to counter-act the tendency for SGMB, RG, and PAC participants to be overly optimistic with critical model variables (Ford, 2010; Sterman, 2010). For example, when KIIs reported a 35% premium for high-quality pork cuts for the Yangon market, a lower bound of 10% and an upper bound of 40% were selected to weight towards worst-case scenarios.

Table 29: Parameters for the multi-variate sensitivity analysis

Parameter	***Base Value***	***Unit***	***Ranges of Uncertainty***
Death rate	0.15	Proportion	Triangular (0.05, 0.3)
Panic selling rate	0.05	Proportion	Triangular (0.025, 0.3)
Length of disease outbreak	26	Weeks	Triangular (10, 52)
Consumer change in pork demand due to disease	-0.3	Proportion	Triangular (-0.1, -0.6)
Change in pork demand during Chinese New Year	0.2	Proportion	Triangular (0.1,0.5)
Sensitivity of Myeik price to inventory coverage	-0.1	n.a	Uniform (-0.05, -0.15)
Sensitivity of Mawlymine price to inventory coverage	-0.05	n.a	Uniform (-0.025, -0.075)
Price elasticity of demand	-0.5	n.a	Uniform (-0.25, -0.75)
Money lender interest rate	0.05	Percentage/month	Triangular (0.04, 0.075)
Time to fatten hybrid pigs	19.3	Weeks	Triangular (17.4, 20)
Slaughterhouse production costs	8.82	US$/pig	Uniform (6.15, 11.0)[a]
Premium for high-quality wholesale pork in Myeik	10	Percent	Uniform (1, 15)
Premium for high-quality pork cuts in Myeik	15	Percent	Uniform (5, 20)
Premium for high-quality pork cuts in Yangon	35	Percent	Uniform (10, 40)

Note: [a] For the PO slaughterhouse's production costs a uniform distribution was used with ± of 25% as the maximum and minimum variables for key input costs exogenous to the model.
Source: Pork VC model simulation

In total, 14 parameters were selected for multi-variate SA performed through Monte Carlo simulations in Stella Architect, using a Latin hypercube sampling (LHS) methodology. The LHS technique has been shown as an efficient method for testing SD models (Ford & Flynn, 2005). When compared to random sampling or stratified sampling, LHS was found as the most efficient design for models with large numbers of uncertain variables (McKay et al., 1979), reducing the required sample size by a factor of ten (Reilly et al., 1987). The SD literature has proposed different sample sizes for the LHS methodology; however, there is no widely acknowledged method for determining the sample size required for LHS (Matala, 2008). In a study using SD modelling to investigate policy options for a regional electric system Ford (1990) found a sample of 40 simulations (with 150 uncertain variables) produced similar uncertainty intervals as doubling the LHS sample to 80 simulations. Following on from this study, Ford (2010) suggests a pragmatic solution to ascertaining the correct sample size for LHS is to double the sample size during SA to check whether uncertainty intervals are altered. McKay (1988) suggested the sample for LHS should be twice the size as the number of uncertain variables, while Manache and Melching (2007) found that 4/3 times the number of uncertain input variable was sufficient to identify sensitive parameters. In a recent study, Kwakkel and Pryut (2015) used a 1000 runs in their LHS within a SD model to determine uncertainties related to the availability of minerals crucial for economic development of nations. Following this recent example and Ford's (2015) suggestion, this research selected a sample size of 1000 for LHS and halved (i.e., 500 runs) and doubled (i.e., 2000 runs) the sample size to check for changes in values of indicator means, coefficient of variation and ultimately, the rank order of institutional and technical upgrading scenarios.

Analysis of the results of the multi-variate SA included calculations of mean, quartiles, minimum and maximum values, standard deviation, confidence intervals, coefficients of variation, and plotting the histograms of the distributions. The multi-variate SA undertaken through a Monte Carlo simulation produced results for the two outcome indicators consistent with a normal distribution, with some minor skewness. The histograms and box plots for the two outcome indicators for S1(individuals, S2(PGs), and S3(POs) are found in Appendix E.

The results of the multi-variate SA support the model's findings regarding financial and pro-poor impacts of the institutional scenarios and technical upgrading activities. The results for the 1000 run multi-variate SA are presented in Tables 30, 31, 32, and 33. The multi-variate SA reduced the mean baseline values for the two outcome indicators by around 10%, which is expected given the weighting in the probability distributions towards worst-case scenarios. As shown in Table 30, the SA ranking of the three scenarios on the aggregate profits of all pig producers did not change. However, the weighting towards worst-case scenarios in SA brought a small delay to the impacts of PG and PO investments in transitioning producers to highly profitable systems. As Table 31 shows, when uncertainty is factored in, S1(individuals).A5 had the broadest pro-poor impact in the short- and medium-term, with S3(POs).A5 eventually delivering the highest impacts in the long-term. The co-efficient of variation (CV) included in Tables 30 and 31 reveals an acceptable level of variation for the institutional scenarios and show that the upgrading interventions reduce risk relative to the baseline. This is also reflected in the strengthening of the project's impacts (in terms of % change from the baseline value) across all three institutional scenarios. S1(individuals).A5 had larger gains in the SA compared to S2(PGs).A5 and S3(POs).A5 though these were not sufficient to disrupt the rank order of institutional scenarios. While the CVs of S1(individual).A5 are the lowest, S2(PGs).A5 and S3(POs).A5 have similar CVs, indicating that greater investments in producer institutions that can invest in value-adding assets bring greater pro-poor and financial impacts at similar risk levels to more modest investments in producer groups that provide transactional services.

The results of the multi-variate SA further strengthen the case for prioritising the technical activities of A1: Microcredit and A3: AHWs. As illustrated in Table 32 and Table 33, any changes in the rank order of upgrading activities across both indicators were a result of improving impacts of A1: Microcredit and A3: AHWs compared with A2: Training and A4: AI. The results of the SA also confirmed the importance of multiple intertwined activities. As shown in Tables 32 and 33, in S2(PGs) and S3(POs), the negative impacts of implementing individual technical activities were more significant in SA; however, the combination of technical activities produced stronger results. For example, in S2(PGs) adding percentage effects from isolated activities in the short-term showed a combined change of -29% from the baseline in terms of producer profits but the effect reverses to a +25% change when activities are implemented simultaneously in S2.A5.

The findings of the SA remained consistent when undertaking LHS with sample sizes of 500 and 2000 runs as shown in Tables B.13 to B.18 found in Appendix F. The mean values of SA differed by less than 1.2% across the SA runs of 500, 1000, and 2000 simulations. The slight change in means resulted in a two minor rank order shifts (see Tables F5 and F6); however, these did not signal any changes to the model's recommendations.

Table 30: Multi-variate sensitivity analysis: Comparison of the aggregate profits of all pig producers across institutional scenarios

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	ST US$	ST Rank	SA US$ (CV) 95% CI [LL, UL]	SA Rank	ST US$	ST Rank	SA US$ (CV) 95% CI [LL, UL]	SA Rank	ST US$	ST Rank	SA US$ (CV) 95% CI [LL, UL]	SA Rank
Baseline	842,965		768,254 (19%) [758,978, 771,531]		1,866,956		1,684,115 (20%) [1,663,177, 1,705,053]		3,043,266		2,702,188 (25%) [2,662,190, 2,742,185]	
S1.A5: Combination	1,382,303	1	1,365,197 (8%) [1,358,770, 1,371,624]	1	3,214,879	2	3,218,349 (11%) [3,195,992, 3,240,707]	2	5,441,792	3	5,411,166 (15%) [5,361,371, 5,460,960]	3
S2.A5: Combination	1,022,314	3	959,624 (14%) [951,376, 967,871]	3	3,199,340	3	3,093,090 (16%) [3,062,508, 3,123,672]	3	7,063,532	2	6,636,282 (20%) [6,552,773, 6,719,790]	2
S3.A5: Combination	1,026,296	2	967,945 (14%) [959,672, 976,217]	2	4,033,651	1	3,596,168 (18%) [3,555,200, 3,637,136]	1	11,205,559	1	9,467,633 (24%) [9,327,316, 9,607,949]	1

Note: ST denotes results from scenario testing. SA provides the mean value from sensitivity analysis. Coefficients of variation (CV) are provided in brackets. LL represents the lower limit and UL represents the upper limit of the 95% confidence interval (CI).

Source: Pork VC model simulation

Table 31: Multi-variate sensitivity analysis: Comparison of the number of pig producers in highly profitable systems across institutional scenarios

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	ST Number	ST Rank	SA Number (CV) 95% CI [LL, UL]	SA Rank	ST Number	ST Rank	SA Number (CV) 95% CI [LL, UL]	SA Rank	ST Number	ST Rank	SA Number (CV) 95% CI [LL, UL]	SA Rank
Baseline	379		340 (22%) [406, 409]		441		396 (20%) [391, 401]		464		388 (26%) [382, 395]	
S1.A5: Combination	480	1	485 (8%) [482, 487]	1	639	2	639 (11%) [635, 644]	1[c]	710	2	652 (12%) [647, 657]	2
S2.A5: Combination	397	3	373 (10%) [370, 375]	3	542	3	508 (16%) [503, 513]	3	704	3	629 (16%) [623, 635]	3
S3.A5: Combination	399	2	374 (11%) [372, 377]	2	684	1	590 (17%) [584, 596]	2[d]	877	1	765 (15%) [758, 772]	1

Note: ST denotes results from scenario testing. SA provides the mean value from sensitivity analysis. Coefficients of variation (CV) are provided in brackets. LL represents the lower limit and UL represents the upper limit of the 95% confidence interval (CI). [c] indicates rankings that have improved in the SA compared with the baseline model run. [d] indicates rankings that have worsened in the SA compared with the baseline model run.

Source: Pork VC model simulation

Table 32: Multi-variate sensitivity analysis: Comparison of the aggregate profits of all pig producers across technical upgrading activities

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	ST US$	ST Rank	SA US$	SA Rank	ST US$	ST Rank	SA US$	SA Rank	ST US$	ST Rank	SA US$	ST Rank
Baseline	842,965		768,254		1,866,956		1,684,115		3,043,266		2,702,188	
Scenario 1: Individual producers												
S1.A1: Microcredit $150K	1,087,576	1	1,050,763	1	2,380,011	1	2,287,546	1	3,940,949	1	3,707,147	1
S1.A1.2: Microcredit $300K	1,261,361	(1)[a]	1,243,903	(1)	2,877,423	(1)	2,792,792	(1)	4,897,681	(1)	4,638,498	(1)
S1.A2: Training	945,149	3	865,292	3	2,089,817	3	1,923,978	3	3,452,985	2	3,122,299	3[d]
S1.A3: AHWs	975,574	2	924,813	2	2,139,809	2	2,053,378	2	3,420,022	3	3,283,421	2[c]
S1.A4: AI	919,824	4	841,039	4	2,027,026	4	1,874,430	4	3,353,877	4	3,024,807	4
S1.A5: Combination	1,382,303		1,365,197		3,214,879		3,218,349		5,441,792		5,411,166	
Scenario 2: Producer groups												
S2.A1: Microcredit $150K	830,903	1	756,258	1	2,171,795	2	2,046,108	1[c]	4,021,996	3	3,744,576	2[c]
S2.A1.2: Microcredit $300K	917,148	(1)	858,844	(1)	2,475,852	(1)	2,379,672	(1)	4,692,074	(1)	4,500,663	(1)
S2.A2: Training	800,067	3	697,972	3	2,141,964	3	1,953,724	3	4,062,055	2	3,681,166	3[d]
S2.A3: AHWs	819,634	2	728,279	2	2,210,552	1	2,025,130	2[d]	4,103,582	1	3,792,198	1
S2.A4: AI	769,025	4	671,354	4	2,044,762	4	1,857,094	4	3,812,834	4	3,018,444	4
S2.A5: Combination	1,022,314		959,624		3,199,340		3,093,090		7,063,532		6,636,282	
Scenario 3: Producer organisations												
S3.A1: Microcredit $150K	835,051	1	764,251	1	2,754,206	2	2,404,078	2	6,835,205	4	5,502,402	3[c]
S3.A1.2: Microcredit $300K	921,469	(1)	866,263	(1)	3,145,440	(1)	2,781,791	(1)	7,730,822	(2)	6,363,430	(2)
S3.A2: Training	804,249	3	705,498	3	2,754,454	3	2,319,272	3	7,153,488	2	5,557,582	2
S3.A3: AHWs	823,966	2	736,393	2	2,955,368	1	2,484,295	1	8,166,828	1	6,373,854	1
S3.A4: AI	773,044	4	679,591	4	2,658,302	4	2,204,966	4	6,890,234	3	5,267,707	4[d]
S3.A5: Combination	1,026,296		967,945		4,033,651		3,596,168		11,205,559		9,467,633	

Note: ST denotes results from scenario testing. SA provides the mean value from sensitivity analysis. Coefficients of variation (CV) are provided in brackets. LL represents the lower limit and UL represents the upper limit of the 95% confidence interval (CI). [a] value in parentheses denotes that ranking of the sub activity A1.2.). [c] indicates rankings that have improved in the SA compared with the baseline model run. [d] indicates rankings that have worsened in the SA compared with the baseline model run.

Source: Pork VC model simulation

Table 33: Multi-variate sensitivity analysis: Comparison of the number of pig producers in highly profitable systems across technical upgrading activities

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	ST Number	ST Rank	SA Number	SA Rank	ST Number	ST Rank	SA Number	SA Rank	ST Number	ST Rank	SA Number	ST Rank
Baseline:	379		340		441		396		464		388	
Scenario 1: Individual producers												
S1.A1: Microcredit $150K	420	1	408	1	539	1	498	1	550	1	491	1
S1.A1.2: Microcredit $300K	477	(1)[a]	465	(1)	635	(1)	590	(1)	636	(1)	561	(1)
S1.A2: Training	399	2	374	3[d]	495	2	445	3[d]	522	2	437	3[d]
S1.A3: AHWs	389	3	388	2[c]	457	3	453	2[c]	507	3	469	2[c]
S1.A4: AI	380	4	344	4	449	4	405	4	483	4	400	4
S1.A5: Combination	480		485		639		639		710		652	
Scenario 2: Producer groups												
S2.A1: Microcredit $150K	343	2	309	1[c]	394	2	361	2	453	2	406	2
S2.A1.2: Microcredit $300K	363	(1)	336	(1)	435	(1)	410	(1)	512	(1)	466	(1)
S2.A2: Training	344	1	280	4[d]	398	1	363	1	474	1	413	1
S2.A3: AHWs	343	2	298	2	378	4	350	3[c]	449	4	402	3[c]
S2.A4: AI	343	2	298	2	389	3	349	4[d]	451	3	386	4[d]
S2.A5: Combination	397		373		549		508		712		629	
Scenario 3: Producer organisations												
S3.A1: Microcredit $150K	343	1	311	1[c]	534	4	448	1[c]	699	4	537	3[c]
S3.A1.2: Microcredit $300K	363	(1)	338	(1)	575	(1)	499	(1)	853	(2)	599	(2)
S3.A2: Training	343	1	284	3[d]	550	2	447	2	751	2	565	2
S3.A3: AHWs	343	1	299	2[d]	556	1	446	3[d]	882	1	644	1
S3.A4: AI	343	1	284	4[d]	540	3	436	4	722	3	530	4[d]
S3.A5: Combination	399		374		684		590		877		765	

Note: ST denotes results from scenario testing. SA provides the mean value from sensitivity analysis. Coefficients of variation (CV) are provided in brackets. LL represents the lower limit and UL represents the upper limit of the 95% confidence interval (CI). [a] value in parentheses denotes that ranking of the sub activity A1.2.). [c] indicates rankings that have improved in the SA compared with the baseline model run. [d] indicates rankings that have worsened in the SA compared with the baseline model run.

Source: Pork VC model simulation

Chapter 6

Discussion

This chapter draws on the results of the research to present the recommended pro-poor upgrading interventions for the TRRILD project and discusses the effectiveness of SGMB tools. Section 6.1 outlines the concentrated pro-poor upgrading interventions selected for their multiplying effects and appropriateness for the TRRILD project's timeframe, resource constraints, and operating context. This is followed by an overview of the TRRILD project's early upgrading efforts in the pork VC in Section 6.2, highlighting short-term outcomes as they relate to the model's recommendations. Section 6.3 concludes the discussion chapter by exploring the effectiveness of system thinking and SGMB tools for engaging stakeholders in VC analysis. Specifically, Section 6.3.1 outline factors influencing the effectiveness of SGMB tools, Section 6.3.2 explores how SGMB participant understanding of the target VCs evolved, and Section 6.3.3 identifies critical lessons learned through the process of using SGMB within a pro-poor development project.

6.1 Recommendations for pro-poor upgrading strategies for the TRRILD project

The purpose of constructing a quantitative SD model for the pork VC was to guide decision-making in the TRRILD project to improve outcomes for VC stakeholders. Results from the model were analysed, simplified, and presented to project partners and stakeholders together to generate a series of recommendations for pro-poor upgrading interventions for the TRRILD project to focus on. The presentation of upgrading recommendations fulfilled a variety of objectives: the action research call for practical knowledge (Reason & Bradbury, 2008); the goal of SD models to improve decision-making (Sterman, 2001); and the need for *ex-ante* evaluations as proposed by advocates for pro-poor VC approaches (Riisgard et al., 2010).

Recommendations for upgrading the pork VC were presented to, and accepted by, TRRILD PAC members in August 2019. This allowed for a three-year implementation period before the project's completion date in October 2022. Following the acceptance of recommendations, the Researcher continued to update the model structure, revise parameters, and rerun simulations to assist real time decision-making when contextual conditions changed, and to address specific queries posed by PAC members. This section outlines the collective body of recommendations from the pork VC chain's *ex-ante* impact evaluations that were shared with PAC members up until September 2020.

6.1.1 Focus on producer institutions

Simulation results showed that the TRRILD project should focus on collective action rather than broadly targeting individual producers. This would entail establishing pig PGs that operate at a transactional level before upgrading to PO status and extending their services by investing in value-adding assets to capture a greater portion of the price paid by consumers. Although the project's short-term financial impacts are highest when targeting the entire population of pig producers, the model clearly demonstrates that investments in the institutional capacity of PGs and POs have medium- and long-term advantages in raising incomes and broadening the pro-poor impact of the project. The institutional arrangements of collective action are critical. PGs provide improved outcomes for members when they retain earnings for investment in collective services. To achieve PO status, they further need to adopt institutional arrangements that encourage investment and discourage side selling. This can include the provision of regular rebates to members, tradable delivery rights, and the issuing of class B shares (Chaddad & Cook, 2004). At the early stage of establishment, PGs can engage in collective buying of inputs and selling of fatteners to reduce transaction costs and improve financial returns to members. The model shows that PG savings are critical at this initial stage of formation. It is suggested that, in lieu of membership fees (which may act as a membership disincentive), the PG should rather retain 20%[39] of price margins for capacity investments. This modest amount would help create a pattern for PG members (who are unused to collective action) and could be then increased as determined by the PG's future investment requirements.

The model's results show that the highest gains for the target villages come from transitioning PGs into POs that can functionally upgrade by investing in a safe and hygienic slaughterhouse that allows them to meet the quality standards demanded by high-end restaurants and supermarkets. It is recommended that the PGs be constituted with institutional arrangements that support a successful transition to POs. This transition would likely follow a path starting with bulk purchase and distribution of inputs, then adding collective marketing of high-quality products to premium buyers, and – lastly – investing in value-adding assets and inclusive business models (IBMs) (Esnard, 2021). Even at the early stages of formation, these constitutions should support: (i) governance arrangements that ensure that control resides with patron members; (ii) different types of shares to raise equity capital from members and non-members; (iii) access to debt capital to help finance investments in value-adding assets; (iv) the development of secondary market mechanisms such as tradable delivery rights for high-quality fatteners; and (v) proportionality between investment,

[39] If PGs negotiate a 5% discount for bulk purchasing of commercial pig feed, then a 4% discount is passed onto members with the PG retaining 1% for future investment. In a similar pattern, if PG bulk selling of fatteners or piglets incurs a 0.125 US$/kg price increase above market rates, the PG would retain 0.025 US$/kg.

patronage, and financial benefits to reduce conflict and encourage members to invest in and patronise their PO (Chaddad & Cook, 2004; Esnard, 2021; Moore & Noe, 1995).

While only the establishment of a safe and hygienic slaughterhouse was modelled, POs can also induce functional upgrading by supplying inputs or services to other VC actors. One suggested option is for POs to invest in the establishment of an input supply shop for commercial pig feed, equipment, and medicines. As the model demonstrated, procurement of quality commercial pig feed is a substantial production cost (around 50% for WF and 80% for FF farmers) and may be prone to supply chain disruptions as it is sourced from Yangon. The project should train POs to manufacture quality pig feed from locally available ingredients and help them to finance these enterprises[40] using a mix of equity, debt, and grant capital. Initial work by the Researcher and the TRRILD project's technical officer showed that using local ingredients can reduce feed costs by 20-30% compared with commercial brands while maintaining similar feed conversion ratios and fat content in pork products. Tanintharyi is home to one of Myanmar's largest marine fishing industries (Department of Fisheries, 2018) with 19 fish processing plants (Mar, 2017) that produce significant volumes of by-products that could be utilised in local feed rations. The other two main ingredients of local pig feed, broken rice and rice bran, are also abundantly available at village and township levels owing to the prominence of rice farming in the region.

6.1.2 High-quality hybrid fatteners

It is recommended that PGs concentrate on selling high-quality hybrid fatteners. The model shows that hybrid pig farming is three to four times more profitable than raising local pig breeds. National data from LVBD (2018), reinforced by feedback at SGMB and RG workshops, point to a shift in consumer preferences towards leaner pork produced by hybrid fatteners. Following patterns in other nations, the demand for higher quality pork is expected to trend upwards as per capita incomes rise (Huynh et al., 2007; Reardon et al., 2012). The model's results show that farmers can be protected from the higher risks involved in hybrid pig farming through a combination of the project's interventions (biosecurity, microcredit, training, and AHWs) and the establishment of PGs and POs. Functional PGs and POs can reduce compliance and unit transaction costs enabling sustained access to these risk-lowering activities and premium markets (Markelova et al., 2009).

Investments in hybrid pig farming by PG members make them susceptible to hold-up problems given the oligopsony power of slaughterhouses in Myeik and Palaw. Increasing the production of hybrid fatteners for the local wholesale market does not protect PG members from collusion between local slaughterhouses to lower farmgate prices, nor does it remove competition from quality hybrid pigs

[40] These enterprises would require financing to construct a retail outlet and storage facilities, purchase mixing equipment, along with working capital to allow the bulk purchasing of ingredients and storage bags.

sold from Mawlymine. Investing in high-quality fatteners for the premium market in Myeik and Yangon would enable PGs to differentiate their products from those sold in Mawlymine and other regional pig producers and help overcome these challenges. This differentiation would rest on PGs enforcing GAHP and biosecurity protocols that improve food safety, and shorter travel times that cause less animal stress. Before a PO makes a large investment in a hygienic, safe slaughterhouse to meet standards for the Yangon premium market, it should engage a local slaughterhouse to butcher high-quality fatteners for sale to local restaurants, hotels, and supermarkets. It is recommended that, together with PG representatives, the project organises a series of meetings with the restaurant association in Myeik to understand the quality standards required and to canvass orders for high-quality wholesale pork cuts from interested customers. Initial KIIs in Myeik found quality conscious restaurants were willing to pay premiums of 10% to 15% over the wholesale price for daily deliveries of a higher-quality product which would supplement the current practise of purchasing frozen pork from Thailand or other countries. Once order numbers are understood, the PGs can engage with a reputable slaughterhouse to make regular deliveries of high-quality pork cuts to restaurants. The project will need to introduce a tagging system to safeguard against opportunistic behaviour and to help assure quality by promoting traceability.

To access premium markets, PGs need to differentiate their products, not only by appearance (i.e., fat content of meat) and taste, but also by credence attributes relating to food safety, environmental, and ethical standards in production. The TRRILD project should work with capable PGs and interested downstream retail partners to develop a set of minimum quality standards (MQS) that define a “high-quality” fattener as per buyer standards and expectations. PGs could work with members and AHWs to clearly explain the standards, to train members, and to monitor farm adherence to the MQS and award tags to sows, piglets, and fatteners accordingly. This provides a helpful first step towards the later development of a participatory guarantee scheme in which other stakeholders (i.e., buyers, consumers, slaughterhouses) are involved in the development, training, and monitoring of product standards (Nelson et al., 2016). Once introduced to the PGs, a tradeable delivery right system (see Section 2.3.3.2) would also be tied to the tagging of high-quality fatteners to help PGs monitor the quality of the animals and assure the buyer that they comply with the MQS.

There is a risk of individual farm failure and PG collapse if PG members are unable to recoup investments in commercial feed, hygienic farm operations, and quality hybrid breeding sows through price premiums. This risk increases if the project provides microcredit lending for upgrading without sufficient biosecurity protocols or a comprehensive AHW network in place. In S2(PGs), the model showed that PGs remain functional even when members are paid the Mawlymine price for their live pigs which is lower than the premium price generated in the model. However, in the model, if slaughterhouses offered live pig prices which are discounted from the Mawlymine prices by 10 to

15%, members dropped out of the PG or became inactive and started side selling their fatteners because the PG no longer provided price or service incentives to continue membership. This suggests that in the early stages of developing a relationship with slaughterhouses, when premiums for high-quality fatteners may not be forthcoming, PGs will remain a viable option if they market their members' fatteners as a substitute for Mawlymine imports.

The model's results indicate that the local unhygienic slaughterhouses are currently highly profitable. Well-established slaughterhouses may therefore resist partnering with PGs for a high-quality product. While the TRRILD project should still canvass existing slaughterhouses for partnerships, external support may be necessary to attract a suitable business partner. This could include training in safe, hygienic slaughtering and butchering of premium cuts along with equipment grants to encourage slaughterhouses to adopt new practices. If slaughterhouses remain resistant to partnering with PGs to establish a premium product, the project should consider supporting a PO through debt or grant capital to establish their own upgraded slaughterhouse as per S3(PO). This would be dependent on progressing initially positive discussions with the local government on increasing slaughterhouse license tenure beyond a 12-month period. The model showed that a PO could repay a loan large enough to finance a hygienic slaughterhouse if the loan was amortised at standard MFI rates over a period of 24 months. The TRRILD project should investigate this further and develop a business case to attract strategic partners, such as premium wholesalers and supermarkets in Yangon who have an incentive to strengthen their supply chain amidst challenges importing frozen premium products and the threat of domestic supply shortages following an outbreak of ASF. Prioritised pig PGs will have to adhere to a common production plan in order to meet the quantity, quality, and consistency requirements of a large premium buyer, like City Mart in Yangon. This plan would need to that ensure there are sufficient high-quality FF hybrid farms to supply piglets of MQS to WF hybrid PG members.

Establishing a slaughterhouse for high-quality hybrid fatteners through a PO has the greatest pro-poor impact. S3(POs) creates a new highly profitable pig enterprise, the hybrid WF system, which is three times more profitable than S2(PGs) in the long-term. When small-scale producers can capture value added from both farm production and processing segments in the chain, producing a smaller number of fatteners (maximum of six per year for a hybrid WF system) is more profitable than the larger and more intensive local breed FF system (which typically includes two sows, and produces 10 fatteners, and 10 piglets per year). When considering horizontal impacts in the VC (Bolwig et al., 2010), the hybrid WF system is highly favourable because it requires less household labour (which is typically provided by women), less technical know-how, lower start-up capital, and a smaller resource base (i.e., time, labour, and land) which make this farming enterprise more accessible and less risky for the poorest members of the village. Moreover, the hybrid WF system reduces the environmental impacts of pig farming (e.g., pig waste, smell, noise pollution, and environmental degradation through roaming). The establishment of a slaughterhouse also delivers significantly higher off-farm employment opportunities than when PGs remain at the transactional level or the project focuses on individual farmers.

6.1.3 Technical upgrading activities

Model results further indicate that the project should implement microcredit, training, and AHWs activities alongside investments in biosecurity protocols to have the greatest medium and long-term impacts on target villages. As shown in the model, and through PAC discussions, AI does not bring substantial impacts to target communities and should not be a focus until the technology is more widespread in Myanmar and POs have the capacity to manage an AI unit.

Given the likelihood and considerable damage to the pork VC from an ASF outbreak, biosecurity practises should be mainstreamed across the other technical upgrading activities. Loans for pig farm upgrades and grants of in-kind support should be made to PG members provisional on investing in additional biosecurity measures, such as footbaths and parameter fencing, and production loans should also cover disinfectants and other related costs. Additionally, loans should be provided only after pig producers are trained on biosecurity and AHWs are established at the community level and are able to monitor and enforce compliance to biosecurity protocols. The adherence to biosecurity guidelines should also be included in the PGs' MQS and other collective selling activities.

The establishment of an AHW network is a priority intervention that needs to occur before PG members upgrade their farm systems to the higher risk hybrid WF or FF systems. The target region has a history of disease outbreaks, poor farmer knowledge on disease and biosecurity protocols, and extremely low vaccination coverage. As PGs invest in higher quality and more costly inputs, such as sows, piglets, and commercial feed, the potential negative impacts from a disease outbreak increase and the importance of AHWs and GAHP (captured in an MQS) for PG members becomes more important. The model shows that a well-functioning AHW network has impacts beyond pig survival rates; it also prevents loan defaults and keeps credit in the system for further upgrading loans, while helping PGs and POs consistently meet supply agreements for premium products. The TRRILD project will also need to provide start-up kits to equip AHWs as vaccinations and equipment are not consistently available on the local market. As the project exits, PGs and POs would need to have strong connections in place with the LBVD and the private sector to enable consistent supply of the necessary equipment and vaccines.

Microcredit loans are another priority project activity as they have the greatest impact on helping producers upgrade their farming systems. However, there are risks because of liquidity stress that will need to be managed. The project should make a minimum of US$150,000 available for upgrading and production loans for pig producers after a competent AHW network is in place. Given the production cycle of pig farming and high entry and production costs, small-scale farmers are likely to experience periods of negative cashflow in the first three years after upgrading with the partner MFI's current loan products and lending practices. Wealthier PG members can draw upon their household savings or take on smaller upgrading loans (i.e., if they are upgrading to produce a high-quality fattener from an existing hybrid farm) to manage this liquidity problem. The model showed there are viable pro-poor options within the policies available to the partner MFI to ease the liquidity stress over the first three years of hybrid pig farming for farmers with less resources. Extending loan terms to 18 months for production loans and 24 months for asset loans along with either a balloon loan, with payments tailored to the production cycle, or a deferred payment loan allows poorer farmers to engage in hybrid FF farming with lower capital reserves. Insisting on first-time borrowers taking small loan sizes and short repayment terms to improve credit worthiness will have a detrimental effect, echoing the findings of Pellegrina (2011). With these specific loan conditions, many PG members will be forced to engage with informal money lenders to fill their credit gaps which will then negatively impact on their ability to meet interest and principal payments from the MFI – especially if there is a disease outbreak. Thus, current risk reducing practices employed by the MFI could have the opposite effect by enhancing producer susceptibility to exiting pig farming and defaulting on their loans.

The focus on high-quality fatteners will require PGs to invest in high-quality breeding sows and boars to maintain genetic integrity. Achieving genetic integrity through AI is considered too risky for the TRRILD project. It is suggested that small breeding sow and boar units are established within prioritised PGs to ensure consistent quality of fatteners for the premium pork market and to achieve cost reductions. The TRRILD project can initially assist prioritised PGs to procure high-quality boars and breeding sows from Yangon which can then be granted to a qualified PG member. The costs of the sow or boar unit can be repaid by this PG member by providing PGs with the equivalent number of piglets over a set period. This will help inject start-up capital into the PG to cover initial expenses. The remaining piglets from the breeder unit can then be sold to PG members for fattening and breeding purposes. Breeding sows and their offspring will need to be tagged to certify the quality and parentage. This type of system would help ensure that PGs begin operations with quality genetic stocks while also lowering the entry costs for PGs to start hybrid pig production. Another pro-poor advantage to this system is that smaller sized loans are required as breeder and boar unit PG members would not have to pay an upfront cost to purchase the initial sows and boars. The reduced loan size, together with initially higher piglet sales will help these breeder farms maintain positive cashflow. As per FAO guidelines (2009), AHWs will need to work closely with PGs to ensure they keep a register of parentage to prevent inbreeding through successive pig production cycles.

The model's findings support feedback from KIIs and FGDs that past technical training events have motivated pig producers to upgrade their farming system but did not fully mitigate risks from disease and cashflow stress. Intensive hybrid pig farming practices differ from the free-roaming system that most PG members follow with their local breeds. Repeated training and exposure to successful PGs will be required to increase the technical knowledge of farmers on hybrid production. Findings from the model's sensitivity analysis show that the impacts of trainings are sensitive to project delays and as such trainings should move ahead concurrently with establishing PGs and an AHW network. To prepare PG members to successfully meet supply and quality standards for premium markets, the TRRILD project will need to train PGs in the agreed MQS. Special attention in training will need to be given to standardising feeding protocols amongst PG members and across PGs to enable them to attain bulk purchasing discounts and produce a consistently high-quality fattener. In S2 and S3, PGs and PO investments in a technical officer help ensure standards are maintained and new PG members are educated, and peer-to-peer learning strengthens technical knowledge in the system. The introduction of a delivery right for high-quality fatteners tied to a tagging system would also provide further incentives for PG members to meet rising pig standards along with the prevention of side selling.

The TRRILD project's MFI partner has a mandate to extend credit beyond PG members. Early information from the MFI's database showed loans were being made to non-PG member pig producers within and outside the 32 target villages. Results from S1 (individual) showed that MFI lending to individuals for local and hybrid breeds, particularly the FF system, would deliver overall positive financial and pro-poor results and could help offset any broker and slaughterhouse financial losses from a focus on PGs and POs. However, the alternative ASF scenario highlighted negative impacts that stem from high dropout rates based on the lending of microcredit without ensuring that biosecurity protocols are in place. Given the likelihood of an ASF outbreak during the project's lifetime, the model's results indicate that the MFI should restrict microcredit loans to only PG members and non-members that have invested in biosecurity infrastructure and practices. If the MFI were to concentrate any additional lending to pig producers outside of PGs but in the same villages, this would further strengthen the ability of PGs to survive disease outbreaks given the high chance of disease passing between pigs in the same villages.

6.2 Implementation of pro-poor upgrading activities

The focus of this research was to undertake an *ex-ante* impact evaluation of the pork VC to provide pro-poor upgrading recommendations for the TRRILD project. It is beyond the scope of this thesis to provide a detailed description of the implementation of these recommendations and project outcomes. This is because the action research portion of this study ended in December 2020, while the project's activities were to continue until October 2022.[41] Additionally, while this study resided in the action research paradigm, restrictions due to the COVID-19 pandemic prevented the Researcher from scheduled travel to Myanmar after January 2020 to help guide the implementation of upgrading activities. This section will, however, provide a brief update on the TRRILD project's initial upgrading efforts in the pork VC until December 2020, highlighting short-term outcomes as they relate to the model's recommendations.

Out of the original 30 PGs constituted[42] by the TRRILD project, 20 PGs were active and focusing on the pork VC. PGs had an average of 34 members, with women comprising 75% of members and 58% of directors. These 20 PGs were all considered "functional," meaning they had a formal constitution that allowed the PG to introduce investor-friendly institutional arrangements, well-defined strategic objectives, elected directors, and evidence of sound financial practices and regular meetings. A considerable transition from local breed to hybrid pig systems had taken place in the PGs, providing evidence that the project's technical activities were effective in supporting pig farmers to upgrade their enterprises. As shown in Table 34, there was a 669% increase in hybrid pigs and 152% increase in local pig numbers held by PG members in the span of one year, along with an extra 118 pig producers joining the pig PGs. This level of PG membership is slightly higher than the 640 members used within the SD model.

Table 34: Status of pig PGs in TRRILD project

	September 2019	*September 2020*
Number of pig PG members	592	710
Number of local breed pigs	507	1,276
Number of hybrid pigs	161	1,238

Source: TRRILD project Year Three Annual Report (WV New Zealand, 2021)

From the 20 pig PGs, 14 had been prioritised for project investments to achieve a systematic production plan to supply 1,000 kgs of premium pork every week. The target figure of 1000 kgs was taken as the project's production goal following conversations with a premium buyer in Yangon who indicated this was their minimum order volume. This equated to a minimum of 14 hybrid FF farms (each with three breeding sows) solely producing piglets for 124 WF farmers who would raise three fatteners twice a year.

The strength of the pig PGs was evidenced by their ability to collectively purchase key inputs. Out of the 14 prioritised pig PGs, seven had started purchasing commercial pig feed in bulk from retailers,

[41] The TRRILD project's impact evaluation was scheduled for the first half of 2022.
[42] The TRRILD project targeted 32 villages but two dropped out during the constitution process.

dividing the feed and bagging it into smaller portions for selling to both members and non-members. These PGs were transacting 10,300 kgs of commercial feed every month and receiving a 3.5% bulk purchasing discount. With the additional benefit of direct delivery to the village, this bulk order discount is close to the 5% estimate used in the SD model. Discount margins were partially passed on to members as the PG retained a small portion of the savings (20%) to cover costs and build its capital base, with non-members paying a slightly higher rate for feed. By the end of September 2020, prioritised PGs had invested US$51,883 of member capital in purchasing commercial pig feed. Ten PGs were also collectively purchasing high-quality piglets from PGs that had established breeding sow units with support from the project, further reducing transaction costs. These piglet purchases were transacted through verbal agreements covering timing, price, and volume.

To ensure the genetic integrity of prioritised PG hybrid fatteners and a consistent quality standard across PG members, the project established four hybrid demonstration farms: two boar units (two boars per unit), and two sow breeding units (three sows per unit). These farms were operated by individual members contracted by their PGs, and the costs of the boar/sow returned to the PG either through regular cash instalments or the equivalent value of piglets, allowing the PG to build up its working capital. Biosecurity guidelines were built into contracts with the demonstration farmers, ensuring their farms were suitable examples for training and exposure visits by PG members. Although quality breeding sows and boars were ordered in September 2019, procurement delays meant they did not arrive in Myeik and Palaw until December 2019, producing the first offspring April 2020, which were weaned in June 2020. Within a year of their introduction, 17 additional PG members had established FF enterprises with offspring from the demonstration farm, initially focusing solely on piglet production. A further 103 PG members had mated the high-quality hybrid boars from demonstration farms with existing sows (following quality and health checks by TRRILD project staff) to produce a total of 707 piglets that met minimum quality standards (MQS) set by the project's technical officer. These high-quality piglets were either sold on to other WF PG members or retained by FF PG members for fattening or replacement of breeding sows. Unfortunately, the introduction of an ear-tagging system to register high-quality sows, fatteners, and piglets did not occur in 2021 because of procurement delays and travel restrictions which meant that scheduled training for AHW on tagging did not take place. Following the success of these farms, five additional PGs were in the process of establishing high-quality boar (2) and breeder (3) units; however, these PGs had decided to collectively own and operate these subsequent units.

The project provided basic swine management training to around 550 farmers each year. This is lower than the estimate of 650 farmers used in the model and reflects the impact of COVID-19 travel restrictions on staff mobility. A training manual on hybrid pig production was developed by TRRILD technical staff in conjunction with LBVD staff, covering systematic pig production, disease prevention, and biosecurity measures. Pre- and post-training tests showed that the proportion of farmers with a sound knowledge of swine management increased from 17% to 71% after training. However, 15% of PG members did not show any knowledge gains and was linked to their unfamiliarity with classroom learning techniques and low literacy levels. As a result, the project shifted its training methods to emphasize exposure visits, practical training (at demonstration unit sites) and the provision of training-of-trainers to AHWs, who would then work closely with small groups of PG members.

The project successfully established AHWs based in each of the 20 PG locations, having an immediate impact in lowering pig mortality among PG members during multiple disease outbreaks that occurred in 2019 and 2020. These village-based AHWs were trained by the TRRILD technical specialist and LBVD officials (both members of the RG) on improved feeding practices, pig house design, sanitation, animal health care (including practical training on vaccinations), and disease prevention. When the perceived risk of an ASF outbreak in the target villages increased, AHWs were provided with refresher training on biosecurity after which they actively supported PG members to comply with biosecurity guidelines while also distributing project-subsidised disinfectants. Although there was no outbreak of ASF in the target villages, there were significant outbreaks of Staphylococcus in Palaw as well as PCV2 (Porcine Circovirus Type 2) across both Myeik and Palaw. AHWs were able to deliver vaccinations to 934 pigs to help prevent Staphylococcus as well as to 1,262 pigs to guard against PCV2. Out of the 710 PG members, only two members' pigs were infected with PCV2, evidence of the impacts of the project's investments in AHWs, training, biosecurity practices, and high-quality breeds. There were indications that AHWs would continue in their roles past the project's completion in 2022. Pig farmers were routinely connecting with AHWs for assistance and vaccinations, with AHWs charging between US$0.33 to US$0.66 per call-out or injection for PG members as a bulk discount and US$1 to US$1.6 for non-PG members. AHWs in Myeik were able to access vaccines with the project's support through local markets or contacts within the LBVD. However, the project was still required to subsidise vaccines for AHWs based in Palaw due to the absence of a local supply from either the LBVD or an input supplier.

Microfinance loans for pig enterprises were made to 81 members across 13 PGs as of September 2020. The PG loan portfolio for the pig VC totalled US$72,866 representing 26.4% of all microfinance loans made to PG members. This was the largest loan category, over twice the amount of the next two highest loan types (rice production: US$32,866 and rubber production: US$32,166), signalling the priority placed on investments into the pork chain compared with other livelihood options.[43] The

[43] Most paddy farmers in target villages take the maximum loan amount available from the MADB to finance seasonal inputs. TRRILD project staff did not report that any other MFIs had extended their operations to cover the target villages.

average loan amount was US$899. Out of the total number of loans, 6% were for less than US$300, 60% were for between US$300 and US$1000, and 34% of loans were for over US$1,333 (equivalent to MMK2,000,000, a common loan category). The high value of loans and large increases in hybrid pig numbers strongly indicate that PG members were using microcredit for upgrading to both hybrid WF and FF systems. Out of the two products on offer by the partner MFI, PG members had prioritised the balloon (63%) over the amortized (27%) loan. However, the MFI had not yet approved the use of the deferred interest loan in this target area. This had deterred some PGs, such as Ma Yin, from taking out microfinance loans to facilitate upgrades. Given the large increase in hybrid pig numbers, PG members were clearly also relying on capital beyond the partner MFI for upgrades to their pig farms, such as household savings, informal money lenders, or the Village Savings and Loan Associations (VSLAs) established by the project. The partner MFI's low portfolio-at-risk rate (less than 0.1%), even in the middle of COVID-19 restrictions, suggests that loans were primarily being made to pig farmers with either significant cash reserves or multiple streams of income.

The live pig price in Myeik and Palaw oscillated sharply in 2019 and 2020 due following multiple shocks to the pork VC system. Monthly live pig prices collected by TRRILD staff are shown in Figure 43 and show significantly larger price movements in 2019 and 2020 compared with the last decade (cf. Figures 15 and 16 developed by SGMB and RG participants). Heavy monsoon rains in June and July of 2019 restricted the transportation of live pigs from outside the region into Myeik and Palaw. The supply of pork in Myeik and Palaw was further compromised by the Myanmar government's import restrictions on live pigs and pork products from ASF affected countries (Wai, 2019), and the local government strictly enforcing an importation ban on live pigs due to an ASF outbreak in northern Myanmar. As a result, live pig prices were steady at 2.5 US$/kg for the second half of 2019, before reaching to 2.71 US$/kg in the first quarter of 2021, a record high in Myeik and Palaw. The pace and magnitude of this upwards price movement resembled price shifts in the SD model's alternative scenario: disease and importation ban (see Section 5.7.1.1 and Figure 40). COVID-19 restrictions were strictly enforced in Myanmar in June of 2020. This included domestic and international travel bans, restrictions on local travel and gatherings, and the closure of restaurants and hotels in Myeik.

The outbreaks of PVC2 and Staphylococcus, and the threat of ASF, further dampened the demand for pork, resulting in plummeting pork prices in July through November 2020. Live pig prices in Myeik and Palaw between August 2020 and November 2020 fell below the cost of production, reaching lows of 1.58 US$/kg. Many of the COVID-19 travel and hospitality restrictions were eased in November and December 2020, and this immediately resulted in live pig prices climbing to 2.08 US$/kg. When these disease, importation ban, and demand changes were populated into S3(POs), the pork VC model was able to retrospectively produce a similar pattern of live pig price changes, as shown in Figure 43.

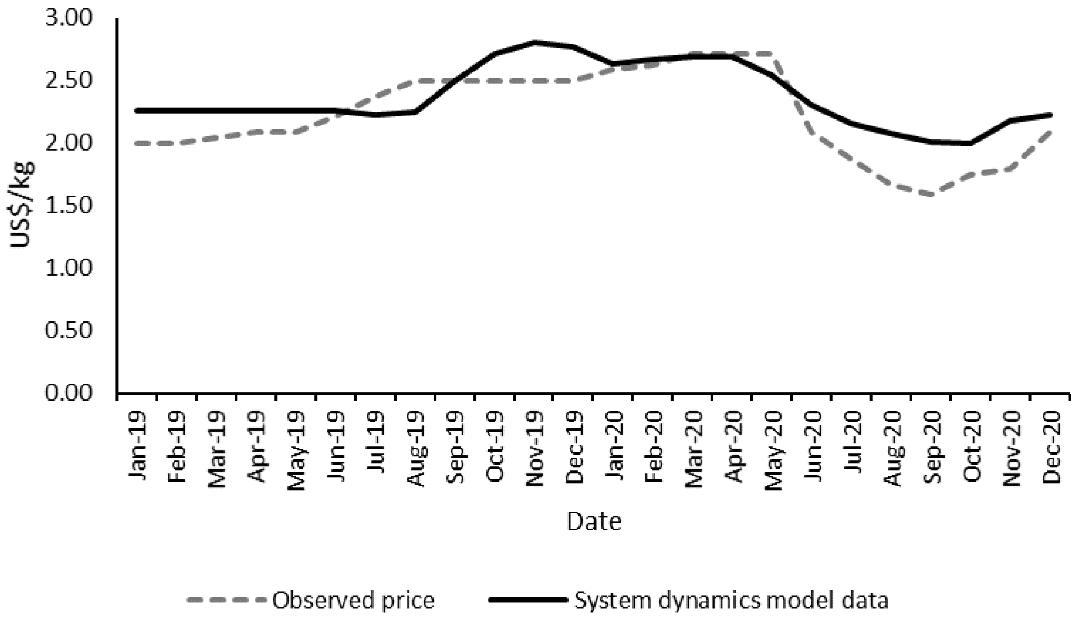


Figure 43: Comparison of actual and predicted slaughterhouse prices of live pigs in Myeik, January 2019 to December 2020
Source: TRRILD project staff and Pork VC model simulation

The large and frequent oscillations in live pig prices made collective selling between PGs and the local slaughterhouses difficult to arrange. Given procurement delays and biological production time lags, the first high-quality PG hybrid fatteners (produced from imported boars) started to reach their optimal selling weight (80 to 96kgs) around April/May 2020. However, the high farm-gate prices at this time meant that PG members were reluctant to consider a long-term supply contract with a single slaughterhouse. The volume of high-quality hybrid fatteners was also too low to garner high interest from the largest slaughterhouses who had concerns about consistency of supply. Most PG high-quality fatteners reached their optimal selling weight after COVID-19 restrictions were enforced in June and July 2020 and this reversed the situation: low demand and sharply falling prices meant there was little motivation for the larger slaughterhouses to discuss a formal agreement with PGs or to pay a premium for a high-quality product. Towards the end of 2020, five of the PGs collectively sold 69 hybrid fatteners (the total value of transaction was US$14,680) to one of the smaller slaughterhouses for 0.2 US$/kg (equivalent to a 7% premium) above the market rate. This new entrant into the slaughterhouse business held one of the smaller licences (three live pigs/day allowance) and appeared motivated to engage with the PG because of the lower transaction costs and higher quality of PG members' pigs.

Once PGs began investing in high-quality hybrid fatteners, the TRRILD project organised a series of meetings with the Myeik restaurant association to reintroduce the PGs and explain their intention to produce higher-quality, hygienic pork products. Following this meeting, orders were canvassed and collected from eleven restaurants. The three priority cuts given by restaurants were shoulder, three-layer, and ribs, with enough demand for an initial order of seven high-quality hybrid fatteners per week. Prices indicated by restaurants were 10 to 15% above the wholesale price, similar to the 10% premium used in the SD model for the Myeik high-quality wholesale market. The project's original plan was to partner with a slaughterhouse in Myeik to fulfil these local orders. This would allow PGs time to firmly entrench a production and quality control system, essential before entering the Yangon premium market and investing in an upgraded slaughtering facility. The project also investigated providing butchering training, and small capital grants to a slaughterhouse to improve safety and hygiene in the chain (e.g., fly screens, cool chain equipment, and vacuum packing equipment). Unfortunately, restaurant orders fell by 70% to 100% owing to COVID-19 restrictions and this activity was placed on hold by the TRRILD project until the situation stabilised.

PG members who made substantial investments in their pig enterprises (such as commercial feed, biosecurity, hybrid breeds, hygienic shelter, etc.) were faced with a series of external shocks in their first year of upgrading. Two of these shocks, multiple disease outbreaks and an importation ban, was included in the SD model, though the demand shock following COVID-19 restrictions was not modelled explicitly. The model's alternative scenario for an ASF outbreak, however, did closely resemble the multiple shocks experienced in 2020 (see Section 5.7.1.6), as it included a 70% drop in consumer demand coinciding with a high pig mortality rate and import restrictions. Only a small number of PG members reacted to these shocks by selling under-weight fatteners for low prices, i.e., panic selling. The model's prediction that live pig prices would sharply rebound following disease and demand shocks helped TRRILD staff to understand and explain the likely upward trend in prices to PG members. This encouraged most PG members to hold on to their fatteners until the live pig price increased in November and December 2020, resulting in small but positive profits. The TRRILD project's MFI partner also tailored its loan products to help farmers manage negative cashflow during this time. This included rescheduling loan repayments, grace periods (principal and interest) of up to three months, removal of fees for withdrawing savings, and the introduction of a group recovery loan product.

Some initial steps in upgrading PGs to POs were taken in 2020 but these were ultimately hampered by the impacts of the COVID-19 pandemic. Based on a capacity assessment of PGs, two of the 14 pig PGs were prioritised for upgrading to PO status with the other 12 PGs remaining at the transactional level. The upgrading process involved the development of enterprise business plans to support value adding strategies. One of these PGs, Ma Yin, was able to finalise a business plan by the end of October 2020. Ma Yin PG's business plan aimed to: (i) expand its existing input supply shop[44] by increasing the volume of feed and range of inputs and (ii) invest in feed-mixing machinery and

[44] The input supply shop was selling 2,500 kgs of commercial pig feed every month, equivalent to monthly sales of US$1,388.

working capital to produce high-quality pig feed from local ingredients. This PG was able to raise US$2,040 of capital from its members and requested a grant of US$2,240 to finance the balance of the proposed investment. LU's other TRRILD-associated PhD student worked with the PG's directors to develop a unique shareholding structure that would give all members a financial interest in the PG (Esnard, 2021). The PG would issue 321 shares valued at US$13.33 per share (equivalent to MMK 20,000 per share) to raise US$4,280 – enough equity capital to finance the investment. PG members would purchase 153 shares (for a total of US$2,040) and the project would provide a grant to purchase 168 shares (for a total of US$2,240). The grant-funded shares would be distributed equally to PG members. The shares were to be tradeable between members, with larger investors who held more shares benefiting from a larger price discount on inputs purchased from the PO. For example, PG members with 4-6 shares would receive a 2% price discount, shareholders with 7-9 shares a 5% discount, and shareholders with ten or more shares a 6% discount. This design aimed to encourage larger patrons to hold a larger number of shares as this helps to align the benefits of patronage (price discounts) with the benefits of investment (dividends and capital gains), so reducing the potential for conflict between investors and patrons that tends to discourage members from investing in and patronising their organisation. This structure exploited the PG's investor-friendly constitution to also allow investment in the scheme by non-PG members. However, by the end of 2020, the PG had yet to move forward with this proposal, given their concerns over the demand for local pig feed due to the recent instability of live pig prices.

The application of SGMB and SD modelling to analyse agri-food value chains, evaluate interventions, and guide project and policy decisions is relatively new. The potential of SD was highlighted by Rich et al. (2011) and applied within pig value chains in Vietnam (Rich et al., 2018). GMB was also used by Lie et al. (2018) to develop a quantitative SD model and evaluate potential policy interventions for the dairy value chain in Nicaragua. While more recently, SGMB was conceptualised to analyse urban food value chains in New Zealand (Rich et al., 2018) and applied to evaluate potential interventions in horticulture value chains in India (Cooper et al., 2021). This research extended these previous studies by developing the first pig SD model that evaluates both financial products and collective action among farmers as possible interventions to upgrade an inefficient agri-food value chain. While these interventions were evaluated *ex-ante*, the SD model proved remarkably accurate in predicting live pig price movements in Southern Myanmar and recommending interventions that were readily adopted by small-scale pig producers. This research also extended previous GMB and SGMB activities as it was embedded in a development project. The flexible and participatory nature of SGMB tools supported the wide engagement of stakeholders in the pig industry and strengthened the uptake of the model's recommendations.

6.3 The effectiveness of spatial group model building tools

Spatial group model building (SGMB) is an emerging participatory modelling practice that builds upon group model building (GMB) to incorporate spatial and temporal dimensions, both highly influential factors that underpin agri-food VCs (Rich et al., 2018; Rich et al., 2021). Even though early practitioners emphasised the importance of including clients in the process of building SD models (Forrester, 1961), GMB emerged as a unique, documented process in the 1990s of jointly constructing SD models with stakeholders (Richardson & Anderson, 1995; Vennix, 1996,). In GMB, stakeholders work together to conceptualize common problems and reach a consensus which improves team building and ownership of the solutions (Vennix, 1996). Thus, GMB sits within the wider genre of participatory research which aims to co-generate knowledge through including community members in obtaining data, conducting analysis, and interpreting and owning the results (Pain & Francis, 2003). Positioned within the TRRILD project and the action research paradigm, the SGMB process added a further dimension to participatory research in that it aimed to increase local participation and ownership in a development intervention, in which "local" refers to agri-food VC stakeholders, with a focus on small-scale producers. While interpretations on the role and effectiveness of participatory tools in development projects are diverse (e.g., Chambers, 1995, 2005; Cook & Kothari, 2001; Mosse, 2004), in this research SGMB was used as both a "means" to development and an "end" in itself (Oakley, 1991). In this regard, the effectiveness of SGMB is linked to its ability to increase the impact of the project, by selecting high payoff, pro-poor upgrading interventions, as well as its ability to empower participants to upgrade their enterprises in the agri-food VC.

This section adds to the body of literature that critically reflects on GMB methods (see Rouwette at al., 2002 and Scott et al., 2015 for a meta-analysis of the effectiveness of GMB) but extends this further by focusing on the effectiveness of an emerging tool, SGMB, in an applied setting. This section will outline factors that influenced the effectiveness of SGMB tools for engaging stakeholders in VC analysis, while highlighting critical lessons learnt from a first-time application of SGMB to develop quantitative agri-food VC models in emerging economies. Next, this section will highlight how SGMB participant understanding of the VCs evolved through the SGMB process. Finally, this section will provide recommendations for future SGMB processes within development initiatives.

6.3.1 Factors influencing the effectiveness of spatial group model building

Layerstack follows in the footsteps of a rich history of easy-to-understand and tactile participatory rural appraisal (PRA) tools that encourage community stakeholders to share and discuss rich contextual information (Narayanasamy, 2009). The Layerstack exercise conducted in the initial SGMB workshop proved an effective tactile tool for engaging a diverse set of stakeholders around temporal and spatial evolution in the VC. A participatory GIS tool, Layerstack, consists of an A2-sized map of the target area over which plastic acetates representing different characteristics of the VC are placed, as shown in Figures 45 and 46. A detailed description of the Layerstack tool is covered by Rich et al. (2018) and Rich et al.[45] (2021), while its application to this research is found in Section 3.3.2.3 and Section 4.1. The Layerstack exercise enabled spatial and temporal features of pork and paddy VCs to surface at the beginning of group learning and problem framing, helping to focus and maximise the subsequent model building process. For example, the Layerstack exercise of the pork VC showed that geographic areas with a high concentration of local breed pig producers overlapped (layer 1) with the decreasing quality of goods and services away from urban centres (layer two), and this constituted 90% of the project's target villages (base map). Participants were initially hesitant to draw on the acetates, but their reluctance soon eased after the MBT demonstrated the impermanent nature of the materials, such as the stickers, whiteboard markers, and post-it notes. The plastic acetates meant it was quick and easy for participants to move stickers, rub out markers, and redraw behaviour modes as the conversation evolved and the group's consensus changed. This made it simpler for participants to disagree with and challenge one another, and more difficult for the participants holding markers to operate as information gatekeepers. When participants monopolised materials and the subsequent recording of information on the acetates, the facilitator could politely request them to hand over the markers/stickers to other stakeholders to encourage wider participation or to update recorded information as the group's consensus evolved.

Figure 44: The Layerstack toolkit
Source: K.M. Rich

One factor restricting the level of engagement in Layerstack was the size of the group, which was 15 in the workshop in Myeik and 16 in Palaw. As shown in Figure 45, this number was too large for all members to physically gather around the Layerstack and see what was occurring, to use the materials to record information, and easily converse with one another. In both workshops, around

[45] This paper is co-authored by the Researcher.

ten participants formed a circle around the map with the remaining members moving in and out of this circle as their attention oscillated, suggesting a maximum of ten participants for future Layerstack exercises. The limited physical space around Layerstack also contributed to a few downstream VC actors excusing themselves from the process when layers not relating to their node were being discussed.

Figure 45: Layerstack exercise during SGMB workshop one in Palaw
Source: Researcher

Layerstack's effectiveness as a tool relied heavily on the facilitation skills of the model building team (MBT). Prior to the first workshop, a mock Layerstack exercise was conducted with MBT members taking turns as the Layerstack facilitator while also role-playing as VC actors. The MBT had distinct roles during the Layerstack exercise: a Lead Facilitator, a Timekeeper (who also ensured a ready stock of consumables), a Notetaker (who took pictures of the different layers and recorded discussion points), a Process Coach, and the last member who acted as a "people's champion." This last role involved physically coming alongside and listening to less vocal participants, interceding for them in the discussion when their opinions were not considered by the wider group, helping with translations between Burmese and Karen, and assisting when literacy ability hindered participation.

While the mock sessions helped MBT members understand the mechanics of the Layerstack tool, there were still facilitation challenges which needed to be addressed by the Process Coach. Firstly, the Lead Facilitator's natural inclination was to "hold the marker" and undertake the drawing/placing of stickers themself. The Lead Facilitator was also more likely to encourage the overtly confident and assertive members of the group to take on information recording roles, rather than sharing responsibility for drawing and placing materials amongst all participants and drawing quieter members into the discussion. Secondly, there was a proclivity for the MBT to passively engage with responses to their questions and not to probe and follow up with "Why?", "When?", "Can you explain?", or "Do you all agree, or is there a different opinion?" question prompts. While challenges were present the MBT clearly grew in confidence through the exercises, helped by a debrief after and between Myeik and Palaw Layerstack exercises[46] and guidance by the Process Coach during the exercise.

Beyond Layerstack, other physical tactile tools were used within the SGMB workshops to increase the quality of engagements with participants. This included the use of coloured cards for the hopes-and-fears script, the water-in-a-glass script for introducing SD terminology, cause-and-consequence mapping on whiteboards, and the physical drawing of CLDs and basic SD concept models on large sheets of paper. During the workshop, any proposed changes to models, questions, or additional information from participants were written on cards/post-it-notes and physically placed on the paper or drawn in with markers. This meant SGMB and RG participants did not have to use the MBT as conduits as they would if SD-specific software packages or Microsoft Word or PowerPoint were used to present CLDs, concept models, etc. The reliance on paper materials, however, meant a large amount of time was dedicated to workshop preparation. For each SGMB workshop up to five CLDs had to be drawn out on large sections of paper (2 metres by 1. 5 metre) as illustrated in Figure 46.

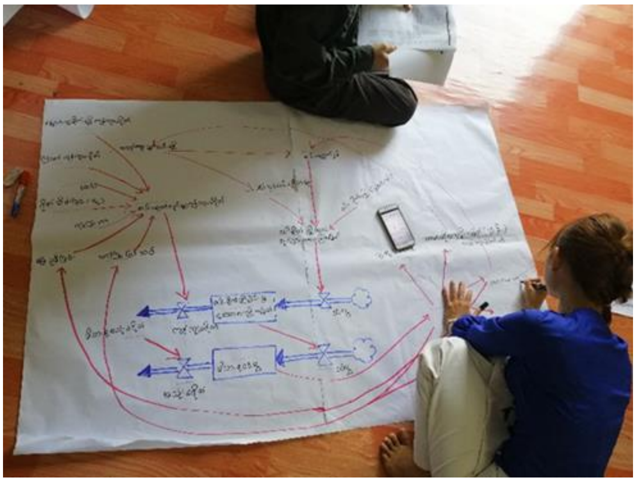


Figure 46: Preparing a concept module for presentation at an SGMB workshop
Source: Researcher

One benefit of this hands-on approach was that the MBT increased their familiarity with the models as they transposed materials and were quick to identify any structural or translation errors. All workshop material was written in the Burmese language with English translations written in pencil in a smaller font to help assist the English-speaking Researcher to engage in sessions. Once prepared, MBT members used the large paper materials to practice explaining the content to each other which was also another opportunity to pinpoint any information gaps. A physical chart of critical

[46] A series of prompt questions were developed to help with facilitation.

information gaps was kept by the MBT, and this was updated by SGMB and RG participants at the end of each workshop as shown in Figure 47.

Figure 47: MBT members discuss information gaps with the RG
Note: Three MBT members at the front of the RG workshop share materials from the SGMB workshop, including a record of information gaps.
Source: Researcher

The plus, minus, interesting (PMI) exercise proved a useful physical tool to guide MBT reflections and to identify lessons learned for the strengthening of future SGMB and RG workshops. The PMI tool has three reflection categories: (i) Plus, the positive elements of the workshop; (ii) Minus, the negative elements of the workshop; and (iii) Interesting, points that are neither positive or negative but are observations or points of interest (Sharma & Priyamvada, 2017). After each workshop, the Researcher led the MBT through the PMI tool by drawing the three columns on the whiteboard (Plus, Minus, Interesting), preceded by a general discussion on the MBT's overall impression on the effectiveness of the workshop as suggested by Hovmand (2014). As the last to be discussed, the "Interesting" category invariably collected the recommended changes to upcoming workshops. The majority of the MBT were surprisingly open and self-critical during the PMI exercises, perhaps associated with experiences working for an INGO in which PMI is extensively used with project design and implementation workshops. The full details from the PMI reflection exercises are found in Table G1 in Appendix G. One example of how discussions using the PMI tool resulted in critical changes is the designation of workshop roles to MBT members. In the first workshops, critical reflections centred on the roles and responsibility of the MBT: the Lead Facilitator tended to "teach" rather than "facilitate and prompt," leaving the Assistant Facilitator largely underutilised. This resulted in the inability to follow agenda times, which led to workshops running overtime. As a result, the MBT decided that the Researcher should co-lead workshop facilitation with the Lead Facilitator, and the three remaining MBT members, with less technical backgrounds but more community facilitation experience, should facilitate small group work. In this way, the Researcher's role merged the facilitator, process coach, team leader, and modeler functions. The merging of Researcher roles was also reported within Helene Lie's research that used a GMB process to build a SD model of the dairy VC in Nicaragua (Lie et al., 2017) and is common in participatory processes (Voinov & Bousquet, 2010). As Table G1 illustrates, by the later workshops, the MBT had become more confident in their roles, agendas were being completed on time, and discussions were richer as facilitation improved.

Further aiding the effectiveness of the process was the physical layout of workshops, which were arranged to enhance group interactions and participation. As shown in Figure 48, chairs were set out in a C-shape, with a central whiteboard behind the frontal space where the facilitators stood. The C-shape meant that all participants could see one another and the MBT were able to walk easily around the room and support participants with comprehension or translation issues and could pass materials developed by participants to the Assistant Facilitator. Walls were kept clear to minimise distractions but also to allow easy access to workshop materials that were placed on the walls as shown in Figure 49. The workshop room also had enough space so that participants could comfortably work in small groups and MBT members could navigate the room during these exercises (Hovmand, 2004, p.70). The MBT quickly learnt that room set-up and preparation required at least 90 minutes, and prior preparation of physical materials (coloured cards, stickers, tape, etc.) greatly helped workshops to run on time. The meeting spaces in both locations were booked for the entire day, as many participants lingered to continue in discussions with the MBT and each other.

Figure 48: Set-up of SGMB workshop in Myeik
Source: Researcher

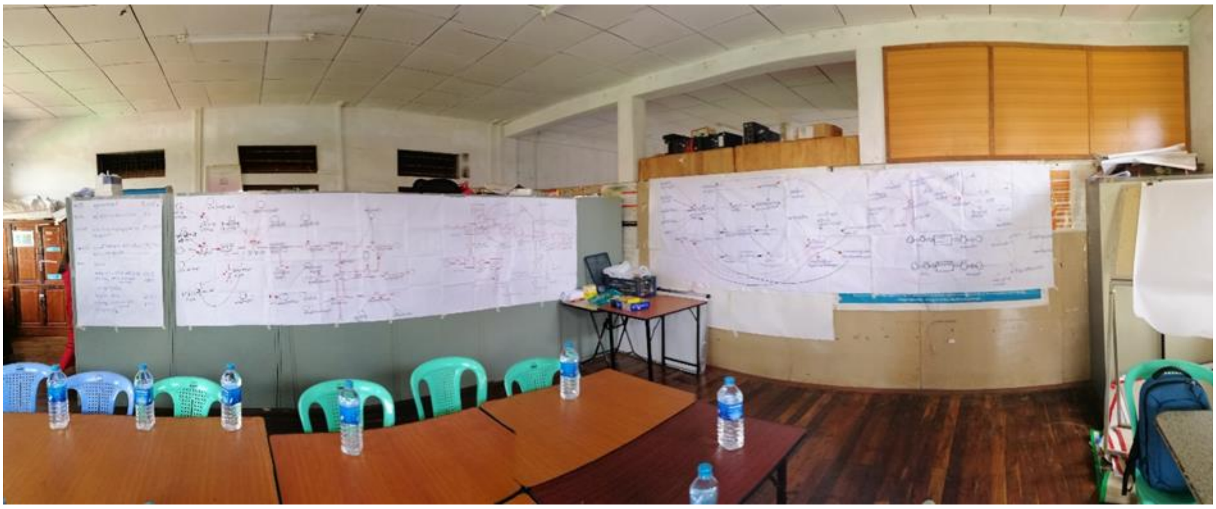


Figure 49: Set-up of SGMB workshop four in Palaw
Source: Researcher

Reported by Vennix (1996) as the most important element for effective GMB facilitation, the attitude of MBT members heavily impacted the effectiveness of the SGMB process. Roles for the MBT members were assigned by the partner INGO to project staff prior to the Researcher arriving in Myanmar. The interim TRRILD Project Manager at the time appointed himself the Lead Facilitator based on project hierarchy and his technical experience which included roles as a university lecturer and township agricultural technical officer in Central Myanmar. The Lead Facilitator had a propensity to practise a teacher-centred approach to workshop facilitation. This “chalk and talk” phenomena (Hardman et al., 2016, p.99) is well documented in the Myanmar education system: teachers are the central source of knowledge, and students are expected to passively receive information from their teacher through rote learning (Oo, 2015). This approach does not naturally align with the attitude and skills that make a strong GMB facilitator. As Vennix (1996) notes, a good facilitator is someone who has a helping attitude, which is characterised by neutrality with respect to the content of the discussion, asking questions to further inquire about the problem, promoting curiosity and inquiry, and facilitating reflection and learning rather than teaching.

Despite training and coaching, the lack of facilitation experience manifested itself in noticeable ways: (i) the Lead Facilitator often spoke more than participants; (ii) the Lead Facilitator disproportionately engaged the more powerful participants; (iii) the Lead Facilitator was hesitant to probe further once someone had shared their opinion, particularly if they were an expert or more powerful person; and (iv) the Lead Facilitator, along with other MBT members, struggled to constructively engage in arguments between participants. It became increasingly clear that the Lead Facilitator perceived himself as a teacher and expert. Vennix (1996, p. 141) cautions against having a facilitator who is a subject matter expert as this can impede the GMB process. However, changing roles within the MBT would have been difficult because of the sensitivity around the hierarchy within the project team.

Considering this, the Researcher took on the role of co-lead Facilitator and sought to coach the Lead Facilitator during the workshop process. Detailed agendas were also used to guide the MBT, along with question prompts to help promote appreciative inquiry. The Lead Facilitator and other MBT members were also reassured that robust discussions between participants were a key part of the process and as facilitators they should actively engage when participants disagreed with one another rather than avoiding confrontation, which would inevitably result in the more powerful participants dominating the discussions. While the Lead Facilitator improved their facilitation skills, workshop outcomes were impacted by their attitude and consequently a decision to replace the Lead Facilitator by another team member earlier on would likely have improved SGMB outcomes. In SGMB four, another MBT member, with strong community facilitation background but limited technical knowledge took over the Lead Facilitator role due to illness and this helped improve the quality of workshop discussions from that point forwards. In fact, all the other MBT members outside of the original Lead Facilitator had strong community development backgrounds with between three to 15 years of experience facilitating workshops in the target area. This greatly helped the development of concept models in SGMB two, three, and four which were drafted through small group work led by these individuals.

Managing the power dynamics between participants was another factor in determining the effectiveness of SGMB sessions. The development literature suggests that participatory processes can be biased towards community members who already wield power (Guijt & Shah, 1998), prove exclusionary to the poor and marginalised (Kapoor, 2002), and mask invisible problems and power imbalances (Mosse, 1994). The negative influence of power differentials between participants on GMB outcomes is also well documented in the SD literature (Van Nistelrooij et al., 2012; Vennix, 1996). While research into the effectiveness of GMB has been almost exclusively conducted in countries with low power-distance cultures, an initial comparison across multiple country contexts showed GMB had comparable effects on communication, insight, learning, and consensus despite differences in power-distance (Lansu et al., 2016). While it was impossible to fully mitigate the influences of power imbalances, several methods were weaved into SGMB exercises to lessen their impact. Group sessions were divided into two separate entities: SGMB workshops with VC actors, and RG workshops with technical experts. This separation was undertaken to facilitate more open discussion among VC actors. Myanmar's history of authoritarian government and teacher-centred education system has led to a reluctance of those with less power, i.e., community members, to speak openly in front of the powerful (Steinberg, 2013), which could have resulted in "group-speak" in the SGMB sessions (Hovmand, 2014). This group-speak was evident in the first SGMB workshop in Palaw where two local government technical officers attended and the tendency to defer to them as the source of "technical knowledge'" by the other participants was strongly apparent. To prevent this from effecting the quality of future workshops, these two technical officers were “promoted” to the RG, which greatly fostered the wider participation of community members in subsequent workshops.

Within SGMB workshops, there were still obvious power differentials – male, older, and wealthier participants spoke more often, and their opinions were less challenged by others, particularly in plenary discussions. To help overcome this and following the example of Lie et al. (2016), the MBT chose small group work as the preferred method for developing model structure, with groups of five to eight participants as the norm (see Figure 50). Participation levels greatly increased in small group work as it enabled experienced facilitators to draw in the less vocal participants. In the early plenary discussions, it was observed that paddy farmers and pig producers were less inclined to speak out and voice different opinions to the more powerful downstream VC actors, who typically spoke first when the floor was opened for discussion.

Figure 50: Small group work to develop concept models
Source: Researcher

To help overcome this, prior to plenary discussions, individuals were asked to write on cards and then turns were taken to read out their cards to the group, after which a plenary discussion was facilitated. The Notetaker also recorded who provided specific feedback, and this was further helped by colour coding the participant’s name tags according to their role in the VC, i.e., farmers had a green background, wholesalers had a yellow background, etc. It was also observed early on that, while female participants were hesitant to speak out in plenary, they frequently initiated side discussions with each other. To help bring their opinions to the fore, the Assistant Facilitator/Translator and Notetaker (both female) would sit among or near to the female group[47] and either encourage them to speak or help summarise their discussion to present to the group.

[47] Female participants from the target villages sat together in all workshops.

During individual writing exercises, these two MBT members would also help participants who struggled with language and literacy barriers (they both spoke Karen) to write their opinions on cards and engage in the discussions.

One of the key factors in building the effectiveness of the SGMB and RG workshops was the training of the MBT. Two days of initial training were provided to the MBT by the Expert Modeller, including practise sessions of key SGMB tools: hopes-and-fears script, introducing SD terminology through the water bottle example, Layerstack, cause-and-consequence mapping, and concept model building. The first RG workshop served as both an introduction to key technical partners and a quasi-practise session for the MBT. Prior to each workshop, the MBT developed a detailed agenda and practised upcoming facilitation techniques. Of particular value in skill-building was the routine of having MBT members explain cause-and-consequence maps, CLDs, and concept models to one another prior to the workshop (see Figure 51). This also helped identify any misunderstandings among the MBT members and increased the MBT's confidence to facilitate, which was particularly needed for RG workshops that were attended by senior government officials. This technique was also adopted during SGMB and RG workshops with participants routinely volunteering to explain updated versions of the concept models in plenary. This helped the MBT to pinpoint specific areas of the model where there were disagreements, as participants were often more willing to correct or questions from "one of their own" rather than the Researcher or the Lead Facilitator.

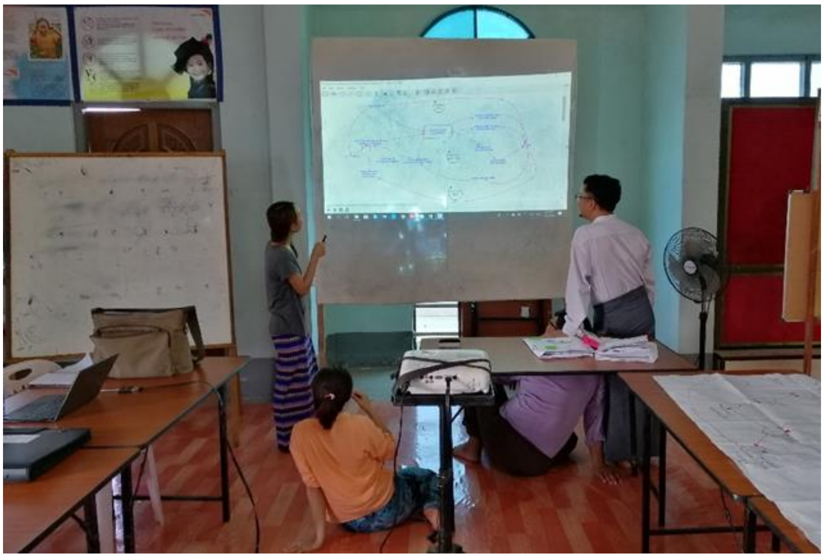


Figure 51: MBT members practise explaining CLDs prior to transposing them to paper
Source: Researcher

Reaching decisions in SGMB and RG workshops through consensus while allowing robust discussions among participants, also proved an important factor for SGMB effectiveness. Decision-making through group discussion and consensus is the common approach for GMB processes as they have been shown to deliver more effective outcomes (Vennix, 1996). Kapoor notes that participatory methods are built on Habermas's notion of an "ideal speech situation," where "discussion is inclusive…coercion free…and open" (2002, p.105). However, in day-to-day activities and formal events, poorer and marginalised community members are often excluded from discussion spaces or their opinions dismissed (Kapoor, 2002; Mosse, 1994). Several approaches were taken to mitigate power imbalances within SGMB and RG workshops while still encouraging open discussions that could expand the mental models of participants. As noted earlier, participants were encouraged to write down their responses to questions prior to sharing to avoid the group-speak phenomenon. Building on this, those who were typically excluded were invited to share their viewpoints early on in plenary discussions. Meanwhile, the MBT made a concerted effort to draw upon these viewpoints during group discussions especially when more vocal or powerful members of the group voiced a differing opinion. For critical decisions (i.e., problem prioritisation, and selecting intervention scenarios and indicators for results) a voting technique was used after options were sought from plenary discussions. In this technique, participants were given three stickers and allowed to place a maximum of two stickers on their preferred options represented by coloured cards on the wall. Participants voted in groups of two or three, as shown in Figure 52 and vote tallies were then shared with everyone for confirmation and discussion.

Figure 52: Voting during the SGMB workshop in Myeik
Source: Researcher

After the initial introductory session, subsequent RG workshops were held following the SGMB workshops, allowing the RG to validate and recommend changes to model structure and parameters. RG members validated around 90% of the structure and parameters originating in the SGMB workshops, with the 10% of suggested changes usually focusing on meso-level information or technical data for interventions, i.e., number of pigs slaughtered per day in Myeik, or the impact of

AHWs on pig mortality. Even when differences in parameter values occurred it was seldom more than a 10% numerical shift. When the changes proposed by the RG were fed back to SGMB participants, there were only a few times when the updated values were not accepted. The main difference between SGMB and RG members was their perspective on the optimal level of model simplicity. SGMB members desired a simple, easy-to-understand model, while in contrast, RG members often expressed the model was oversimplified and further technical data should be included. The MBT strove to keep the model as simple as possible (Sterman, 2000); however, complexity invariably began to increase when the qualitative concept model was quantified using Stella Architect.

Conflict management skills were also needed to promote effective decision-making in the SGMB and RG workshops. During SGMB workshops one and two, there were notable disagreements between farmers and downstream processors (represented by slaughterhouse owners and brokers in the pork chain, and millers in the rice chain). This resulted in heated exchanges centring on the reasons behind low farm-gate prices – farmers accused processors of collusion to reduce prices while processors blamed the poor quality of products and logistical constraints. Initially, MBT members were uncomfortable with this type of intra-group conflict and tried to quickly change the subject or passively let the dominant party lead the argument. It took some convincing for MBT members to accept that cognitive conflict in GMB processes generally increases the quality of decisions (Vennix, 1996, p.156) and was a normal part of the process. The Researcher and MBT discussed this at length between workshops and time was spent training the MBT in basic conflict management techniques, such as diagnostic and action alternative interventions (Vennix, 1996). By the third and fourth SGMB sessions, conflicts about who was to blame for problems in the VC had noticeably lessened; instead, participants focused their discussions on the structure of CLDs and concept models. During the fourth SGMB workshop, participants started to reference the specific structure and relationships within the system as the cause of problems rather than pointing to individual personality traits or behaviours. Underpinning this shift was the informal social exchanges between participants before and after workshops and during food and beverage breaks. Early in the process, VC actors did not mix socially, but by the end of the fifth workshop, strong relationships had developed between individuals from the various VC nodes. MBT members commented that many of these relationships had evolved into business transactions, i.e., slaughterhouse owners discussing their quality standards with participants which later helped PGs make sales to these businesses. This trust among between SGMB participants was supported by the results of the pre- and post-SGMB questionnaire (see Section 6.4). However, this enhanced trust did not extend to VC actors that did not attend the SGMB workshops.

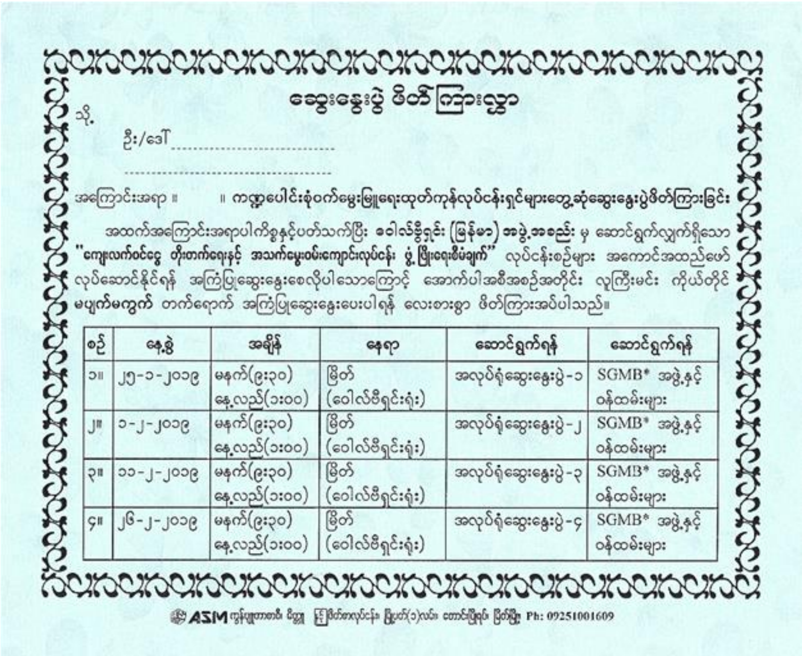
Factors relating to physical tools and facilitation methods discussed above helped foster the commitment of SGMB participants to the model's upgrading recommendations. In the SGMB workshop, there were seven paddy farmers and nine pig producers from the target communities, from which two paddy farmers and two pig producers become leaders[48] in their respective producer groups. In Year Three of the TRRILD project (i.e., following the conclusion of the SGMB workshops and decisions on the upgrading recommendations), a PG prioritisation exercise was conducted. PGs were ranked by their level of collective action, strategy development, capacity of directors, and the capacity of members to support the chosen strategy. Accordingly, the strongest four PGs were selected for support from the TRRILD project to upgrade into Producer Organisations (POs). This support was to include equity capital for investments in value adding assets and prioritising POs for loans from the MFI partner. Following their prioritisation, it was discovered that all four of these PGs (pork VC: Ma Yin and Payi Taung, and paddy VC: Pyin Gyi and Kwe Kue) were led by former SGMB participants and had moved ahead with the model recommendations at a rapid pace compared with other PGs. This included these PGs placing bulk orders for high-quality fertiliser and commercial pig feed, establishing hybrid breeding units and boar units, entering into a supply contract with a rice miller, and investing in value-adding assets without support from the TRRILD project (such as tractors, harvesters, and a pig feed shop). TRRILD project staff commented that the increased understanding on VC dynamics brought into these groups by former SGMB participants, now PG directors, was a key factor in the group's success.

In addition to individual ownership, local government buy-in for upgrading recommendations was critical to the success of the TRRILD project, given the government's role in approving project designs and yearly workplans, authorising travel for international staff, selecting the villages that receive government assistance, and deciding on local policies. The key Regional and Township technical staff for agriculture and livestock departments joined as RG members and requested a number of follow-up meetings with the MBT to discuss how they could better support project implementation. This manifested itself in helping the project team procure high-quality paddy seed from a government seed farm, indicating willingness to grant a five-year license for a high-quality slaughterhouse constructed with project support, and ensuring project target villages received AHW and seed multiplication training.

A necessary complement to a discussion of the effectiveness of SGMB tools is an acknowledgement of caveats. Though engagement in workshops and ownership of model recommendations were high, there was also evidence of fatigue among SGMB and RG participants during the model building process. Participants were made aware of the required commitment levels at the beginning of

[48] Each of these SGMB members was from a different village, so there were four PGs with directors who participated in the SGMB process.

workshop one. However, even while energy levels within workshops were consistent, the number of participants decreased from an average of 13 attending workshops one to four and 10 attending workshop five as shown in Table A6 in Appendix A. Dropouts are common in participatory research; participants have many other responsibilities and their interests in the project and willingness to participate can change over time (Cornwall & Jewkes, 1995). Nevertheless, there were contributing factors to lower participation levels in later stages: paddy harvesting was taking place at the time of SGMB workshop five in Palaw, and monsoon rains made travel to SGMB workshop five in Myeik difficult. The hopes-and-fears exercise at the beginning of workshop one provided an opportunity to address any concerns participants had regarding their commitment early in the process. Farmers from the target villages noted that the project was already one year into implementation and they had not seen any change in their villages; and other participants requested to know workshop times well in advance to ensure they could attend. To address these concerns, documents covering the project's purpose, timeline, and key activities were shared with participants, along with a timeline of the SGMB workshops (see Figure 53).



ဆွေးနွေးပွဲ ဖိတ်ကြားလွှာ

သို့

ဦး/ဒေါ် ....

....

အကြောင်းအရာ ။ ။ **ကဏ္ဍာပေါင်းစုံဝက်မွေးမြူရေးထုတ်ကုန်လုပ်ငန်းရှင်များတွေ့ဆုံဆွေးနွေးပွဲဖိတ်ကြားခြင်း**

အထက်အကြောင်းအရာပါကိစ္စနှင့်ပတ်သက်ပြီး **ဝေါလ်ဗွီရှင်း (မြန်မာ) အဖွဲ့အစည်း** မှ ဆောင်ရွက်လျှက်ရှိသော **"ကျေးလက်ဝင်ငွေ တိုးတက်ရေးနှင့် အသက်မွေးဝမ်းကျောင်းလုပ်ငန်း ဖွံ့ဖြိုးရေးစီမံချက်"** လုပ်ငန်းစဉ်များ အကောင်အထည်ဖော် လုပ်ဆောင်နိုင်ရန် အကြံပြုဆွေးနွေးစေလိုပါသောကြောင့် အောက်ပါအစီအစဉ်အတိုင်း လူကြီးမင်း ကိုယ်တိုင် **မပျက်မကွက်** တက်ရောက် အကြံပြုဆွေးနွေးပေးပါရန် လေးစားစွာ ဖိတ်ကြားအပ်ပါသည်။

စဉ်	နေ့စွဲ	အချိန်	နေရာ	ဆောင်ရွက်ရန်	ဆောင်ရွက်ရန်
၁။	၂၅-၁-၂၀၁၉	မနက်(၉:၃၀) နေ့လည်(၁:၀၀)	မြိတ် (ဝေါလ်ဗီရှင်းရုံး)	အလုပ်ရုံဆွေးနွေးပွဲ-၁	SGMB* အဖွဲ့နှင့် ဝန်ထမ်းများ
၂။	၁-၂-၂၀၁၉	မနက်(၉:၃၀) နေ့လည်(၁:၀၀)	မြိတ် (ဝေါလ်ဗီရှင်းရုံး)	အလုပ်ရုံဆွေးနွေးပွဲ-၂	SGMB* အဖွဲ့နှင့် ဝန်ထမ်းများ
၃။	၁၁-၂-၂၀၁၉	မနက်(၉:၃၀) နေ့လည်(၁:၀၀)	မြိတ် (ဝေါလ်ဗီရှင်းရုံး)	အလုပ်ရုံဆွေးနွေးပွဲ-၃	SGMB* အဖွဲ့နှင့် ဝန်ထမ်းများ
၄။	၂၆-၂-၂၀၁၉	မနက်(၉:၃၀) နေ့လည်(၁:၀၀)	မြိတ် (ဝေါလ်ဗီရှင်းရုံး)	အလုပ်ရုံဆွေးနွေးပွဲ-၄	SGMB* အဖွဲ့နှင့် ဝန်ထမ်းများ

ASM ... Ph: 09251001609

Figure 53: Document provided to participants outlining SGMB process
Source: Researcher

RG members also shared some misconceptions about the location of the project and how they could be involved. However, once the scope of the project was better understood (i.e., working across the entire VC rather than providing handouts to individual community members) government technical officers invited their department directors to attend subsequent RG meetings with them. The first four SGMB and RG workshops took place over a seven-week period and this length of engagement appeared appropriate to maintain participation levels. A much longer gap occurred between workshop four and five which was five months for the pork VC model and 11 months for the paddy

VC model. This length of time was likely too long as it took some effort to reengage participants in both the processes and to reorientate them to the concept models and the scenarios developed for testing.

6.3.2 Analysis of spatial group model building participants' understanding of the pork value chain

Studies have demonstrated the ability of GMB to increase participant understanding of a problem, commitment to a course of action, and to bring about changes in behaviour (Rouwette, et al. 2002; Rouwette, et al. 2011; Scott et al. 2016). To add exploratory insights to the wider body of GMB knowledge, a written pre- and post-SGMB questionnaire was developed by the Researcher to investigate the effectiveness of SGMB in transforming participant understanding of the VC. While Scott et al. (2016) and Rouwette et al. (2002) warn against the methodological problems of using self-reporting to measure the effectiveness of the GMB process, pre- and post-questionnaires remain a valuable and widely used tool for evaluating GMB (Lansu, et al. 2016; Rouwette et al., 2011, Vennix, et al., 1993).

The full pre- and post-SGMB questionnaire, including Myanmar translations, is found in Appendix H, Table H1. The first part (Part A) of the questionnaire focused on participant understanding of the VC, specifically around connections with other actors, value addition, marketing, and ability to upgrade. The second part (Part B) of the questionnaire centred on relationships between VC actors, to gauge levels of trust, collective action, and coordination. The last section (Part C) sought to understand the effectiveness of the SGMB workshops in engaging participants in VC analysis and upgrading. A total of 33 questions were included, out of which 29 used a five-point Likert scale: five points for "strongly agree," four points for "agree," three points for "neutral," two points for "disagree," and one point for "strongly disagree." The use of five-point Likert scales is commonplace in social science and GMB research for measuring changes in attitudes and behaviours (Joshi et al., 2015; Lansu et. al, 2016). The remaining four questions were open-ended and collected data on trust and connections between VC actors, and perceptions of critical challenges.

In total, there were 28 respondents to the first questionnaire and 16 respondents to the follow-up, of which there were 15 overlapping participants. The lower respondent numbers compared to attendees in SGMB one is because of the omission of the two technical officers who were transferred to the RG. The reduced number of respondents in SGMB five reflects the lower attendance owing to the time lag between the workshops. The overall results from the pre- and post-SGMB questionnaires are found in Tables H2 and H3 in Appendix H. The data from the 29 questions with Likert responses were analysed through SPSS using a paired sample t-test to determine changes in the mean value of responses between the pre- and post-SGMB questionnaires. Tables 35 and 36 present the pre-SGMB and post-SGMB mean values, mean differences, t-scores, and significance levels for the 15 paired sample questionnaires. Table 37 shows the mean values for the post-SGMB questionnaire related to participant perspectives on the SGMB workshop and their ownership of upgrading recommendations.

The results in Tables 35 and 36 show nine questions in which the mean response changed significantly between SGMB one and five (Question six with $P < 0.01$, Questions 13, 16, and 18 with $P < 0.05$, and Questions one, ten, 12, 23 and 28 with $P < 0.10$). The overarching trend for Part A questions which centred on participant self-reported knowledge of the VC shows a decline in mean between the first and last SGMB workshop. Participants were less confident that they knew all the key people in the VC, understood the types of relationships between VC actors, knew the characteristics that resulted in increased prices for their products, and understood all the potential markets. In Part B, levels of trust in other VC actors decreased between SGMB one and SGMB five. Participants were less trusting that VC actors were always fair and honest and could be depended upon for help when they faced a problem in their businesses.

It is worth noting that these results contrast with the Researcher's initial hypothesis that SGMB participants' self-reported knowledge of the VC and trust in other VC members would increase during their involvement in the SGMB workshops. Instead, the results suggest that the SGMB process expanded the mental models of the participants to the extent that they became more aware of the complexity of the system and thus their confidence in the depth of their understanding of the VC decreased. This is supported in part by the findings of Rouwette et al. (2011, p.18) who noted that when GMB participants develop a model showing multiple interlinkages between problem elements, they may understand the problem is even more complex than they earlier thought. Rouwette et al. (2011) rationalised this as the reasons why perceived behavioural control scores (i.e., participant perceptions of "the ease of implementing options") remained neutral following GMB sessions. However, in this research there is evidence that the wider knowledge gained of a complex system (i.e., the VC) had a positive impact on the SGMB participant willingness to upgrade their enterprises. From SGMB workshop one until the final SGMB workshop, participant knowledge on how to improve their products to earn additional income increased (Question 16) as did their perception that improving their business was within their own ability. i.e., behavioural control (Question 18). This is further supported by the example of SGMB participants taking leadership positions in the strongest PGs in the TRRILD project, as highlighted in Section 6.3.1.

Table 35: Results from paired sample t-tests of pre- and post-spatial group model building questionnaire, Part A: Value chain

Questions	Pre-test		Post-test		Paired Differences		
	M	N	M	N	M	t	Sig.
1. I know all the key people in the VC.	4.07	15	3.60	15	.467	1.825*	.089
3. There are opportunities to increase my income from paddy/pork.	4.27	15	4.13	15	.133	.807	.433
4. I understand how different people in the VC add value to the product.	3.80	15	3.93	15	-.133	-.487	.634
5. I understand the differences in profit people in the VC make from the value they add to the product.	4.07	15	3.93	15	.133	.564	.582
6. I understand all the types of relationships (friend, contract, cash-buyer, etc.) between the different actors in the VC.	3.80	15	2.87	15	.933	3.761***	.002
7. I understand that men and women have different roles in the VC.	4.14	14	4.00	14	.143	.806	.435
9. I know the quality characteristics of products that earn a higher price.	4.00	15	4.07	15	-.067	-.292	.774
10. I know the volume of products that earn a higher price.	3.80	15	3.40	15	.400	1.871*	.082
11. I know at what times of year the prices for products are higher.	4.00	15	3.93	15	.067	.323	.751
12. I know what type of products are demanded by consumers.	4.07	15	3.73	15	.333	1.784*	.096
13. I have a good understanding of all the potential markets for my products.	3.93	15	3.33	15	.600	2.806**	.014
14. I have a good understanding of how the VC effects (positive and negative) the livelihoods of poorer communities.	4.13	15	4.00	15	.133	.695	.499
15. The VC does little harm to the natural environment.	3.27	15	3.40	15	-.133	-.354	.728
16. I understand how I can improve my products to earn extra income.	4.00	15	4.33	15	-.333	-2.646**	.019
17. I am interested in using new practices in my business.	4.53	15	4.47	15	.067	.367	.719
18. Making improvements to my paddy/pork business is beyond my ability.	3.60	15	3.07	15	.533	2.779**	.015
19. I have a good understanding of the key challenges to earning more income from the VC.	4.13	15	3.93	15	.200	1.146	.271

Note: M refers to the Mean of paired responses, N refers to the Number of paired responses, t refers to the t score, and sig. refers to the level of significance. * indicates P < 0.1, ** indicates P < 0.05, and *** indicates P < 0.01.

Source: SPSS paired sample t-test

Table 36: Results from paired sample t-tests of pre- and post-spatial group model building questionnaire, Part B: Relationships

Questions	*Pre-test*		*Post-test*		*Paired Differences*		
	M	N	M	N	M	t	Sig.
21. My suppliers/buyers always provide me with the information I require for my business.	3.79	14	3.79	14	.000	.000	1.000
22. All members of the VC are always fair and honest in their negotiations with me.	3.43	14	3.43	14	.000	.000	1.000
23. There are specific members of the VC which are always fair and honest in their negotiations with me.	3.86	14	3.64	14	.214	1.883*	.082
24. Members of the VC may use opportunities to hurt me financially.	3.21	14	2.71	14	.500	1.165	.265
25. I only trust specific members of the VC to give me a fair price for my goods or services.	3.64	14	3.86	14	-.214	-.563	.583
26. There are more benefits for me when I work closely with all members of the VC.	3.96	14	4.14	14	-.286	-.939	.365
27. There are more benefits for me when I work closely with specific members of the VC.	3.86	14	3.86	14	.000	.000	1.000
28. I can depend upon my relationships with specific VC members when I have a problem with my business.	4.00	14	3.64	14	.357	2.110*	.055

Note: M refers to the Mean of paired responses, N refers to the Number of paired responses, t refers to the t score, and sig. refers to the level of significance. * indicates $P < 0.1$.
Source: SPSS paired sample t-test

Table 37: Results from post-spatial group model building questionnaire, Part C: Effectiveness of SGMB

Questions	*Post-test*	
	M	N
29. The model that we developed together accurately represents the complex and dynamic processes in the value chain.	4.00	15
31. The model helps me understand how I can make more income from the value chain.	4.13	15
32. Following my participation in the workshops, I have used what I have learnt to improve my business.	3.53	15
33. I have shared with many of my friends/family/business partners what I have learnt from the workshops.	3.67	15

Note: M refers to the Mean of paired responses and N refers to the Number of paired responses
Source: Participant spatial group model building questionnaires

SGMB participants' strengthened relationships with specific VC actors and expanded knowledge of feedback loops in the VC were evident in responses to the four open-ended questions. After SGMB workshop five, participants listed an expanded set of the key actors in the VC (Question two). For the pork VC, participant contacts now extended to include pig feed shops, medicine shops, veterinarians, and the LBVD. Meanwhile in the paddy chain, quality seed producers and the township agricultural officer were identified as key actors in the chain. These additional nodes in the VC, while largely absent in pre-SGMB responses, were now listed in post-SGMB questionnaires as members of the VC that were fair and honest (Question 23) and as members of the VC with whom participants worked closely (Question 27). Interestingly, while there was a fair amount of antagonism towards slaughterhouse owners in initial workshops, producers in the pork chain also included slaughterhouse owners and buyers as trusted entities in the post-questionnaire. In Question 20, participants were asked to list the key challenges to earning more income from the VC. The majority of responses elicited prior to the SGMB process were surface-level problems, that were easily observable to participants and centred around the actions of other identifiable entities. However, following SGMB workshop five, the challenges identified were either root causes within problem feedback loops or problems that participants had more agency to overcome. For example, in the pork SGMB workshop's pre-questionnaire, participant responses centred on the unstable prices of live pigs or unfair relationships with brokers, but in the post-questionnaire they prioritised disease outbreaks, and the quality of hybrid breeding sows and boars as the main challenges. A similar phenomenon was reflected in the paddy VC, where pre-questionnaire responses centred around poor quality roading and labour shortages, two problems largely beyond the control of participants to overcome. In contrast, in the post-questionnaire responses, participants noted access to capital for investments in labour-saving technologies, such as harvesters and tractors, and access to quality seeds that ensures timely harvesting as the key challenges to overcome. Both challenges were identified in cause-and-effect exercises and concept models as leverage points in the system.

Responses in Part C of the questionnaire, as shown in Table 37, indicated the SGMB workshops were an effective tool for engaging participants in VC analysis and upgrading. From the 14 respondents, 12 people reported that they "agreed," and one person stated they "strongly agreed" that the model accurately represented the complex and dynamic processes in the VC. Additionally, 13 participants reported that they "agreed" and one participant that they "strongly agreed" that the model helped them to understand how to increase their income from the VC. Most participants noted that the opportunity to collaborate and form relationships with other stakeholders in the workshop was the most important outcome of the SGMB process. This was closely followed by the gaining of knowledge. The effectiveness of SGMB in increasing knowledge (Questions 29, 30, and 31) was higher than its ability to encourage participants to share and use the knowledge (Questions 32 and

33). This is unsurprising given that the workshop preceded the rollout of the TRRILD project's technical activities and the noted lag between learning and behaviour change. Nevertheless, 71% of participants reported they had used what they learnt in the SGMB workshops to improve their business and 86% of participants stated they had shared learning from the workshop with friends, family, or business partners.

6.3.3 Lessons learned from applying systems thinking and tools within a pro-poor development project

The original nature of the research encourages reflection on the methods employed, analysing challenges, and critical success factors of developing pro-poor VC upgrading recommendations using SGMB tools. To the Researcher's knowledge, this is the first-time research applying systems thinking and participatory model building tools has been undertaken in Myanmar. In addition, previous applications of GMB and SGMB in VC analysis have provided general policy recommendations; however, this research embedded SGMB in a development intervention with the express purpose of selecting pro-poor upgrading activities. In this section, several macro-level themes are described, acting as lessons learned and discussion points to help guide future applications of SGMB within development interventions.

6.3.3.1 Model purpose

An early, shared understanding as to the purpose of a quantitative SD model is critical to ensure the resultant model supports project decision-making. The SD literature encourages stakeholders to see SD models as useful decision support tools, rather than precise forecasting instruments (Sterman, 2000, Vennix, 1999). This tension in purpose was present in the project to some degree. A section of project stakeholders understood the model as a helpful tool to make more informed, and hence better, decisions, while others desired a model that would make precise predictions. For project stakeholders on the latter end of the spectrum (i.e., models are precision forecasting instruments), the model should be as close as possible a representation of the target VCs. This view naturally leads to an increasingly complex quantitative model, one that will bear less and less resemblance to the original CLDs and concept models developed with SGMB stakeholders. This search for realism lengthens the time for developing a "finished" model (i.e., a model that is thorough enough to provide upgrading recommendations), as the model's boundary and structure grow to accommodate complexity. For the stakeholders who envisioned the model as a decision-support tool, the aim is for a simpler, even a parsimonious, model that provides insights into critical feedback loops and relationship that drive system behaviour. An understanding around the specific elements that *drive* system behaviour leads to simplification through restricting the model's boundary and core structure. For example, when 20% of the structure in a system can be shown to *drive* 90% of the behaviour, a decision around whether to model the remaining 80% of the structure should be explored. Agreement among stakeholders on model purpose, boundaries, and structure can ultimately lead to a simpler and more pliable model that requires fewer resources to develop and is easier to understand by the wider set of stakeholders, especially those intimately involved in bringing about the model's recommendations, i.e., VC actors and the TRRILD project team. A simpler model would also enhance the ability of an expanded group of stakeholders (i.e., project team members, donors, RG and SGMB participants) to use and iteratively update the model, particularly if the model were hosted online or built through open-access software, such as Insight Maker (https://insightmaker.com/).

The purpose of the SD model in determining the strategic direction of a development project should also be clear to direct the timing of the modelling process. One question that needs addressing early in the project is: Are the model's recommendations going to help determine the overall scope and direction of the project, or rather, will the model assist the project team to allocate resources within a set of pre-determined options? The TRRILD project's design document, budget, and workplan were approved in August 2017 with the project officially starting in September of the same year. The modelling process, however, did not begin until January 2019 with the pork VC's upgrading recommendation approved in August 2019, almost two years into the project's five-year timeframe. As a result, the problems identified and the model's boundary, as well as the scenarios run for the *ex-ante* impact evaluation were strongly influenced by the project's existing framework and activities. The timing of the modelling process constrained the ability to explore other options for project interventions, such as changes to the slaughterhouse policy, or strengthening the LBVD's service delivery. Bringing SD modelling earlier into the design process could have elicited a more sustainable and impactful development intervention. Once target VCs and geographic location have been decided upon an SGMB process could help define the project's strategy, including the element of the market system to focus on (supporting functions, rules, or the core supply and demand functions), how resources should be allocated to different project partners, and even the type of partners required for an effective project consortium.

6.3.3.2 A mixed methods approach

In a data scarce environment, such as Myanmar, future SGMB processes could employ a mixed methods approach to strengthen the reliability and validity of the model and its recommendations. Participatory model building is a time-consuming process, requiring dedicated resources, commitment by stakeholders, as well as technical expertise in model building (Lie, 2017). The SGMB tools used in this research identified spatial and temporal dynamics, and leverage points in the VC system that would not have surfaced if the project had solely relied on traditional VCA methods, such as surveys, FGDs, and KIIs (Rich et al., 2018). Moreover, as Lie (2017) noted, using participatory methods to construct an SD VC model promotes team learning, consensus decision-making, and commitment to the model's recommendations. Triangulation in this research was built using the RG and supplementary KIIs and FGDs.[49] Secondary data covering the target population area was limited, consisting only of the TRRILD project's baseline survey (Snoxell & Lyne, 2018), two rapid VC assessment (Rich, 2018; ACCESS Advisory, 2019), and a household economic assessment (WV Myanmar, 2018). Even though a diverse set of stakeholders were involved in the SGMB process, there is a risk that the views expressed, or the data obtained in workshops did not adequately represent the target population. Conducting a survey of key VC actors once the initial concept model had been developed could have helped address knowledge gaps identified in the SGMB process. In this research, several small surveys undertaken by the TRRILD project were drawn upon to supplement data from the SGMB and RG workshops, including a survey of PG members and a survey of restaurants and hotels regarding their demand for high-quality pork cuts. Another potential option to overcome data scarcity and reduce the resources involved in participatory model building is to start with an existing, validated model structure and use a smaller number of workshops and surveys to contextualise it (Vennix, 1996). This would enhance the scalability of SGMB and GMB processes, shifting limited project or donor resources towards nuanced model enhancement and context specific scenario testing.

A challenge of using SD models for VC analysis is the reliance on aggregated data (Lie, 2017) which can treat smallholder farmers as a homogenous group. This research attempted to overcome this challenge by using model arrays that captured six different pig enterprises. One advantage of using additional survey data is to further understand the diversity of small-scale pig farmers, enhancing the ability of the model to consider the horizontal impacts of VC upgrading scenarios (Riisgard et al., 2010). For example, additional information around the asset base, gender, additional livelihood sources, and demographics of pig producers would help to further understand the project's impacts on the wellbeing of targeted household and any multiplier effects from the interventions. This could include socio-economic measures such as expenditure on education, health, or nutrition. Any use of mixed methods approaches will likely add to the cost and time of conducting an SGMB process and would therefore need to consider resource constraints and align to the purpose of the model.

6.3.3.3 Training of the model building team

The effectiveness of any GMB process relies on skilled facilitation by the MBT (Vennix, 1996). Strong facilitation skills aid in developing a robust model that includes critical structure and feedback loops but also ensures ownership of the model's results, leading to behaviour changes within participants. Much thought needs to be given to whom should be on the MBT, what their roles are, and the type of training they require. Rather than selecting the roles of MBT members before training, roles

[49] Including the KIIs and FGDs undertaken within a traditional VCA of the target area by an external agency (ACCESS Advisory, 2019).

should be assigned after an assessment of team member capacity following the training and mock exercises. In the research, two days of training was provided to the team before the first RG workshop; however, the MBT still struggled to fully fulfil their roles and responsibilities until after the second SGMB workshop. While these challenges could have been lessened by a better allocation of roles to team members, it also suggests further practise exercises were warranted. This could include practise sessions on difficult-to-grasp exercises and further workshop run-throughs with mock participants. Ideally, the MBT should be confident in facilitating SGMB exercises before the first RG workshops, especially when key project partners, like local government officials, are members of the RG.

The scope of training provided to the MBT should be determined by the role the SD model plays in the development project. In the TRRILD project, the Researcher was primarily responsible for developing the SD model and the *ex-ante* impact evaluation. This meant the Researcher led the MBT, co-facilitated the workshops, constructed the quantitative SD model, and presented *ex-ante* recommendations to the PAC over a two-year period (i.e., field research and analysis-of-results stage of a PhD degree). However, if the SD modelling is included in the design phase and iterative modelling is a priority throughout the project, then dedicated project staff would need to be equipped to lead the process throughout the project's lifetime. This would entail more detailed training and then ongoing coaching and mentoring by an expert modeller and budget support for a full-time modeller to be integrated into the project team. While the modelling process was iterative to a degree, after a certain point the lead modeller's focus (as a PhD student) turned to the writing up and dissemination of the results.

Further integration of the lead SD modeller into the project team is also recommended where time, budget, and logistics allow. This would see the SD modeller being based in the project site for extended periods of time, providing easier access to target communities, key stakeholders, and project decisionmakers. If resources are restricted, deeper integration should happen at the front end of the project as this allows the lead modeller to better understand the phenomena under study and to help select the makeup of the MBT and the composition of SGMB and RG participants. In this research, deeper integration was partially achieved through the background of the Researcher, who had previously worked in Myanmar for the partner INGO, including time in the project's target area. The connection between the Researcher and the project location was also made stronger through having two TRRILD project staff join as participants of the RG. The ease of communication with these project staff through email and video chat meant that they evolved into gatekeepers for the RG, which was especially valuable in seeking additional technical data during the process of converting the qualitative concept model into a quantitative SD model which took place in New Zealand.

6.3.3.4 Selection of spatial group model building and reference group participants

Ideally the selection of SGMB and RG participants should take place once the MBT has a solid understanding of the SGMB process and the broad issues and actors involved in the VC. In this research, the selection of the SGMB and RG participants happened prior to the Researcher's arrival in Myanmar given the logistics of organising and inviting remote producers to the workshops. As the model-building workshops progressed, it became evident that additional stakeholder perspectives would have delivered more insightful workshop discussions. This meant several people were later added to the RG workshop (e.g., heads of the township's livestock and agricultural departments), and KIIs outside of the workshops were conducted with paddy and pork retailers, paddy mill owners, and input supply shop owners. In retrospect, it would have been helpful for owners of the two large paddy mills and representatives from the Myeik restaurant association to have joined SGMB workshops as these actors eventually served as the project's critical partners for upgrading the VCs. In the end, the MBT had multiple meetings with the two largest paddy mill owners, resulting in the introduction of a supply contract for a high-quality paddy variety between one mill owner and a PG. For the pork VC, the Researcher conducted several meetings with individual restaurant owners to understand their quality and demand requirements and was able to video call into a restaurant association meeting with 26 restaurant owners to canvas orders for high-quality pork cuts.

When the purpose of GMB is to support decision-making in a development project, key project decision makers need to be involved in the model-building process to build trust in the model's recommendations. The overall governance of the TRRILD project was provided by the PAC, which consisted of the representatives from the four project partners. Only one member of the PAC participated in the SGMB and RG workshops, and this was limited to the first round of SGMB and RG workshops. As a result, the Researcher represented the model's recommendations to the PAC through formal and informal mechanisms. Formal presentations were given of the preliminary results after the field research phase (March 2019) and then of the final recommendations after SGMB five (July 2019 and January 2020). Informal updates were given to PAC members at various stages. For example, the MFI partner asked for help in developing loan products for pork and paddy producers based on the model's results, and the TRRILD project's Chief of Party (CoP) requested a cost-benefit analysis of the introduction of AHWs in the target villages. While these showed the value and confidence that were placed in the model, ownership of the model's recommendations would have been strengthened by having PAC members, particularly the project CoP, more fully involved in the process. Implementation challenges in the project would have benefited from a deeper knowledge of the model's results by project decision-makers, including delays in providing loans to PGs for investing in value-adding assets, and a reluctance to extend credit lines to pig producers to help manage liquidity stress during the fluctuations in live pig prices extending from COVID-19 restrictions to restaurants and disease outbreaks.

Chapter 7
Conclusions

This research used systems thinking and participatory SGMB methods to develop a SD model of the pork VC in Myeik and Palaw townships in the Tanintharyi region of Myanmar. The quantitative SD model was used to conduct an *ex-ante* impact evaluation of potential pro-poor upgrading strategies for implementation within the TRRILD project. The *ex-ante* scenario testing quantified the impacts and trade-offs of upgrading strategies among pork VCs actors, with a focus on small-scale farmers. Analysing the results of the scenario testing generated a series of pro-poor upgrading recommendations for the TRRILD project.

This chapter summarises the main findings of the SGMB process and the *ex-ante* impact evaluation in Section 7.1, with the key recommendations made to the TRRILD project covered in Section 7.2. The research's contribution to theory and methods is highlighted in Section 7.3, followed by a summary of policy implications in Section 7.4. Challenges to the research are outlined in Section 7.5, and Section 7.6 concludes the chapter with recommendations for future research.

7.1 Summary of main findings

The SGMB process highlighted the constraints and importance of small-scale pig production as a livelihood strategy in the target villages of the TRRILD project. For farmers with access to arable farmland, pig production helped diversify household incomes, lowering vulnerability to shocks. For the resource poor, pigs were a form of savings used to alleviate temporary cashflow problems and to finance inputs for subsistence crops and non-farm enterprises. Small-scale pig farmers were broadly categorised into two production systems: the smaller and less costly WF system, and the larger and more intensive FF system. Local breed pigs were predominantly farmed by small-scale farmers, even though slaughterhouses increasingly sought hybrid pigs to meet rising consumer demand for leaner pork and premium cuts. A government licensing system for pig slaughtering allowed slaughterhouses to assume the role of "lead" actors in the VC. These slaughterhouses operated at low food safety standards and had little incentive to invest in hygienic, food-safe facilities. The majority of hybrid pigs sent to local slaughterhouses were imported from outside the region, while retailers seeking premium pork cuts relied on frozen imports to meet quality standards. Small-scale pig producers in the project's target villages faced significant barriers as they sought to increase production capacity or upgrade their enterprises from WF to FF systems and from local breeds to hybrid pigs. These obstacles included large price oscillations, high transaction costs, limited horizontal and vertical coordination, frequent disease outbreaks, and liquidity problems.

An SD model was developed to conduct an *ex-ante* impact evaluation of pro-poor upgrading strategies proposed for the pork VC. The quantitative SD model comprised seven modules that captured critical sub-sectors and feedback loops identified by SGMB and RG participants, including new innovations to model collective action and the provision of credit. Stakeholders selected three institutional scenarios for testing and comparison: S1 (focusing on individual pig producers), S2 (establishing pig PGs), and S3 (transitioning PGs to POs). In conjunction with the institutional scenarios, five technical upgrading activities were tested: microcredit, technical training on hybrid pig production, AHWs, AI, and jointly implementing all four technical activities.

A baseline model spanning fifteen years was simulated to allow comparisons against a benchmark of no project interventions. In the baseline model, the price of live pigs rose steadily although significant outbreaks of swine disease caused substantive price fluctuations. These large price spikes induced small-scale producers to either increase production capacity or to upgrade to higher value – but riskier – pig enterprises. When live pig prices fell sharply due to the subsequent oversupply of fatteners, small-scale producers became over-indebted and dropped out of pig farming. The potential four-fold increase in profits provided a strong incentive for farmers to upgrade from local to hybrid breeds as well as from WF to FF systems. However, the anticipation of higher profits was offset by the larger risks inherent within these systems. Hybrid FF farming systems experienced longer and deeper periods of negative cashflow owing to higher pig mortality rates, the fluctuating live pig price, and the substantial loan payments to informal moneylenders. Pig farmers upgraded steadily from local breed WF to local breed FF farming systems, with a third of upgraded FF farmers, though, dropping out and returning to WF systems. Importantly, small-scale pig producers were still unable to upgrade in large numbers to the highly profitable hybrid FF system because they could not access affordable loans to finance breeding sows and appropriate housing and the high risks due to price fluctuations and disease outbreaks.

The model established a clear rank order of individual technical activities: (1) AHWs, (2) microcredit, (3) technical training, and (4) AI. The establishment of village-based AHWs generated the largest financial gains for farmers because lower pig mortality rates protected poorer farmers from negative cashflow and loan defaults. Maintaining higher pig stocks during disease outbreaks meant farmers could rapidly scale-up production and take advantage of favourable post-disease prices, generating a strong positive flow-on effect to farm profitability and allowing further farm investments. The ability of PGs (S2) and POs (S3) to retain earnings allowed almost universal coverage of AHW services for members, while less than a quarter of pigs were covered in S1 (individuals). Formal microcredit loans had the greatest impact on the number of pig producers upgrading to highly profitable systems, with some risks for poorer farmers. Microcredit doubled the proportion of farmers who dropped out of FF systems because it exacerbated the consequences of negative cashflow. The technical training of pig producers delivered around two-thirds the impacts of microcredit and AHW. Training alone did not encourage upgrading but did help to increase the profitability of current pig enterprises. AI exerted minimal system impacts and involved high risks.

Combining technical activities resulted in a healthy interaction effect, delivering two to three times higher aggregate profits for pig producers than the highest single activity. This combined impact was particularly important in S2 (PGs) and S3 (POs) where individual activities had a short-term negative impact but, significantly, a well-sequenced combination of upgrading activities ensured short-term positive pro-poor and financial outcomes. Individual technical activities were unable to fully overcome liquidity problems faced by PG and PO members; however, combining these activities protected members from negative cashflows, and prevented PGs and POs from nascent collapse when member profits, PG rebates, and PG services were low. The risk-lowering ability of PGs and POs encouraged members to rapidly transition from moderately profitable WF to highly profitable FF systems, activating reinforcing feedback investment loops.

Investing in the institutional arrangements of collective action delivered delayed, but more substantial, pro-poor and financial impacts. While S1 (individuals) had the highest short-term financial benefit, these gains quickly plateaued. In contrast, establishing PGs (S2) that provide transaction services delivered close to twice the long-term economic benefits of focusing on individual farmers (S1). Meanwhile, transitioning PGs to POs (S3) that can finance value-adding assets grew aggregate incomes by three times that of S1 (individuals) and twice that of S2 (PGs), while also bringing 24% more pig producers into highly profitable systems. Project investments in POs, and to a lesser extent PGs, created a pathway for poorer pig producers with lower capital and risk tolerance to engage in a moderately profitable farming system (hybrid WF) and then transition to a highly profitable system (hybrid FF). Institutional arrangements that encouraged both retained earnings and rebates for members increased the financial position of members and the inclusiveness of the PG/PO. Increasing the proportion of retained earnings for investment in value-adding assets enabled a more inclusive PO while also generating higher profits for members.

The model identified two areas of concern regarding producer liquidity. In S1 (individuals), established hybrid FF farmers faced periods of negative cashflow soon after the project exits. PG and PO members in S2 and S3 likewise experienced significant liquidity problems when they took on microcredit loans to upgrade farms to hybrid FF or WF systems. Increasing the length of loan terms combined with either a balloon or deferred payment schedule and selling a higher portion of piglets enabled producers to maintain positive cashflows, albeit with overall reductions in farm profits.

Each institutional scenario had a different impact on downstream actors in the pork VC. S1 (individuals) magnified the current system leading to profit increases for brokers and slaughterhouses. Cumulative profits for brokers and slaughterhouses fell slightly in S2 (PGs) and S3 (POs), while all three scenarios substantially increased off-farm employment. The increases in off-farm wages in S2 (PGs) and S3 (POs) largely offset losses experienced by brokers and slaughterhouses in the system. The model suggested that a safe, hygienic slaughterhouse capable of producing premium pork cuts is a sound investment for a strategic partner, while also revealing that, once established, a PO could finance this asset with debt capital borrowed at market rates.

Sensitivity analysis conducted with alternative scenarios and stochastic parameters strengthened the model's original findings: the greatest pro-poor and financial gains result from well-sequenced investments in AHWs, microcredit, and training alongside the establishment of PGs that transition to POs. An alternative scenario that modelled an emerging ASF threat showed that project impacts are sustainable when biosecurity practices are interwoven into the combination of technical activities. However, providing microcredit loans prior to risk-lowering technical activities could cause sustained negative impacts in target villages.

7.2 Contribution to the TRRILD project

The research provided the TRRILD project with technical advice while concurrently strengthening the understanding and ownership of interventions by project beneficiaries and staff alike. Analysing the findings of the *ex-ante* impact evaluation led to focused and prioritised pro-poor upgrading recommendations for the project's pork VC. The recommended interventions were then shared with TRRILD stakeholders for discussion and research informed decision-making in the project. All the study's recommendations were adopted by the TRRILD PAC and guided project implementation through the research period.

The research recommended that the TRRILD project should focus on collective action rather than broadly targeting individual producers. The project should initially establish pig PGs that operate at a transactional level and later upgrade to PO status by investing in value-adding assets for forward and backward integration in the VC. The research indicated that significant project resources should be allocated to create investor-friendly institutional arrangements as these encourage more inclusive and profitable PGs and POs. PGs need to retain earnings to maintain collective services because these improve financial outcomes for members. To upgrade PGs to POs, institutional arrangements that encourage investment and discourage side-selling need to be adopted. The institutional arrangements should allow (i) control to reside with patron members; (ii) different types of shares to raise equity capital from members and non-members; (iii) proportionality between investment and patronage; and (iv) secondary markets for equity shares. Considering their pro-poor and economic benefits, the research encouraged the TRRILD project to work closely with prioritised POs to develop enterprise business plans that would appeal to equity investors, including smallholder patrons and strategic partners, and formal lenders as partners in a well-structured IBM.

High-quality hybrid fattener production was also recommended by the research. A well-sequenced combination of technical activities initiated by the project and sustained by functional PGs and POs, helps to protect small-scale producers from high levels of risk inherent in hybrid pig farming. The burgeoning premium pork market should be targeted, first in Myeik and later Yangon, to overcome hold-up problems and collusion between slaughterhouses. To differentiate their products, PGs would need to develop a set of achievable food safety, environmental, and ethical minimum quality standards (MQS) that participating members must satisfy in their farming operations. As a first-step, PGs and project staff could partner with interested retailers in Myeik and a reputable slaughterhouse to make regular deliveries of high-quality pork cuts. Small breeding sow and boar units established by the project within prioritised PGs would help lower costs and maintain the genetic integrity of fatteners and continued access to premium markets. A common production plan based on piglets and sows from breeding units that meet the MQS would be required to satisfy a contract to supply a consistent quantity of high-quality fatteners. Introducing a tagging system would also help safeguard against opportunistic behaviour by PG members and the slaughterhouse, while assuring quality by promoting traceability. Creating a tradeable delivery right based on MQS and tied to the tagging system would further assist PGs to monitor quality and fulfil supply contracts.

The research showed that slaughterhouses may resist partnering with PGs and as a result the project should provide incentives to attract a reputable business partner. Incentives could include training and equipment grants to encourage partnerships with an existing slaughterhouse, but if this fails, then the project should consider supporting a PO through a mixture of equity, grant, and debt capital to establish their own upgraded slaughterhouse. Establishing a partnership with a slaughterhouse creates a less resource intensive, but profitable, pig system – the hybrid WF – widening the membership and profitability of POs which in turn leads to wider, deeper, and more sustainable project impacts.

The project was recommended to jointly implement AHWs, microcredit, and technical training activities alongside investments in biosecurity protocols. The sequencing of interventions is shown as critical by the research. A well-trained and equipped AHW network should be established first, and technical training completed before formal microcredit loans are made available for farm upgrades. The research advised that the partner MFI make a minimum of US$150,000 available for asset and seasonal loans, while lengthening loan terms and offering balloon and deferred repayment schedules as these conditions help poorer village households to benefit from PG membership by upgrading to hybrid pig farming. Given the increased risk of an ASF outbreak, the research suggested that the MFI restrict microcredit loans only to those PG members and non-members who have invested in biosecurity infrastructure and practices.

The SGMB process changed the mental models of participants, fostered ownership of interventions, and strengthened project implementation. Participants' understanding of the VC widened, trust with known VC actors grew, and confidence to upgrade increased, leading to improved short-term project outcomes. It is noteworthy that all four POs prioritised for upgrading had a former SGMB participant as a director, while RG members had used their own resources to support pig vaccination campaigns and the procurement of high-quality inputs. Project staff were able to reference the model to make critical decisions on how to support the pig industry through price and disease shocks, including shifting project budget to support biosecurity practices and debt relief.

7.3 Contributions to theory and methodology

In an advancement over a traditional VCA, systems thinking and SGMB tools show how critical feedback loops and causal relationships in the VC system work to prevent small-scale farmers from upgrading. Participatory SGMB tools quickly bring to the surface the contextual temporal and spatial dynamics affecting the VC. Moving beyond a qualitative analysis, the SGMB process and SD modelling tools quantify these causal relationships in the system, allowing for an *ex-ante* evaluation of intervention impacts across a wide range of VC actors. This evaluation enables trade-off analysis and the selection of strategies that have positive and sustainable benefits for small-scale farmers. Trade-off analysis also helps identify coordination issues and actors potentially resistant to upgrading, narrowing solutions to those that have a higher chance of success. The ability to conduct quantitative trade-off analysis across different actors and time horizons can also help decision-makers to rationalise investments in upgrading activities that have longer pay-off times or initially lower beneficiary numbers, such as establishing PGs that transition to POs.

Diverse barriers prevent small-scale farmers from engaging in high VCs (Trienekens, 2011), making entry points or catalytic activities difficult to determine. An SGMB informed SD model helps distil the complex nature of agri-food VCs by identifying "root" system problems, thus improving the targeting of upgrading interventions. The research highlights that a well-sequenced, multipronged approach is required to deliver sustainable and far-reaching benefits to small-scale farmers. Microcredit catalyses small-scale producers to "step up" into higher value systems, while AHWs and training in GAHPs are important risk-lowering mechanisms allowing small-scale producers to "hold on" during the inevitable shocks. In markets with price volatility, the ability to "hold on" permits small-scale producers to enjoy favourable prices, leading to further investments. The research also demonstrates the value of collective action as part of a multipronged approach. PGs that transition to POs help sustain and multiply the short injections of technical assistance from development projects and enable a larger number of poorer small-scale farmers to both “step up” and “hold on”. Importantly in VCs where there is possible collusion or domination by a lead actor, such as a slaughterhouse, POs and PGs improve negotiation capacity because of their ability to meet quality requirements of premium buyers as well as increasing the potential for forward and backward integration, a “stepping out” into value-adding activities.

The research proposes that institutional arrangements are critical to the success of collective action, particularly in contexts such as Myanmar where financial services are weak resulting in limited access to term loans of modest size, leading to a “missing middle” (Milder, 2008). Investor-friendly institutional arrangements assist PGs to transition into POs that can finance value adding assets and engage in IBMs while encouraging member patronage. Importantly, the research demonstrates that shifting project resources to “soft” activities (like constituting PGs with appropriate institutional and governance arrangements) are critical to ensuring that “hard” activities (like capital or asset grants) have pro-poor multipliers. These multipliers stem from inclusion (grant capital gives even the poorest members a meaningful financial interest in their PO), equity (members can realise capital gains on their patronage-based shareholding), employment (creating off-farm jobs), and higher incomes (through value-added products).

The research widens the corpus of GMB theory by documenting a first-time application of SGMB to upgrading small-scale farmers within an agri-food VC project. Unlike earlier studies that stopped at policy recommendations (Lie et al., 2018), this research was guided by action research principles and embedded in a development intervention, such that the SD model’s findings helped determine the project’s pro-poor upgrading strategies. The SGMB processes described in this research therefore provide a roadmap for future pro-poor applications to follow. This roadmap includes examples of process timelines, workshop agendas, team compositions, SGMB exercises and scripts, and VC modules, along with lessons learned from reflections on the process. These insights can be applied to future initiatives using SGMB and systems thinking to upgrade agri-food VCs and to other community-based research topics in which spatial dynamics are important considerations within messy problems.

Importantly, the research adds several innovative modules and methods to the body of SD model structure. First, the research showcases endogenized product pricing for small-scale producers by linking the farmgate price and the aggregate system price. These connections allow both higher-level (regional) and lower-level (village) system changes to inform pricing. Second, the research presents a credit module for simulating the impacts of different financing options for small-scale farmers in the VC. The credit module includes functionality to alter the stock of credit available, prioritise different loan products, and adjust loan conditions. Finally, the research extends the collective action structure of McRoberts et al. (2013) to create PG and PO modules. These modules shed light on the financial and pro-poor performance of different PG and PO institutional structures and their impacts on the wider VC system. The PG module includes functionality around membership, retained earnings to finance PG transactional services, and rebates for members. The PO module's additional structure captures the ability to invest in a value-adding assets. The credit, PG, and PO modules are considered beta versions and further refinement is anticipated as these modules are absorbed into future SD VC modelling processes.

7.4 Policy implications

Several contextual and wider policy implications arise from the research's findings that development agencies should consider a multipronged approach when working to upgrade small-scale farmers. Complex constraints and diversity amongst farmers require intertwined and reinforcing, as opposed to siloed, intervention strategies. This research shows that a well-sequenced combination of technical training, horizontal and vertical coordination mechanisms, disease prevention, and micro and meso-credit delivers the highest pro-poor and financial outcomes for small-scale pig producers. While some farmers can successfully upgrade their enterprises with the assistance of one or two activities, poorer farmers require more layered support. There is pressure for development projects to cover large target populations, and this often limits the range of technical support available to farmers. However, the research suggests that by narrowing their investments to broadly supporting a smaller number of committed small-scale farmers within a PG or PO, development agencies will achieve greater inclusion and financial outcomes. POs that adopt institutional arrangements which encourage compliance with supply contracts and investment in value-adding assets can attract strategic business partners and successfully enter premium markets. These POs can remain inclusive of poorer members when grant capital contributed by donors to finance value-adding assets is treated as equity capital invested by members, with each member receiving an equal number of shares or through the provision of tradeable delivery rights.

The research also indicates that the provision of affordable and appropriate credit is critical for small-scale farmers in Myanmar to upgrade their agri-food enterprises. MFIs and other financial institutions need to develop loan products to address smallholder liquidity problems. This includes products that allow small-scale farmers to finance seasonal inputs that result in products that meet the quality and food safety requirements of premium markets, along with meso-sized loans to finance lumpy, value-adding assets. Finance for durable assets needs to have longer repayment periods than those currently offered by MFIs (two years) and optional repayment schedules (deferred, graduated, or balloon) that align well with anticipated cash inflows. Importantly, these meso-sized loans should be available to well-structured groups, such as POs, without requiring each member to accept liability for "their" share of the PO's loan. Assets purchased by the PO can be liquidated by its directors to repay outstanding loans in the event of a default. Members therefore risk losing their equity capital in the event of a default and should not be expected to assume the lender's risk in their personal capacity. Development projects could include instruments, such as tradable class B shares and equity capital injections, to help leverage additional financial resources from the private sector that facilitate IBMs. Findings from the research also suggests that the risks for MFIs of lending to poorer small-scale producers reduce when these clients are provided with targeted loan products and supported with technical activities, such as training, access to AHWs, and biosecurity guidelines through membership in functional PGs and POs.

Testing intervention strategies in a virtual modelling environment is a cost-effective method for development agencies to trial different upgrading solutions with little risk of harm from experimentation with non-traditional approaches. SD models improve decision-making, leading to a better allocation of scare development resources and an increased ability to target interventions to vulnerable or marginalised groups. This technique is particularly applicable to complex, interconnected environments, like agri-food VCs, in which interventions may create winners at the expense of losers and result in unintended negative consequences that manifest well after the action.

Additionally important, development partners should understand the rationale for using VC SD models early in the project process. Within an already designed project, SD modelling guides the implementation of pre-selected upgrading activities and the allocation of resources. In contrast, embedding SD modelling from a project's inception enables policy makers to test a wider set of upgrading approaches, helping to set the project's strategic direction and design. This latter approach requires more flexibility on behalf of donor agencies and, as such, it fits well within those agencies that apply adaptive aid management principles. For modelling insights to fully saturate these decision spaces, key project decision-makers need to recognise that they are also stakeholders in the modelling process and further engage within RG or SGMB workshops.

7.5 Challenges and limitations to the research

Several practical constraints limited the effectiveness of the research's participatory SD modelling methods in determining pro-poor upgrading strategies. First, the timing of the SGMB process meant that the scope of research (and model) was, to a large extent, bounded by the TRRILD project's existing design documents. This limited opportunities for the research to investigate a wider set of pro-poor policy options for upgrading the pork VC. Second, although a total of twelve weeks was spent in Myanmar across three field trips, lengthier or more frequent trips would have assisted data gathering and analysis. Field timeframes were selected to accommodate project workplans, resulting in the qualitative SGMB processes being undertaken in Myanmar, with quantitative SD model building largely completed remotely from New Zealand. This inhibited the co-creation of the quantitative SD model with SGMB and RG participants, lessening their ability to learn directly from interactions with a quantitative model. The time spent training and completing mock-up workshops with the model-building team could, in hindsight, have been lengthened, leading to improved workshop facilitation that further garnered stakeholder engagement. Additionally, not having the VC retail segment involved early in the SGMB process stunted the development of the model's downstream structure, and possibly slowed the creation of partnerships with strategic business partners. Third, due to COVID-19, restrictions were placed on domestic and international travel in Myanmar from March 2020. This restricted in-person interactions with the TRRILD team, SGMB and RG participants, and target communities that were planned for the iterative modelling process. While on-line discussions enabled further model iterations, the reduction in workshops and KIIs limited dialectic interactions that would have led to subsequent model refinement and improved decision-making. Lastly, the participatory phase of this research involved cross-cultural interactions. As a result, the Researcher's worldview and language skills shaped his interactions with participants in workshops, KIIs, and FGDs, thus influencing how data was collected and interpreted.

As noted in other VC research using SD approaches (Lie, 2017), one challenge of using SD models is the reliance on aggregated data. While aggregation helps to model system behaviour and understand macro- and meso-level patterns, it can result in small-scale farmers being treated as a homogenous group. Other agricultural simulation models, such as agent-based modelling, enable further heterogeneity at the farm-level (Berger, 2001), though they are constrained by their inability to interact with system-level evolutions and employ less-intuitive and more complicated computer programming tools than SD applications. The research sought to overcome this challenge and infuse pro-poor methods into the model through categorising small-scale farmers by production system and introducing limited heterogeneity through arrays in the SD modelling software, Stella Architect. These categorisations were based on a rapid VC assessment and SGMB and RG information and therefore did not fully capture the diverse range of small-scale farmers in the target villages. Important contextual information relating to gender, ethnicity, household assets, and alternative livelihood strategies of pig producers was therefore likely excluded from the research. A deeper understanding of household savings and wealth would have helped advance the credit and investment portions of the SD model. However, gathering this information through survey instruments and building more complicated models to accommodate the additional data would have added significant cost and time, impacting other areas of the research.

The sensitivity analysis reported in this thesis was conducted to determine whether plausible uncertainty altered the model's pro-poor upgrading recommendations. Alongside a range of alternative contextual scenarios, 14 parameters were treated as stochastic variables. More detailed methods to determine model sensitivity could have been employed had resources and time allowed. For example, Chapman and Darby (2016) select a larger range of unreliable parameters and test the general sensitivity of each parameter by running multiple simulations with a uniform distribution over a ± 50% error range. The sub-set of parameters that exhibit general sensitivity (i.e., they significantly alter model behaviour and/or the results of scenario testing) could then be further explored individually or through various combinations to understand the key drivers behind changes in model behaviour or scenario results.

7.6 Recommendations for future research

This research provided an initial application of SGMB to upgrade pro-poor VCs within an international development project. The SGMB process documented within this research can be applied to other agri-food VCs in different contexts to generate further insights into the effectiveness of participatory modelling tools to engage stakeholders in VCA and upgrading. Future research could take a more longitudinal approach, documenting how the SD model and its findings evolve over time and how the modelling process changes mental models of participants and the direction of upgrading interventions from original intentions. As well as further resources, this practice would also require integrating adaptive management techniques into the development intervention and flexibility on behalf of the donor and implementing partners.

It was beyond the scope of the research to analyse and compare observable outcomes of the project and VC system behaviour against model predictions. Future research could likewise document the medium- and long-term outcomes of upgrading interventions and VC behaviours within a development intervention and compare them to the *ex-ante* model findings. Such research covering the *ex-post* evaluation of SD models could help determine the extent that structure, parameters, and modules accurately reflect system behaviour across different contexts. This information would help build confidence in the use of SD modelling tools for VCA and upgrading, while also creating a knowledge bank of basic model structure that can form the building blocks of future initiatives.

Because participatory model-building processes are resource heavy, donors and practitioners alike should ask questions about value for money, short-cut methodologies, and ability to scale. The applicability of template approaches will gain currency for future research as the knowledge bank of VC SD models grows. This research would include understanding the scale of model adaption needed between different countries (e.g., transferring the pork VC SD model in this research to Timor-Leste), and different VCs (e.g., transferring the credit module developed in this research to a model of the paddy VC). Additionally important is an investigation into scaling up or scaling down of models in order to understand the level of system aggregation in VC models which provide the most effective insights. Finally, future research could also examine how the most important system insights can be captured by more parsimonious models and whether these simpler models further enhance stakeholder learning and ownership.

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Appendix A

Spatial group model building agendas and timeline

Table A1: SGMB workshop one agenda

Length (mins)	***Public Agenda***	***Team Agenda***
	Pre-workshop	
	Arrival and registration	- Prepare room: walls free from distraction, water and snacks on desks, books and pens on desks, desks in C shape, and Layerstack ready - Register participants and supply with name tags (colour of tag representing participant's role in the VC)
10	Research information sharing and consent gathering	- Distribute research information and consent forms - Explain and clarify purpose of research and conditions of consent - Request signatures and collect consent forms
75	Baseline survey	- Explain purpose of baseline survey and anonymity - Facilitator reads aloud questions and clarifies understanding - Assistant Facilitators assist individual participants who struggle to understand questions or language
	Workshop	
15	1. Formal welcome and introductions	- General welcome and introduction of Model Building Team (MBT) - Participants stand and introduce themselves
5	2. Overview of the TRRILD project and SGMB workshops	- Overview of the TRRILD project, covering timeline, key outcomes, and relationship to SGMB workshops - Overview of SGMB process, including five workshops, timing, and expected level of participation - Distribute one-page information sheet on TRRILD project and SGMB process (in Myanmar language)
5	3. Overview of workshop	- Explain key sessions and how long will be spent on them - Explain lunch details and location of bathrooms
30	4. Hope and fears	- Each participant writes hopes and fears for the model building process on two coloured cards - Participants come to front of group and briefly explain hopes and fears - Hopes and fears cards are stuck on whiteboard and collated into similar groups by Facilitator - Facilitator summarises common themes and addresses any concerns
20	5. Introduction of SD concepts and terminology	- Introduce terminology of stocks, flows, and converters with examples from agriculture - Highlight terminology with coke-in-bottle example, show coke as stock and add converters to change flow rate - Draw behaviour over time graph of water in bottle - Ask for examples of stocks, flows, and converters in the VC, and draw on whiteboard
	Lunch	
90	6. Layerstack exercise to map VC system	- Introduce Layerstack, showing maps, acetates, markers, and stickers - Briefly show Layerstack from SGMB training as an example - Allow 15 minutes for each layer, this includes time for Facilitator to summarise key information before moving on to the next layer - Ensure there is discussion and active participation, noting down any disagreements
45	7. VC problem prioritisation	- Remind participants of VC problems identified through the Layerstack exercise

Length (mins)	*Public Agenda*	*Team Agenda*
		- Participants individually write down one key problem on coloured cards and then present to group, answering any questions from plenary - Problem cards placed on whiteboard - Facilitator compiles problem cards into common themes and asks if any problems are missing - Assistant Facilitator writes additional problems on cards and places on whiteboard - Participants are given three stickers and vote for top problems by placing stickers (maximum two per card) on problem cards - Facilitator counts voting and presents top three problems to the group, while confirming nature of problem
10	8. Wrap-up	- Summarise workshop and thank participants - Remind participants of the next workshop
Planned length: 10.00 to 15.00 (30 mins for lunch) Actual length: 10.15 to 16.10 (Myeik); 10.00 to 16.00 (Palaw)		

Source: Researcher

Table A2: SGMB workshop two agenda

Length (mins)	*Public Agenda*	*Team Agenda*
Pre-workshop		
	Arrival and registration	- Prepare room: walls free from distraction, water and snacks on desks, books and pens on desks, desks in C shape, and Layerstack ready - Register participants and distribute name tags
Workshop		
10	1. Formal welcome and overview of the day	- General welcome, including recap on previous workshop and agenda for current workshop
15	2. Review of SD concepts and terminology	- Review of stocks, flows, and converters - Elicit example of stocks from VC and facilitate group to draw a simple stock and flow diagram on whiteboard
95	3. Cause-and-consequence mapping of priority problems	- Review prioritised VC problems in plenary and break into small groups - Groups develop reference modes for problems and draw behaviour over time graphs in centre of whiteboard - Individuals within small groups write causes and consequences of problems on coloured cards - Individual participants place "cause" cards on left side of reference mode. Facilitator sorts causes into common themes and adds further 'causes' and draws in relationships by asking the prompt question, "What causes this?" (repeat for consequences on right side of reference mode, but using the key question, "Then what happens?") - Facilitator draws in relationships linking problem consequences to problem causes, documenting polarity of relationships and key feedback loops - Each small group presents map to plenary - Facilitator leads plenary discussion for each map and makes updates based on group consensus - Facilitator summarises final version of cause-and-consequence maps and reference modes
Lunch		
10	4. Decide on modules for development	- Facilitator summarises common issues and themes that emerged across cause-and-consequence maps

Length (mins)	*Public Agenda*	*Team Agenda*
		- Discussion in plenary on which modules should be included in the model to ensure common themes and issues are accounted for
60	5. Develop preliminary concept modules	- Present preliminary Production and Finance Casual Loop Diagrams (CLDs) on paper sheets that were prepared earlier and discuss in plenary, highlighting key stocks, flows, and converters - Update CLDs through post-it notes, and markers based on plenary discussions
10	6. Wrap-up	- Summarise workshop and thank participants - Remind participants of the next workshop
Planned length: 10.00 to 13.50 (30 mins for lunch) Actual length: 10.15 to 14.30 (Myeik); 10.00 to 15.00 (Palaw)		

Source: Researcher

Table A3: SGMB workshop three agenda

Length (mins)	*Public Agenda*	*Team Agenda*
Pre-workshop		
	Arrival and registration	- Prepare room: walls free from distraction, water and snacks on desks, books and pens on desks, desks in C shape, and Layerstack ready - Register participants and distribute name tags
Workshop		
10	1. Formal welcome and overview of the day	- General welcome, including recap on previous workshop and agenda for current workshop
15	2. Present basic SD model	- Introduce simple production and system pricing and marketing modules in Stella Architect - Demonstrate how SD models can produce graphs which resemble reference mode behaviour and how these are altered with changes to model variables - Explain that the next step to building a functional SD model of the VC is to develop CLDs of the modules using SD structure
95	3. Development of CLD for modules	- Divide participants into small groups in order to develop CLDs for remaining modules on large paper sheets - CLDs use SD concepts, such as stocks, flows, and converters using stocks. CLDs include polarity of relationships and if consensus among participants, parameters to define relationships - Each group presents CLD to plenary - Presenter facilitates discussion and updates CLDs, using post-it notes to record structural changes and markers for changes to causal relationships and polarity
Lunch		
60	4. Review CLD for all modules and add data	- Facilitator presents each CLD to plenary and highlights key structure and relationships - Discussions in plenary to agree on key variables, including basic behaviour and parameters for graphical functions
10	5. Wrap-up	- Summarise workshop and thank participants - Remind participants of the next workshop
Planned length: 10.00 to 13.40 (30 mins for lunch) Actual length: 10.10 to 14.20 (Myeik) 10.00 to 14.00 (Palaw)		

Source: Researcher

Table A4: SGMB workshop four agenda

Length (mins)	Public Agenda	Team Agenda
Pre-workshop		
	Arrival and registration	- Prepare room: walls free from distraction, water and snacks on desks, books and pens on desks, desks in C shape, and Layerstack ready - Register participants and distribute name tags
Workshop		
10	1. Formal welcome and overview of the day	- General welcome, including recap on previous workshop and agenda for current workshop
75	2. Present combined modules and validate	- Present the modules on large sheets of paper and explain connections between the modules - Explain that taken as whole they represent the concept model of the VC and highlight the key feedback loops which generate behaviour of the system - Request volunteer from among participants to explain the concept model, including connections between and key feedback loops - Gather feedback on concept model in plenary, with any final changes added to the model through coloured cards and markers
60	3. Validate model data and fill in data gaps	- In plenary present data sheets for model variables in two columns (one column for SGMB participants and one column for RG participants) - Review model data, focusing on variables with no data or variables with large discrepancies between SGMB and RG data
Lunch		
20	4. Selection of interventions for scenario testing stage	- Explain that the concept model will be converted into an SD model with Stella Architect and show basic SD model example used in SGMB Two - Explain that participants need to help decide the potential project interventions for the scenario testing stage - Participants individually write two project interventions on coloured cards and one-by-one shares with group - Facilitator sorts cards under similar themes on whiteboard and summarises and clarifies meaning - Three voting stickers are distributed to each participant to vote on top three interventions (maximum two voting stickers per card)
20	5. Selection of indicators to analyse results	- Explain that participants need to help decide on indicators to measure the impacts of the interventions - Participants individually write two indicators on coloured cards and one-by-one shares with group - Facilitator sorts cards under similar themes on whiteboard and summarises and clarifies meaning - Three voting stickers are distributed to each participant to vote on top three interventions (maximum two voting stickers per card)
20	6. Wrap-up	- Summarise workshop process and thank participants - Update participants on the next steps which will take place in New Zealand: finalising the SD model, undertaking scenario testing, and analysing results - Update participants on the purpose and likely timing of SGMB Five - Present workshop certificates and take final group photo
Planned length: 10.00 to 14.00 (30 mins for lunch) Actual length: 10.20 to 15.30 (Myeik) 10.00 to 14.00 (Palaw)		

Source: Researcher

Table A5: SGMB workshop five agenda

Length (mins)	***Public Agenda***	***Team Agenda***
Pre-workshop		
	Arrival and registration	- Prepare room: walls free from distraction, water and snacks on desks, books and pens on desks, desks in C shape, and Layerstack ready - Register participants and distribute name tags
Workshop		
20	1. Formal welcome and overview of the day	- General welcome - Recap on workshop process and the summarise the process to complete the quantitative SD model, undertake scenario testing, and analyse results - Share workshop agenda
40	2. Present updated concept model	- Present the updated concept model (drawn on paper prior to workshop), highlighting each of the modules and key feedback loops - Discussion in plenary with any feedback recorded on coloured cards and placed on model
90	3. Present results of scenario testing	- Present the updated SD model using Stella Architect - Point out the corresponding structure from the concept model which is now embedded in the SD model - Show how scenario testing changes the results of the SD model - Through simple power point slides present results of each scenario, pausing afterwards to collect any feedback or answer questions - Write feedback on whiteboard
Lunch		
20	4. Present parameters for sensitivity analysis	- Explain that the SD model uses data provided from SGMB and RG workshops and other secondary sources - Explain that some variables in the model have a wide range and/or have a significant impact on the model's results - Present these variables and facilitate discussion and agreement on the low and high points of the range
40	5. Follow-up VC survey	- Remind participants of the baseline knowledge survey from SGMB One and reaffirm anonymity - Explain that this is a follow-up questionnaire covering the same questions but also containing a section on the SGMB process - Facilitator reads questions aloud and clarifies understanding - Assistant facilitators assist participants who struggle to understand and help with translation as necessary
20	6. Wrap-up	- Summarise workshop process and thank participants - Update participants on the next steps: project to decide on interventions and timeline for starting of activities
Planned length: 10.00 to 14.20 (30 mins for lunch) Actual length: 10.30 to 15.00 (Myeik) 10.00 to 14.30 (Palaw)		
Post-workshop		
60	Focus Group Discussion with select participants	- Follow-up questions with workshop participants (four producers and at least one member from other VC nodes) to explore learning from workshops

Source: Researcher

Table A6: Timeline of the model building process

Date	*Activity*	*Participants*	*Objectives*
7/01/2019 – 11/01/2019	SGMB training	Researcher and Expert Modeler	1. Familiarise Researcher with SGMB tools and observe SGMB workshops
21/01/2019 – 23/01/2019	Training workshop for Myanmar MBT team	MBT: 6	1. SGMB team members understand basic SD concepts 2. SGMB team members understand their roles and workshop purposes 3. Practise facilitation of SGMB tools, such as Layerstack and casual loop diagrams
24/01/2019	RG workshop 1	MBT: 6 RG: 8	1. Introduce TRRILD project and research 2. Participants understand SD, SGMB, and RG principles and commit to workshops 3. Identify problems within VCs
Myeik: 25/01/2019 Palaw: 28/01/2019	SGMB workshop 1	MBT: 6 Myeik: 15 Palaw: 15	1. Introduce TRRILD project and SGMB process 2. Survey of participants' VC knowledge and behaviours 3. Introduce basic SD concepts and terminology 4. Map out VC spatial dynamics using Layerstack 5. Identify and prioritise VC problems
Myeik: 01/02/2019 Palaw: 04/02/2019	SGMB workshop 2	MBT:5 Myeik: 15 Palaw: 14	1. Develop reference modes 2. Complete cause-and-consequence mapping 3. Select modules for model structure 4. Present and refine CLDs
06/02/2019	RG workshop 2	MBT: 5 RG: 10	1. Review and revise module structure 2. Parameterise modules
Myeik: 11/02/2019 Palaw: 03/02/2019	SGMB workshop 3	MBT: 5 Myeik: 15 Palaw: 13	1. Review and revise module structure 2. Parameterise modules
20/02/2019	RG workshop 3	MBT: 5 RG: 10	1. Review and revise model structure 2. Parameterise model
Myeik: 26/02/2019 Palaw: 27/02/2019	SGMB workshop 4	MBT: 5 Myeik: 12 Palaw: 12	1. Validate and parameterise concept model 2. Elicit and prioritise indicators and interventions for scenario testing
01/03/2019	RG workshop 4	MBT: 5 RG: 8	1. Validate and parameterise model 2. Elicit and prioritise indicators and interventions for scenario testing
04/2019 – 08/2019	Model finalisation and scenario testing for pork VC	Researcher and Expert Modeler	1. Finalise pork SD model 2. Undertake scenario testing and analyse results 3. Develop recommendations on upgrading
08/08/2019	Combined SGMB and RG workshop 5 for pork VC	MBT: 4 SGMB: 10 RG: 4	1. Validate final pork SD model 2. Discussion of results and priority interventions 3. Follow-up survey and FGD on SGMB participants' VC knowledge and behaviours

08/2019	Discussion of pig model results with TRRILD partners (in-person and remotely)	Researcher and Expert Modeler Project Partners: 5	1. Present model results and recommendations for pork upgrading interventions for TRRILD project
Palaw: 22/01/2020 Myeik: 23/01/2020	SGMB and RG (Rice) workshop 5	MBT: 4 SGMB: 10 RG: 2	1. Validate final rice SD model 2. Discussion of rice results and priority interventions 3. Follow-up survey and FGD on SGMB participants' VC knowledge and behaviours
01/2020	Monitoring of pork VC interventions	Researcher	1. Monitor implementation of pork upgrading interventions for revisions to model
08/2019 – 12/2020	Remote follow-up with RG and TRRILD staff	Researcher	1. Review and revise model 2. Provide recommendations based on revisions

Note: The table also provides the dates for the SGMB workshops for the rice VC as these workshops are included under Objective Four of this thesis.
Source: Researcher

Appendix B

Pork value chain system dynamics model

This appendix provides a snap-shot of the modules within the Stella Architect-developed pork VC SD model. The corresponding equations are found in Appendix C.

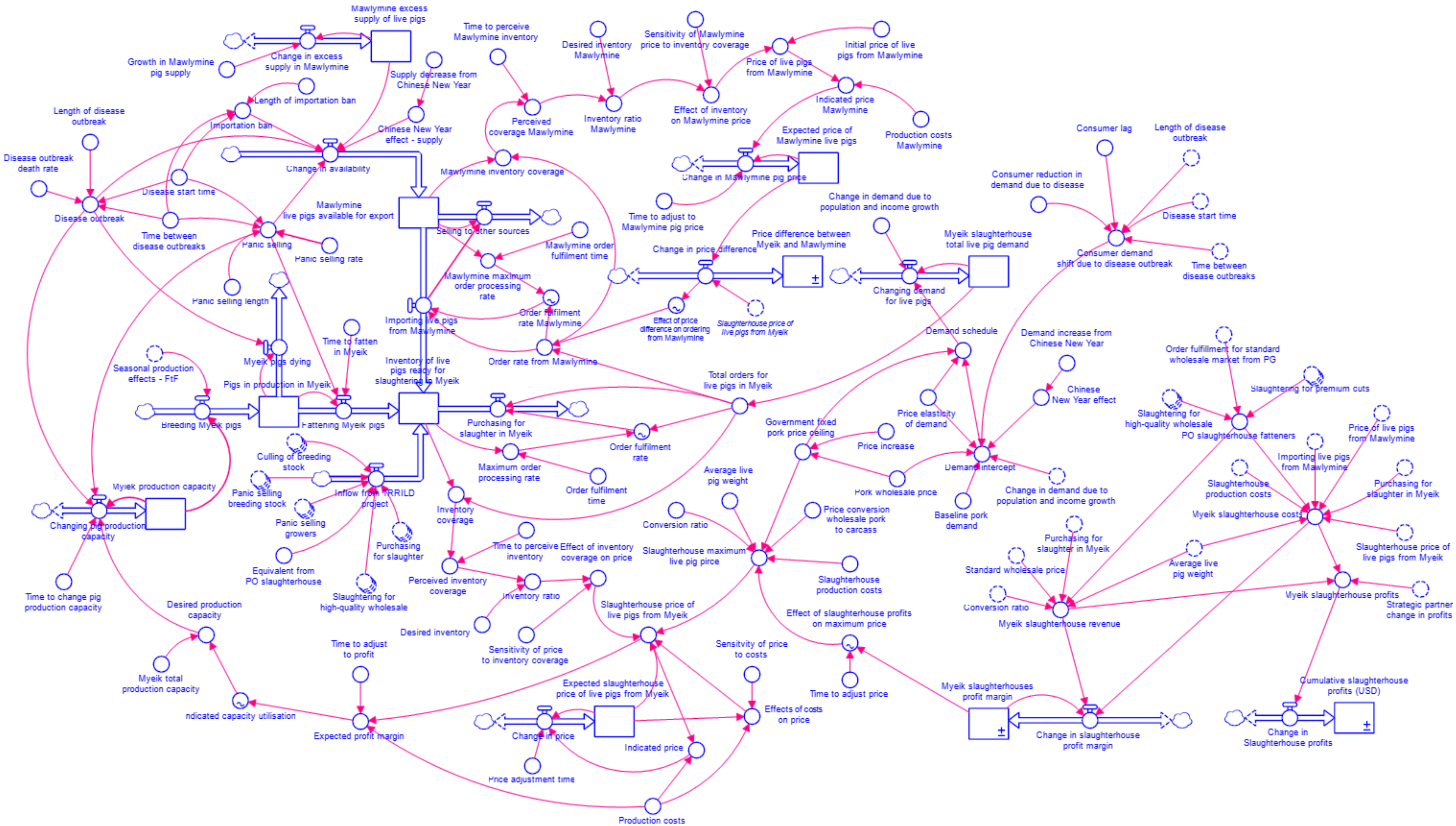

Figure B1: System pricing and marketing module developed in Stella Architect

Source: Pork VC SD model developed by the Researcher

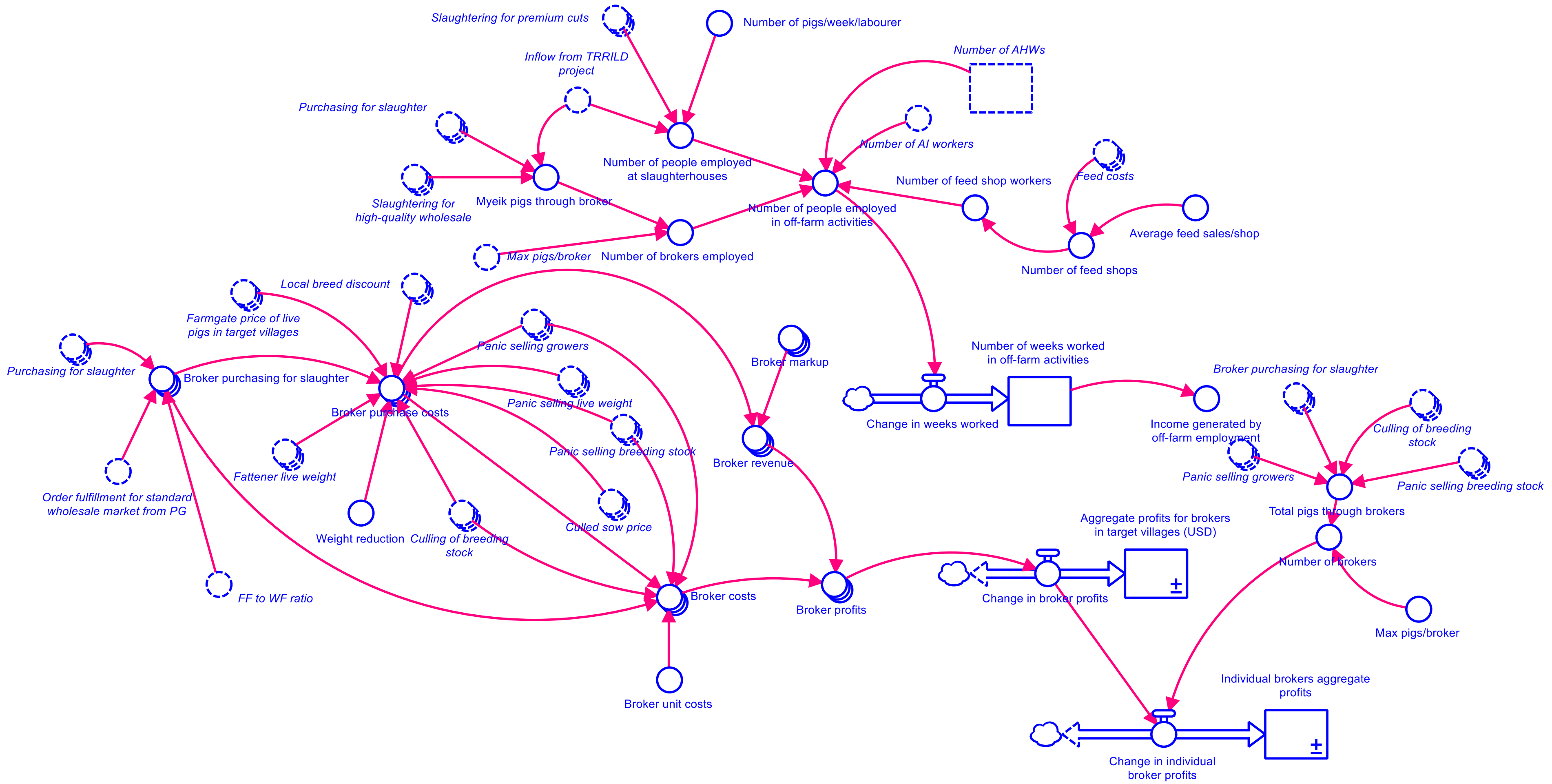

Figure B2: System pricing and marketing module (off-farm employment) developed in Stella Architect

Source: Pork VC SD model developed by the Researcher

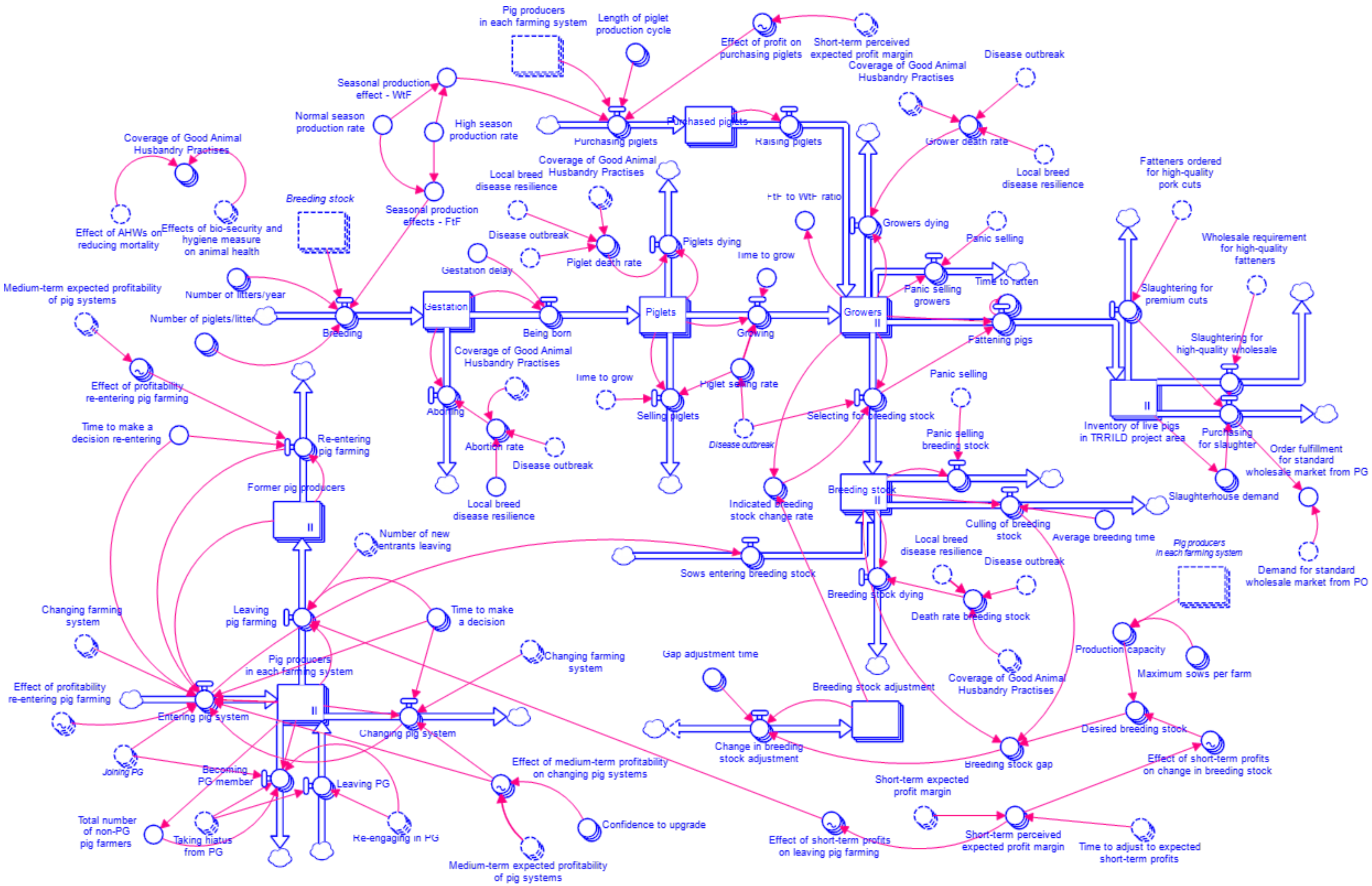

Figure B3: Pig production module developed in Stella Architect

Source: Pork VC SD model developed by the Researcher

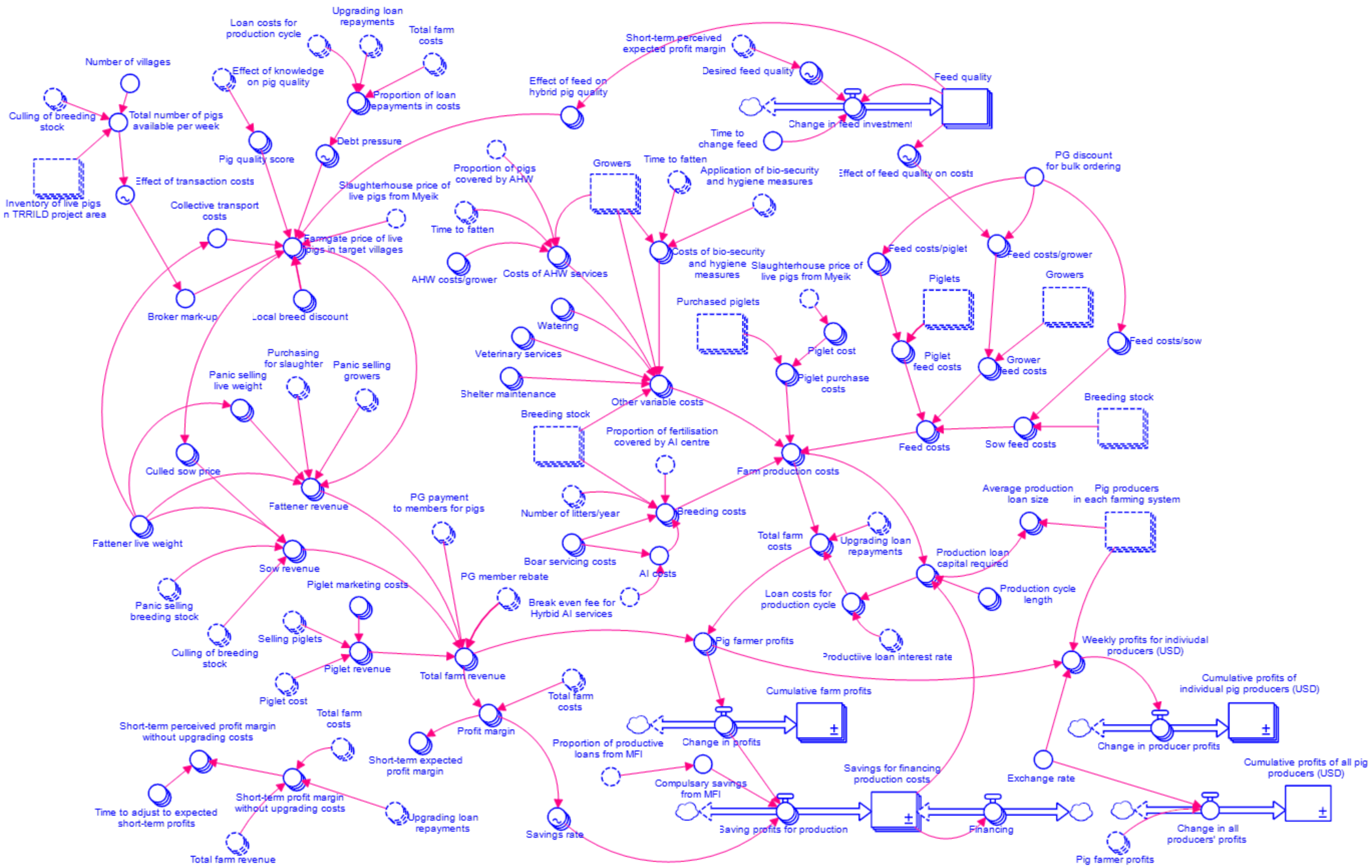

Figure B4: Farmer finance module developed in Stella Architect

Source: Pork VC model developed by the Researcher

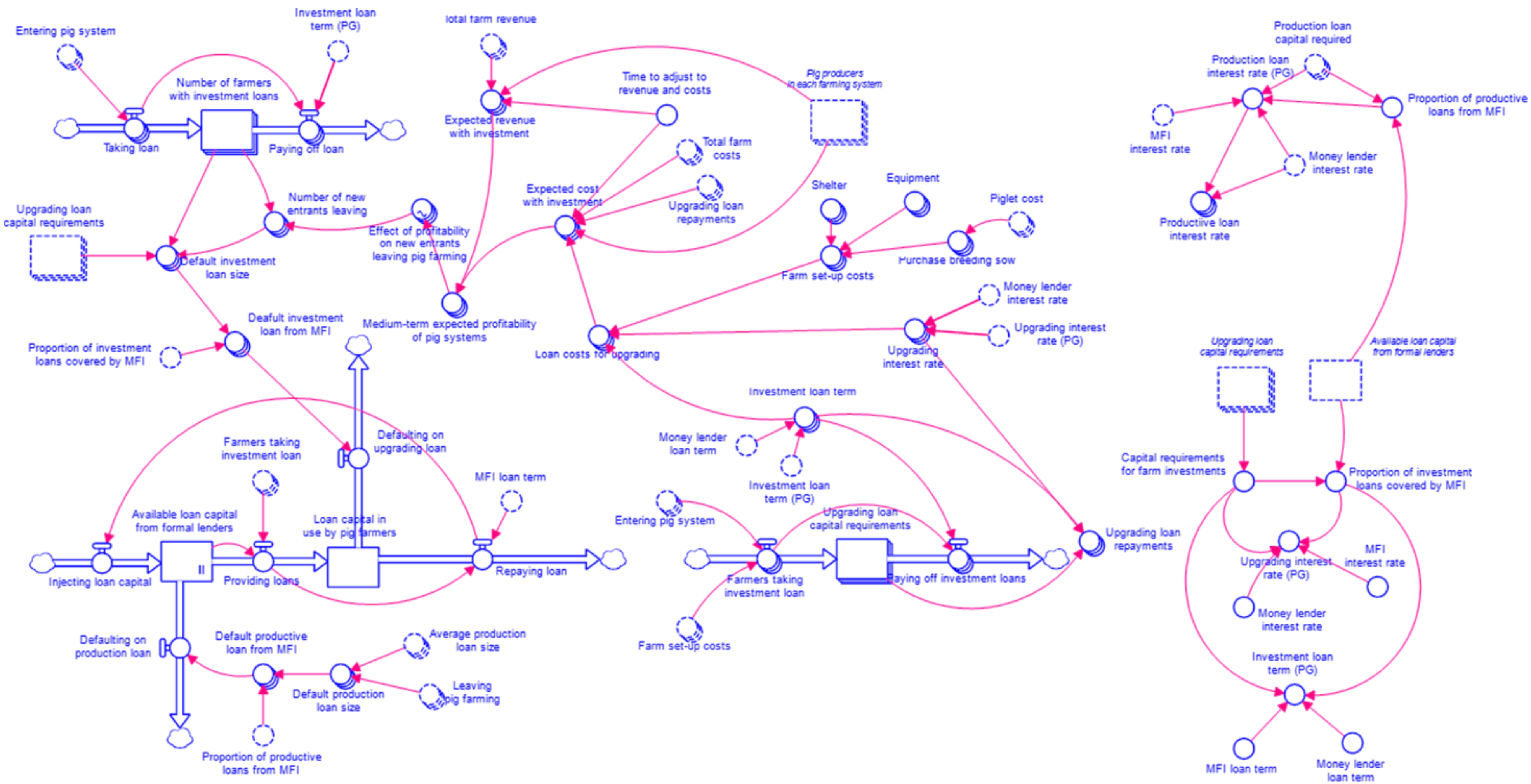

Figure B5: Credit and investment modules developed in Stella Architect

Source: Pork VC model developed by the Researcher

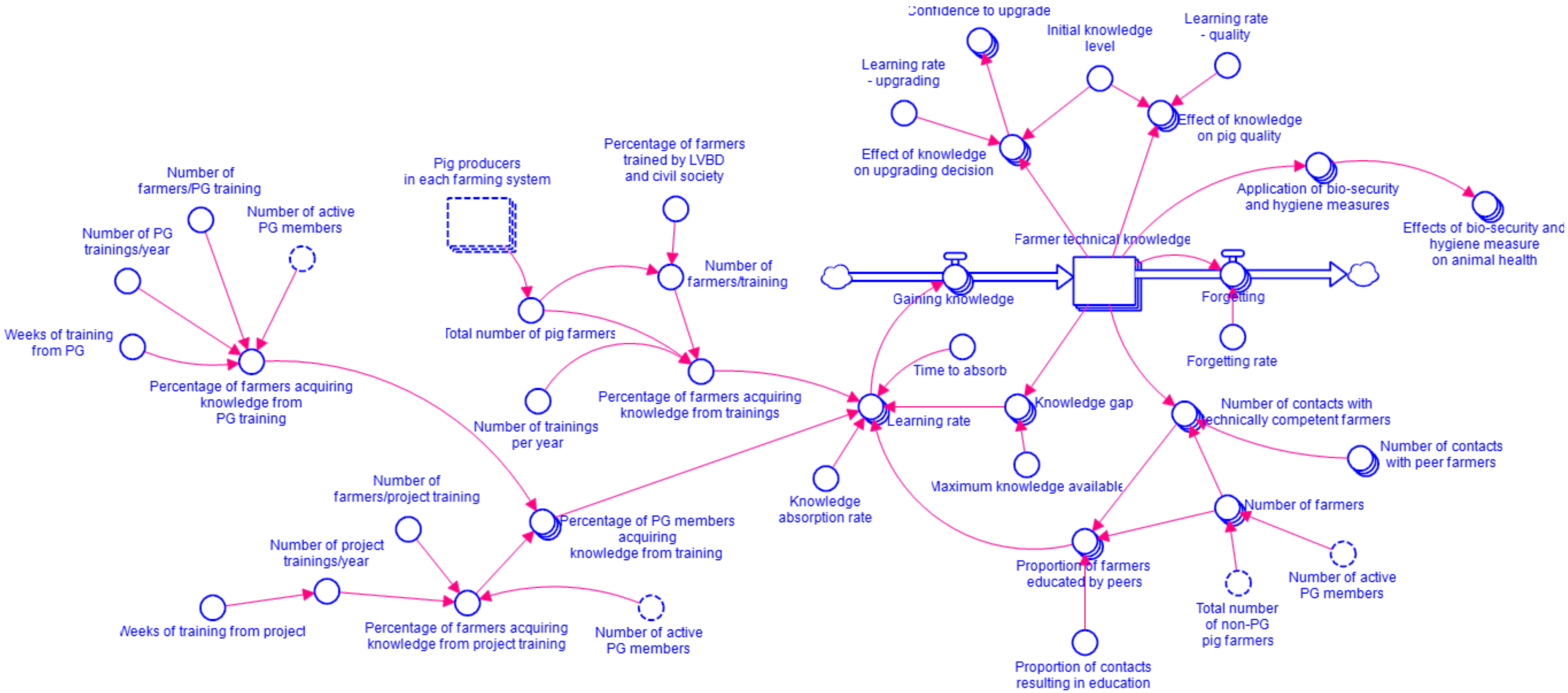

Figure B6: Knowledge module developed in Stella Architect
Source: Pork VC model developed by the Researcher

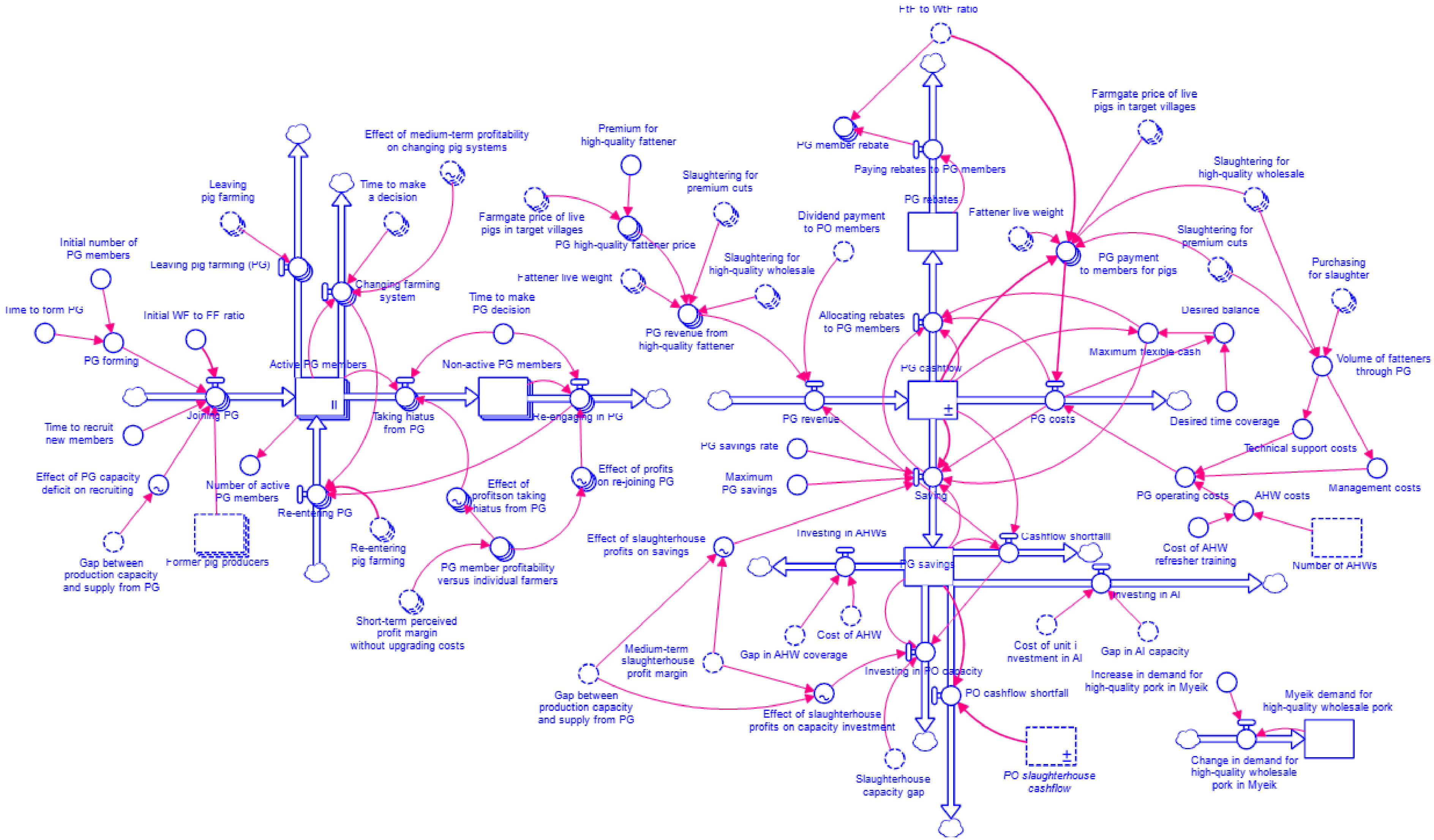

Figure B7: Collective action module (PG portion) developed in Stella Architect

Source: Pork VC model developed by the Researcher

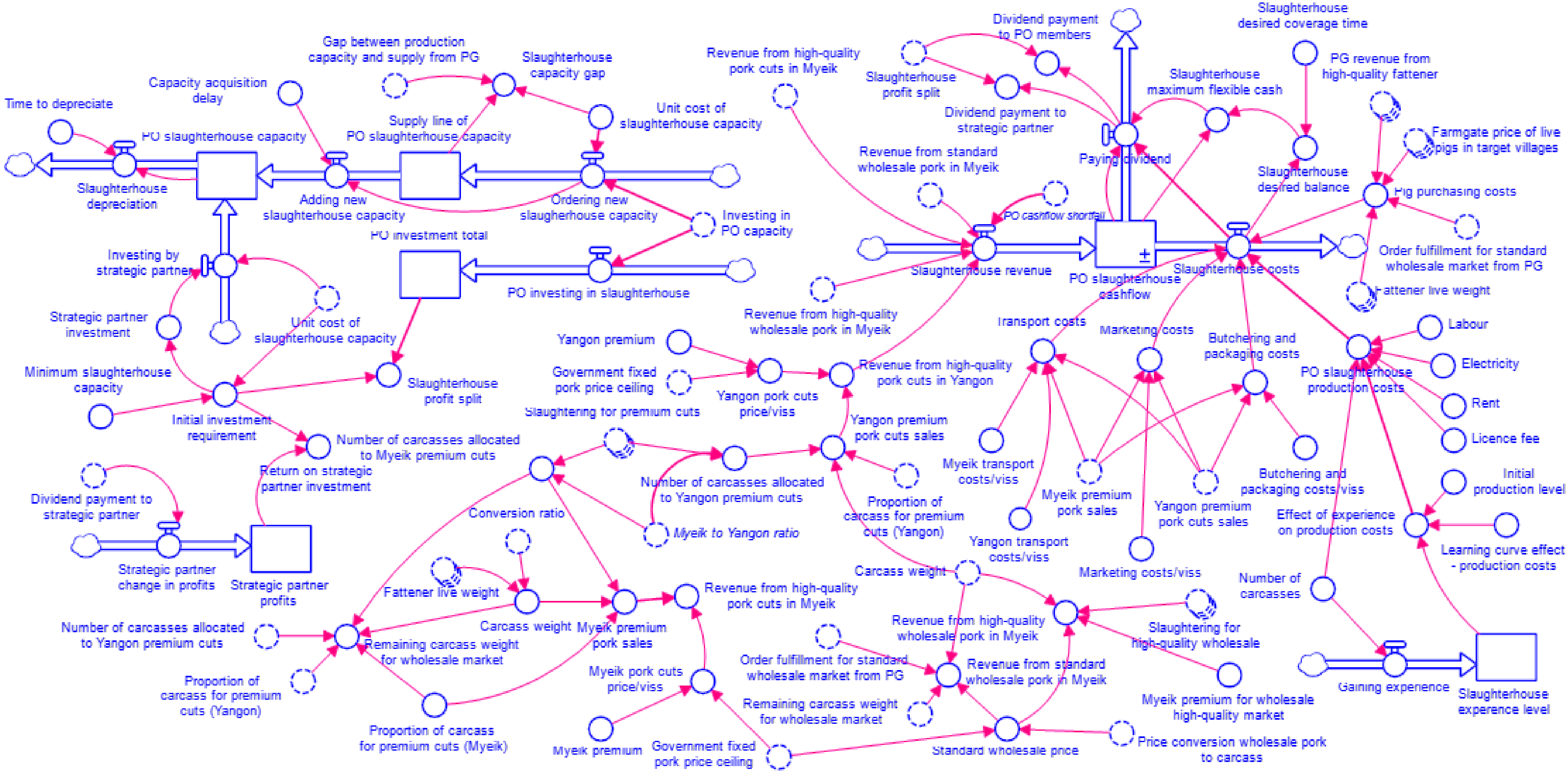

Figure B8: Collective action module (PO portion) developed in Stella Architect

Source: Pork VC model developed by the Researcher

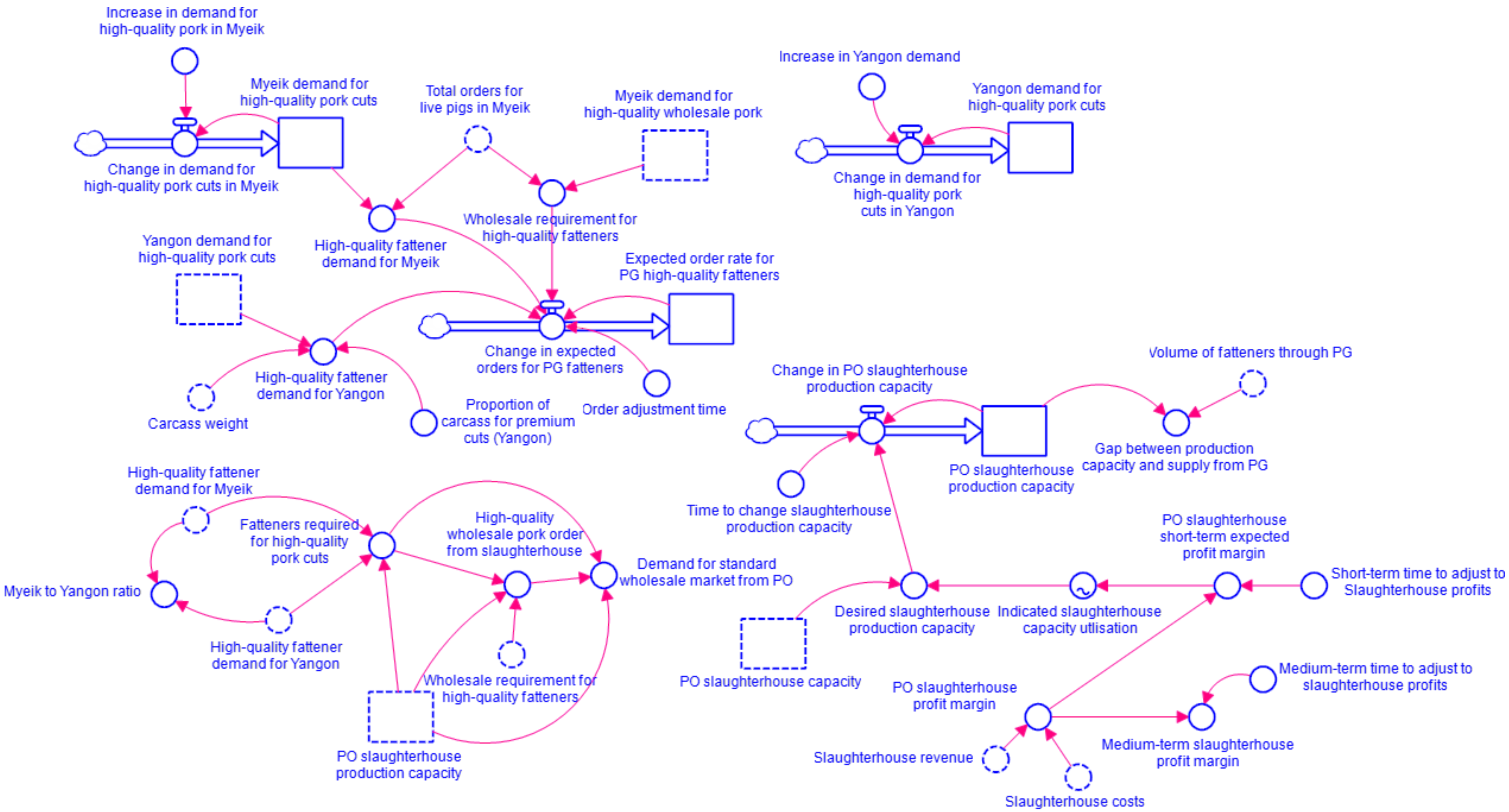

Figure B9: Collective action module (PO portion): Demand and slaughterhouse capacity structure developed in Stella Architect

Source: Pork VC model developed by the Researcher

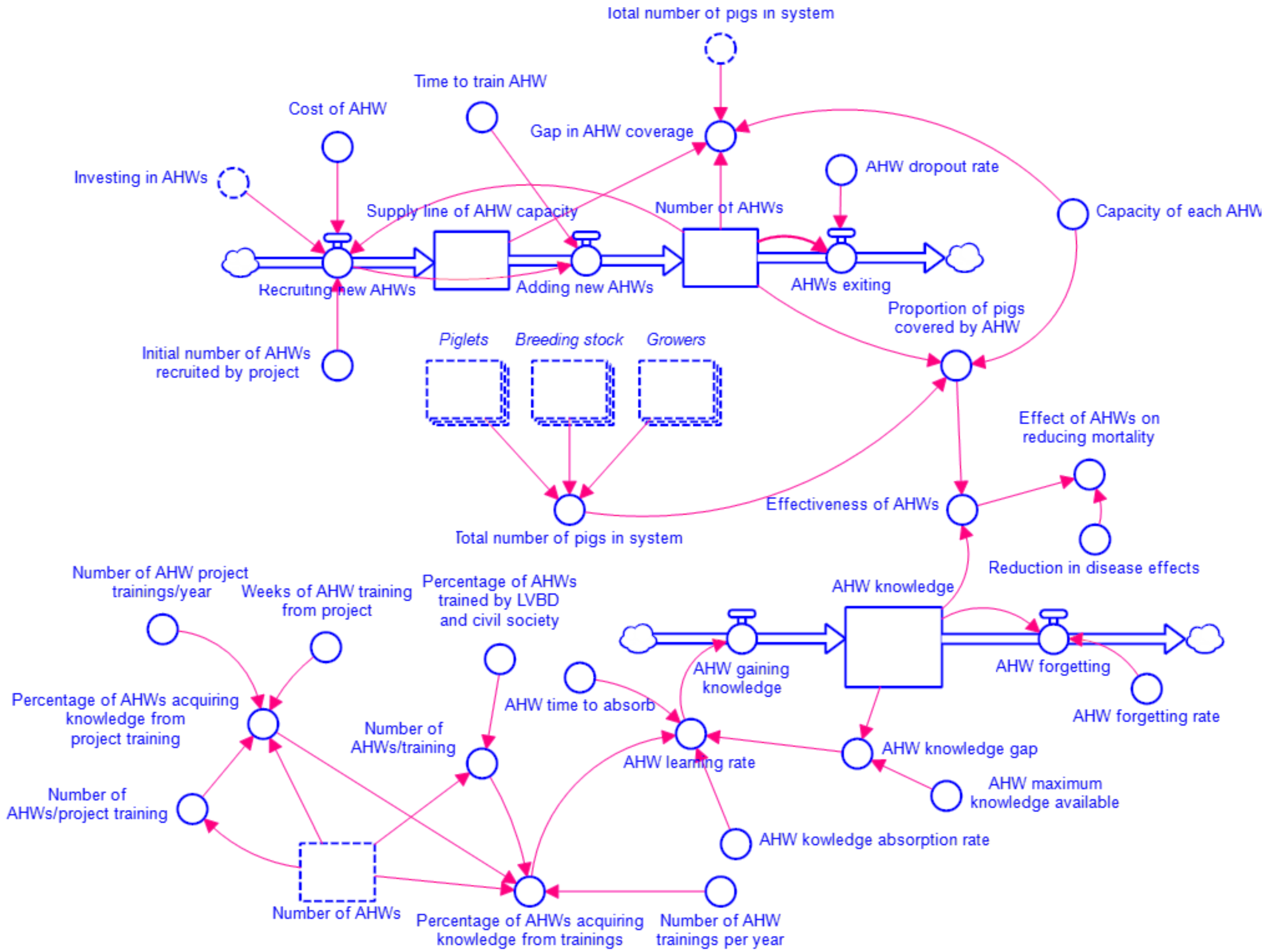

Figure B10: Animal Health Worker scenario structure developed in Stella Architect

Source: Pork VC model developed by the Researcher

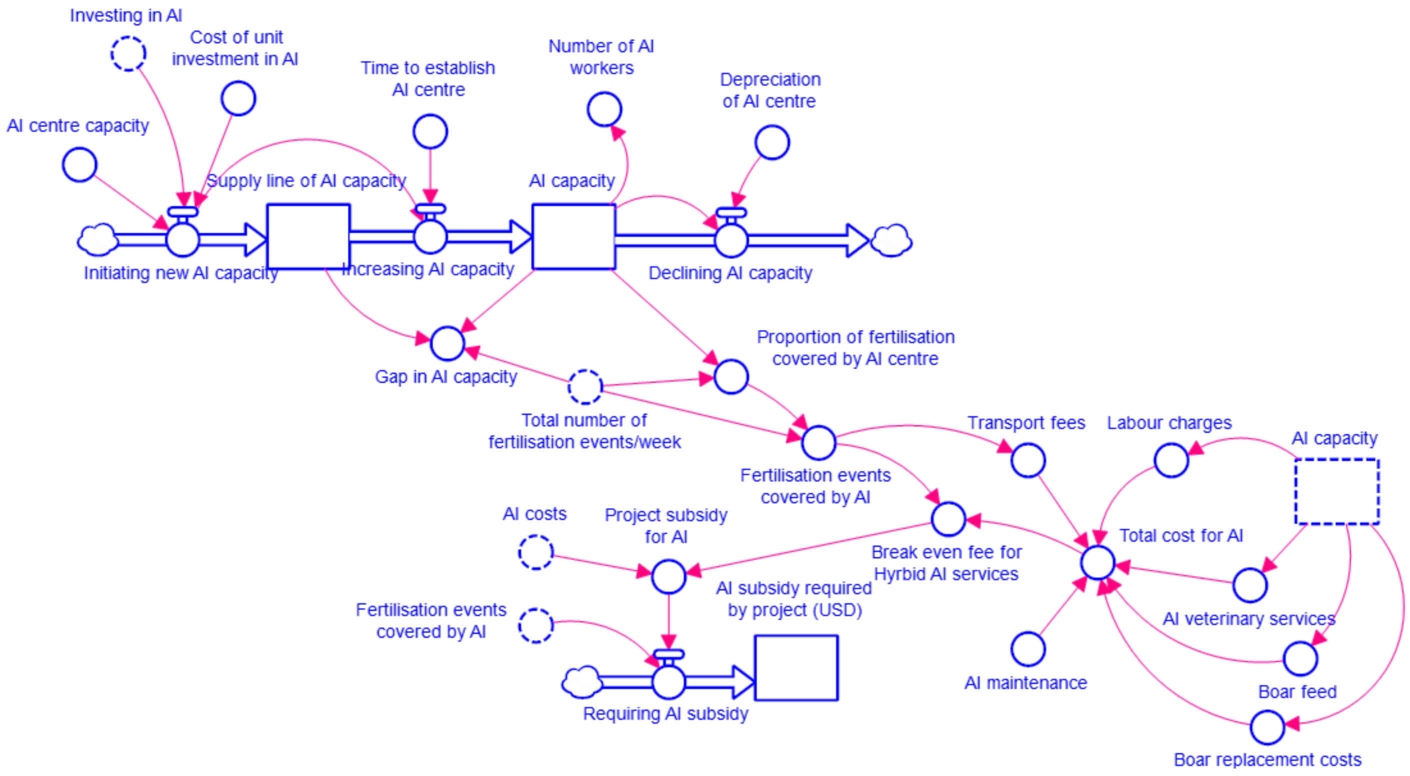

Figure B11: Artificial Insemination scenario structure developed in Stella Architect
Source: Pork VC model developed by the Researcher

Appendix C

Baseline data for pork value chain system dynamics model

Table C1: Baseline data for system pricing and marketing module

Structure	***Baseline***	***Unit***	***Source***
Stocks			
Mawlymine live pigs available for export	800	Pigs	SGMB
Pigs in production in Myeik	5460	Pigs	SGMB
Inventory of live pigs ready for slaughtering in Myeik	1400	Pigs	SGMB
Myeik production capacity	210	Pigs/week	SGMB and RG
Expected price of Mawlymine live pigs	5100	Kyats/viss	SGMB
Price difference between Myeik and Mawlymine	0	Kyats/viss	[b]
Myeik slaughterhouse total live pig demand	700	Pigs/week	SGMB
Slaughterhouse profit margin	0	Unitless	
Cumulative Myeik slaughterhouse profits (USD)	0	US$	
Expected slaughterhouse price of live pigs from Myeik	5000	Kyats/viss	SGMB
Myeik slaughterhouse profit margin	0	Unitless	
Number of weeks worked in off-farm activities	0	Weeks	
Aggregate profits for brokers in target villages (USD)	0	US$	
Individual brokers aggregate profits	0	US$	
Flows			
Changing pig production capacity	((Desired_production_capacity-Myiek_production_capacity) /Time_to_change_pig_production_capacity)-(Disease_outbreak*Myiek_production_capacity)-(Panic_selling*Myiek_production_capacity)	Pigs/week	
Breeding Myeik pigs	Myiek_production_capacity*(1+"Seasonal_production_effects_-_fatteners")	Pigs/week	
Fattening Myeik pigs	(Pigs_in_production_in_Myeik/Time_to_fatten_in_Myeik)+(Pigs_in_production_in_Myeik*Panic_selling)	Pigs/week	
Inflow from TRRILD	SUM(Purchasing_for_slaughter)+SUM("Slaughtering_for_high-quality_wholesale") +SUM(Culling_of_breeding_stock)+SUM(Panic_selling_breeding_stock)+SUM(Panic_selling_growers)+Equivalent_from_PO_slaughterhouse	Pigs/week	
Change in availability	SMTH1((Mawlymine_excess_supply_of_live_pigs*(1-Disease_outbreak)*(1+Panic_selling)*("Chinese_New_Year_effect_-_supply")*(1+Importation_ban)), 2)	Pigs/week	

Structure	***Baseline***	***Unit***	***Source***
Selling to other sources	Mawlymine_live_pigs_available_for_export-Importing_live_pigs_from_Mawlymine	Pigs/week	
Importing live pigs from Mawlymine	(Order_fulfillment_rate_Mawlymine*Order_rate_from_Mawlymine)	Pigs/week	
Purchasing for slaughter in Myeik	Total_orders_for_live_pigs_in_Myeik*Order_fufillment_rate	Pigs/week	
Change in Mawlymine pig price	(Indicated_price_Mawlymine-Expected_price_of_Mawlymine_live_pigs) /Time_to_adjust_to_Mawlymine_pig_price	Kyats/viss/week	
Change in price difference	Expected_price_of_Mawlymine_live_pigs-Slaughterhouse_price_of_live_pigs_from_Myeik	Kyats/viss/week	
Changing demand for live pigs	(Demand_schedule-Myeik_slaughterhouse_total_live_pig_demand) +(Myeik_slaughterhouse_total_live_pig_demand*Change_in_demand_due_to_population_and_income_growth)	Pigs/week	
Change in price	(Indicated_price-Expected_slaughterhouse_price_of_live_pigs_from_Myeik) /Price_adjustment_time	Kyats/viss/week	
Change in slaughterhouse profit margin	(Myeik_slaughterhouse_revenue/Myeik_slaughterhouse_costs)-Slaughterhouse_profit_margin	Unitless	
Change in slaughterhouse profits	Myeik_slaughterhouse_profits/1500	US$/week	
Change in weeks worked	"Number_of_people_employed_in_off-farm_activities"	Weeks	
Change in broker profits	(Broker_profits[Individual_local,FarrowtoFinish]+Broker_profits[Individual_local,WeantoFinish]+Broker_profits[Individual_hybrid,FarrowtoFinish]+Broker_profits[Individual_hybrid,WeantoFinish])/1500	US$/week	
Change in individual broker profits	Change_in_broker_profits/Number_of_brokers	US$/week/broker	
Variables			
Disease outbreak	STEP(Disease_outbreak_death_rate*DT, Disease_start_time)-STEP(Disease_outbreak_death_rate*DT, (Disease_start_time+Length_of_disease_outbreak))+STEP(Disease_outbreak_death_rate*DT, (Disease_start_time+Time_between_disease_outbreaks))-STEP(Disease_outbreak_death_rate*DT, (Disease_start_time+Time_between_disease_outbreaks+Length_of_disease_outbreak))[a]	Unitless	
Length of disease outbreak	26	Weeks	SGMB
Disease outbreak death rate	0.15	Proportion	SGMB and RG
Time between disease outbreaks	208	Weeks	SGMB and RG
Disease start time	72	Week	
Panic selling	STEP(Panic_selling_rate*DT, Disease_start_time)-STEP(Panic_selling_rate*DT, Disease_start_time+Panic_selling_length)+	Unitless	

Structure	Baseline	Unit	Source
	STEP(Panic_selling_rate*DT, Disease_start_time+Time_between_disease_outbreaks)-STEP(Panic_selling_rate*DT, Disease_start_time+Time_between_disease_outbreaks+Panic_selling_length)[a]		
Panic selling rate	0.05	Proportion	
Panic selling length	10	Weeks	SGMB
Supply decrease from Chinese New Year	-0.2	Unitless	SGMB
Chinese New Year effect - supply	1+ (STEP(Supply_decrease_from_Chinese_New_Year, 4)-STEP(Supply_decrease_from_Chinese_New_Year, 8)) +(STEP(Supply_decrease_from_Chinese_New_Year, 56)-STEP(Supply_decrease_from_Chinese_New_Year, 60))[a]	Unitless	SGMB
Importation ban	IF "Disease_scenario_on_/_off" = 1 THEN STEP(-1, Disease_start_time+4)-STEP(-1, Disease_start_time+4+Length_of_importation_ban) + STEP(-1, Disease_start_time+Time_between_disease_outbreaks+4)-STEP(-1, Disease_start_time+(Time_between_disease_outbreaks+4)+Length_of_importation_ban)[a] ELSE 0	Unitless	
Length of importation ban	26	Weeks	RG
Growth in Mawlymine pig supply	0.06	Proportion	RG
Time to fatten in Myeik	26	Weeks	SGMB
Order rate from Mawlymine	(Total_orders_for_live_pigs_in_Myeik*Effect_of_price_difference_on_ordering_from_Mawlymine)	Pigs/week	
Order fulfilment rate Mawlymine	GRAPH(Mawlymine_maximum_order_processing_rate/Order_rate_from_Mawlymine) (0.000, 0.000), (0.200, 0.100), (0.400, 0.300), (0.600, 0.500), (0.800, 0.700), (1.000, 0.900), (1.200, 1.000), (1.400, 1.000), (1.600, 1.000), (1.800, 1.000), (2.000, 1.000)	Unitless	
Mawlymine maximum order processing rate	Mawlymine_live_pigs_available_for_export/Mawlymine_order_fulfillment_time	Pigs/week	Sterman (2010)
Mawlymine order fulfilment time	1	Week	SGMB and RG
Mawlymine inventory coverage	Mawlymine_live_pigs_available_for_export/Order_rate_from_Mawlymine	Pigs	Sterman (2010)
Perceived coverage Mawlymine	SMTH1(Mawlymine_inventory_coverage, Time_to_perceive_Mawlymine_inventory)	Unitless	Sterman (2010)
Time to perceive Mawlymine inventory	1	Week	SGMB
Desired inventory Mawlymine	1	Unitless	
Inventory ratio Mawlymine	Perceived_coverage_Mawlymine/Desired_inventory_Mawlymine	Unitless	Sterman (2010)
Sensitivity of Mawlymine price to inventory coverage	-0.05	Unitless	

Structure	***Baseline***	***Unit***	***Source***
Effect of inventory on Mawlymine price	Inventory_ratio_Mawlymine^Sensitivity_of_Mawlymine_price_to_inventory_coverage	Unitless	Sterman (2010)
Price of live pigs from Mawlymine	Initial_price_live_pigs_Mawlymine*Effect_of_inventory_on_Mawlymine_price	Kyats/viss	Sterman (2010)
Initial price of live pigs from Mawlymine	5100	Kyats/viss	SGMB
Indicated price Mawlymine	MAX(Price_of_live_pigs_from_Mawlymine, Production_costs_Mawlymine)	Kyats/viss	Sterman (2010)
Production costs Mawlymine	4800	Kyats/viss	RG
Time to adjust to Mawlymine pig price	1	Week	SGMB
Effect of price difference on ordering from Mawlymine	Effect_of_price_difference_on_ordering_from_Mawlymine = GRAPH(Change_in_price_difference) (-1000, 1.000), (-800, 1.000), (-600, 0.977), (-400, 0.950), (-200, 0.900), (0, 0.800), (200, 0.653), (400, 0.528), (600, 0.400), (800, 0.300), (1000, 0.200)	Unitless	SGMB
Total orders for live pigs in Myeik	SMTH1((Myeik_slaughterhouse_total_live_pig_demand), 4)	Pigs/week	
Order fulfilment rate	Order_fulfilment_rate = GRAPH(Maximum_order_processing_rate/Total_orders_for_live_pigs_in_Myeik) (0.000, 0.000), (0.200, 0.100), (0.400, 0.300), (0.600, 0.500), (0.800, 0.700), (1.000, 0.900), (1.200, 1.000), (1.400, 1.000), (1.600, 1.000), (1.800, 1.000), (2.000, 1.000)	Unitless	
Mawlymine order fulfilment time	1	Week	
Maximum order processing rate	Inventory_of_live_pigs_ready_for_slaughtering_in_Myeik/Order_fulfilment_time	Pigs/week	Sterman (2010)
Inventory coverage	Inventory_of_live_pigs_ready_for_slaughtering_in_Myeik/Total_orders_for_live_pigs_in_Myeik	Unitless	Sterman (2010)
Perceived inventory coverage	SMTH1(Inventory_coverage, Time_to_perceive_inventory)	Unitless	Sterman (2010)
Time to perceive inventory	1	Weeks	SGMB
Desired inventory	2	Weeks	
Inventory ratio	Perceived_inventory_coverage/Desired_inventory	Unitless	
Effect of inventory coverage on price	Inventory_ratio^Sensitivity_of_price_to_inventory_coverage	Unitless	Sterman (2010)
Slaughterhouse price of live pigs from Myeik	MIN ((Effect_of_inventory_coverage_on_price* Expected_slaughterhouse_price_of_live_pigs_from_Myeik*Effects_of_costs_on_price), Slaughterhouse_maximum_live_pig_pirce)	Kyats/viss	Sterman (2010)
Effect of costs on price	1+Sensitvity_of_price_to_costs*((Production_costs/Expected_slaughterhouse_price_of_live_pigs_from_Myeik)-1)	Unitless	Sterman (2010)
Sensitivity of price to costs	0.25	Unitless	
Production costs	4500	Kyats/viss	SGMB
Indicated price	MAX(Slaughterhouse_price_of_live_pigs_from_Myeik, Production_costs)	Kyats/viss	Sterman (2010)
Price adjustment time	26	Weeks	
Expected profit margin	SMTH1((Slaughterhouse_price_of_live_pigs_from_Myeik/Production_costs), Time_to_adjust_to_profit)	Unitless	
Time to adjust to profit	26	Weeks	

Structure	Baseline	Unit	Source
Indicated capacity utilisation	= GRAPH(Expected_profit_margin) (-1.000, 0.000), (-0.800, 0.000), (-0.600, 0.000), (-0.400, 0.000), (-0.200, 0.000), (0.000, 0.100), (0.200, 0.200), (0.400, 0.300), (0.600, 0.400), (0.800, 0.500), (1.000, 0.550), (1.200, 0.600), (1.400, 0.650), (1.600, 0.700), (1.800, 0.750), (2.000, 0.800), (2.200, 0.850), (2.400, 0.900), (2.600, 1.000), (2.800, 1.000), (3.000, 1.000)	Unitless	SGMB
Desired production capacity	Indicated_capacity_utilisation*Myeik_total_production_capacity	Pigs/week	
Myeik total production capacity	700	Pigs/week	RG
Time to change pig production capacity	26	Weeks	
Slaughterhouse maximum live pig price	(((Government_fixed_pork_price_ceiling*(Average_live_pig_weight*Conversion_ratio)*Price_conversion_wholesale_pork_to_carcass)-Slaughterhouse_production_costs)/Average_live_pig_weight)*Effect_of_slaughterhouse_profits_on_maximum_price	Kyats/viss	
Slaughterhouse production costs	14,230	Kyats/pig	SGMB and RG
Conversion ratio	0.833	Proportion	SGMB
Average live pig weight	55	Viss	SGMB
Price conversion wholesale pork to carcass	0.8575	Proportion	
Government fixed pork price ceiling	Pork_wholesale_price*(1+Price_increase)	Kyats/viss	RG
Price increase	STEP(0.07, 256)+STEP(0.07, 612)	Kyats/viss	RG
Pork wholesale price	8500	Kyats/viss	SGMB and RG
Baseline pork demand	700	Pigs/week	SGMB
Demand intercept	LN((Baseline_pork_demand*((1+Change_in_demand_due_to_population_and_income_growth*Chinese_New_Year_effect*Consumer_demand_shift_due_to_disease_outbreak)^TIME))/(Pork_wholesale_price^Price_elasticity_of_demand))	Unitless	Sterman (2010)
Demand schedule	EXP(Demand_intercept)*Government_fixed_pork_price_ceiling^Price_elasticity_of_demand	Unitless	Sterman (2010)
Price elasticity of demand	-0.5	Unitless	
Chinese New Year effect	1+ +(STEP(Demand_increase_from_Chinese_New_Year, 4)-STEP(Demand_increase_from_Chinese_New_Year, 8)) +(STEP(Demand_increase_from_Chinese_New_Year, 56)-STEP(Demand_increase_from_Chinese_New_Year, 60))[a]	Unitless	
Demand increase from Chinese New Year	0.2	Proportion	RG
Change in demand due to population and income growth	0.06/52	Proportion	SGMB and RG
Consumer lag	4	Weeks	SGMB and RG

Structure	***Baseline***	***Unit***	***Source***
Consumer reduction in demand due to disease	-0.3	Proportion	SGMB and RG
Consumer demand shift due to disease outbreak	1+ STEP(Consumer_reduction_in_demand_due_to_disease, Disease_start_time)-STEP(Consumer_reduction_in_demand_due_to_disease, Disease_start_time+Length_of_disease_outbreak+Consumer_lag)+ STEP(Consumer_reduction_in_demand_due_to_disease, Disease_start_time+Time_between_disease_outbreaks)-STEP(Consumer_reduction_in_demand_due_to_disease, Disease_start_time+Time_between_disease_outbreaks+Length_of_disease_outbreak+Consumer_lag)[a]	Unitless	
Effect of slaughterhouse profits on maximum price	GRAPH(SMTH1(Slaughterhouse_profit_margin, Time_to_adjust_price)) (0.9000, 0.900), (0.9500, 0.950), (1.0000, 1.000), (1.0500, 1.000), (1.1000, 1.000), (1.1500, 1.000), (1.2000, 1.000), (1.2500, 1.050), (1.3000, 1.100), (1.3500, 1.150), (1.4000, 1.200)	Unitless	
Time to adjust price	4	Weeks	
Myeik slaughterhouse profits	Myeik_slaughterhouse_revenue-Myeik_slaughterhouse_costs	Kyats/viss	
Myeik slaughterhouse revenues	((Purchasing_for_slaughter_in_Myeik)*Average_live_pig_weight*Conversion_ratio*standard_wholesale_price)	Kyats	
Number of high-quality pigs slaughtered	((Purchasing_for_slaughter_in_Myeik-"Number_of_high-quality_pigs_slaughtered")*Average_live_pig_weight*Conversion_ratio*standard_wholesale_price)+("Number_of_high-quality_pigs_slaughtered"*standard_wholesale_price*Average_live_pig_weight*Conversion_ratio*"%_premium_for_wholesale_HQ")	Pigs	
Myeik pigs through broker	Inflow_from_TRRILD_project-(SUM("Slaughtering_for_high-quality_wholesale")+Purchasing_for_slaughter[PG_hybrid,FarrowtoFinish]+Purchasing_for_slaughter[PG_hybrid,WeantoFinish])	Pigs	
Number of pigs/week/labourer	23.3		RG
Number of people employed at slaughterhouses	(Inflow_from_TRRILD_project+SUM(Slaughtering_for_premium_cuts))/"Number_of_pigs/week/labourer"		
Number of people employed in off-farm activities	Number_of_people_employed_at_slaughterhouses+Number_of_brokers_employed+Number_of_AHWs+Number_of_AI_workers+Number_of_feed_shop_workers		RG
Number of feed shop workers	Number_of_feed_shops*3		RG
Number of feed shops	(Feed_costs[PG_hybrid,WeantoFinish]+(Feed_costs[Individual_local,FarrowtoFinish]*0.5)+(Feed_costs[Individual_local,WeantoFinish]*0.2)+(Feed_costs[Individual_hybrid,FarrowtoFinish]*0.8)+(Feed_costs[Individual_hybrid,WeantoFinish]*0.5)+Feed_costs[PG_hybrid,FarrowtoFinish])/"Average_feed_sales/shop"		

Structure	Baseline	Unit	Source
Income generated by off-farm employment	"Number_of_weeks_worked_in_off-farm_activities"*5*(7500/1500)	US$	RG
Average feed sales/shop	3,000,000	Week	RG
Broker purchasing for slaughter	Individual: Purchasing_for_slaughter PO: (Purchasing_for_slaughter)-(Order_fulfillment_for_standard_wholesale_market_from_PG*FF_to_WF_ratio)	 Pigs/week	
Broker purchase costs	(Broker_purchasing_for_slaughter*Farmgate_price_of_live_pigs_in_target_villages*(1)*Fattener_live_weight*(1-Weight_reduction)*Local_breed_discount) + (Culling_of_breeding_stock*Culled_sow_price*(1)*Fattener_live_weight*(1-Weight_reduction)*Local_breed_discount) + (Panic_selling_growers*Farmgate_price_of_live_pigs_in_target_villages*(1)*Panic_selling_live_weight*(1-Weight_reduction)*Local_breed_discount) + (Panic_selling_breeding_stock*Culled_sow_price*(1)*Fattener_live_weight*(1-Weight_reduction)*Local_breed_discount)	Kyats	
Broker costs	Broker_purchase_costs+((Broker_purchasing_for_slaughter+Panic_selling_growers+Panic_selling_breeding_stock+Culling_of_breeding_stock)*Broker_unit_costs)	Kyats	RG
Broker unit costs	7500	Kyats/pig	RG
Broker revenue	Broker_purchase_costs*(1+Broker_markup)	Kyats/pig	RG
Broker profits	Broker_revenue-Broker_costs	Kyats	
Total pigs through brokers	SUM(Panic_selling_growers)+SUM(Broker_purchasing_for_slaughter)+SUM(Culling_of_breeding_stock)+SUM(Panic_selling_breeding_stock)	Pigs	
Number of brokers	SMTH1(Total_pigs_through_brokers/"Max_pigs/broker", 104)	Brokers	
Max pigs/broker	10	Pigs/week	RG
Weight reduction	0.02	Percent	RG
Myeik slaughterhouse costs	(Slaughterhouse_price_of_live_pigs_from_Myeik*(Purchasing_for_slaughter_in_Myeik-Importing_live_pigs_from_Mawlymine) *Average_live_pig_weight) +(Price_of_live_pigs_from_Mawlymine*Importing_live_pigs_from_Mawlymine*Average_live_pig_weight) +(Slaughterhouse_production_costs*(Purchasing_for_slaughter_in_Myeik))	Kyats	

Note: [a] Repeats until end of model run time. [b] Blank source denotes data or equations which were developed by the Researcher.
Source: Pork VC model

Table C2: Baseline data for pig production module

Structure	*Baseline*	*Unit*	*Source*
Stocks			[a]
Gestation	0	Foetuses	
Piglets	0	Piglets	
Growers	1	Growers	
Breeding stock	Pig_producers_in_each_farming_system	Sows	
Inventory of live pigs in TRRILD project area	0	Fatteners	
Purchased piglets	0	Piglets	
Breeding stock adjustment	Breeding_stock_gap	Unitless	
Pig producers in each farming system	Local FF: 192 Local WF 768 Hybrid FF: 160 Hybrid WF: 160	Pig producers	PG survey
Former pig producers	0	Pig producers	
Number of pig producers who drop out	0	Pig producers	
Cumulative number of fatteners sold	0	Fatteners	
Flows			
Purchasing piglets	(Pig_producers_in_each_farming_system*Effect_of_profit_on_purchasing_piglets*(1+"Seasonal_production_effect_-_piglets"))/Length_of_piglet_production_cycle	Piglets/ week	
Raising piglets	Purchased_piglets		
Breeding	((Breeding_stock*"Number_of_litters/year"*"Number_of_piglets/litter")*(1+"Seasonal_production_effects_-_fatteners"))/52	Foetuses / week	
Aborting	Gestation*Abortion_rate	Foetuses / week	
Being born	Gestation/Gestation_delay	Piglets/ week	
Piglets dying	Piglets*Piglet_death_rate	Piglets/ week	
Growing	(Piglets*(1-Piglet_selling_rate))/Time_to_grow	Piglets/ week	
Selling piglets	(Piglets*Piglet_selling_rate)/Time_to_grow	Piglets/ week	
Selecting for breeding stock	IF Disease_outbreak > 0 THEN 0 ELSE (Growers/2)*Indicated_breeding_stock_change_rate	Gilts/ week	
Growers dying	Grower_death_rate*Growers	Growers/ week	
Panic selling growers	Panic_selling*Growers	Growers / week	

Structure	*Baseline*	*Unit*	*Source*
Fattening pigs	(Growers-(Selecting_for_breeding_stock))/Time_to_fatten	Growers/ week	
Slaughtering for premium cuts	PG Hybrid*:* "Order_for_high-quality_premium_cuts"*FF_to_WF_ratio	Fatteners / week	
Slaughtering for high-quality wholesale	PG Hybrid: "Demand_for_high-quality_wholesale"*FF_to_WF_ratio	Fatteners/ week	
Purchasing for slaughter	Individual: Slaughterhouse_demand *PG:* (Slaughterhouse_demand-(Slaughtering_for_premium_cuts+"Slaughtering_for_high-quality_wholesale"))		
Panic selling breeding stock	Breeding_stock*Panic_selling	Sows/ week	
Culling of breeding stock	(Breeding_stock/Average_breeding_time)	Sows/ week	SGMB
Breeding stock dying	Breeding_stock*Death_rate_breeding_stock	Sows/ week	
Sows entering breeding stock	Entering_pig_system[FarrowtoFinish]	Sows/ week	
Change in breeding stock adjustment	(Breeding_stock_gap-Breeding_stock_adjustment)/Gap_adjustment_time	Unitless	
Entering pig system	Individual local FF: ((Pig_producers_in_each_farming_system[Individual_local,WeantoFinish]/2)*"Effect_of_medium-term_profitability_on_changing_pig_systems"[Individual_local,FarrowtoFinish])/Time_to_make_a_decision[Individual_local,WeantoFinish]+((Former_pig_producers[Individual_hybrid,FarrowtoFinish]/2)*"Effect_of_profitability_re-entering_pig_farming"[Individual_local,FarrowtoFinish])/"Time_to_make_a_decision_re-entering" Individual local WF: "Re-entering_pig_farming"[Individual_local,WeantoFinish]+"Re-entering_pig_farming"[Individual_local,FarrowtoFinish] Individual hybrid FF: (Changing_pig_system[Individual_hybrid,WeantoFinish]+Changing_pig_system[Individual_local,FarrowtoFinish])+Changing_pig_system[PG_hybrid,FarrowtoFinish] Individual hybrid WF: ((Pig_producers_in_each_farming_system[Individual_local,WeantoFinish]/2)*"Effect_of_medium-term_profitability_on_changing_pig_systems"[Individual_hybrid,WeantoFinish])/Time_to_make_a_decision[Individual_local,WeantoFinish]+ "Re-entering_pig_farming"[Individual_hybrid,WeantoFinish]+((Former_pig_producers[Individual_hybrid,FarrowtoFinish]/2)*"Effect_of_profitability_re-	Pig producers/ week	

Structure	***Baseline***	***Unit***	***Source***
	entering_pig_farming"[Individual_hybrid,WeantoFinish]/"Time_to_make_a_decision_re-entering") PG hybrid FF: Joining_PG[PG_hybrid,FarrowtoFinish]+Changing_farming_system[PG_hybrid,WeantoFinish] PG hybrid WF: Joining_PG[PG_hybrid,WeantoFinish]+"Re-entering_pig_farming"[PG_hybrid,FarrowtoFinish]+"Re-entering_pig_farming"[PG_hybrid,WeantoFinish]		
Changing pig system	Individual local FF: (("Effect_of_medium-term_profitability_on_changing_pig_systems"[Individual_hybrid,FarrowtoFinish]*Pig_producers_in_each_farming_system[Individual_local,FarrowtoFinish])/Time_to_make_a_decision[Individual_local,FarrowtoFinish]) Individual local WF: (((Pig_producers_in_each_farming_system[Individual_local,WeantoFinish]/2)*"Effect_of_medium-term_profitability_on_changing_pig_systems"[Individual_local,FarrowtoFinish])/Time_to_make_a_decision[Individual_local,WeantoFinish])+ (((Pig_producers_in_each_farming_system[Individual_local,WeantoFinish]/2)*"Effect_of_medium-term_profitability_on_changing_pig_systems"[Individual_hybrid,WeantoFinish])/Time_to_make_a_decision[Individual_local,WeantoFinish]) Individual hybrid FF: 0 Individual hybrid WF: (("Effect_of_medium-term_profitability_on_changing_pig_systems"[Individual_hybrid,FarrowtoFinish]*Pig_producers_in_each_farming_system[Individual_hybrid,WeantoFinish])/Time_to_make_a_decision[Individual_hybrid,WeantoFinish]) PG hybrid FF: 0 PG hybrid WF: Changing_farming_system[PG_hybrid,WeantoFinish]	Pig producers / week	
Becoming PG member	Individual (Pig_producers_in_each_farming_system/"Total_number_of_non-PG_pig_farmers")*(Joining_PG[PG_hybrid,FarrowtoFinish]+Joining_PG[PG_hybrid,WeantoFinish]) PG	Pig producers / week	

Structure	***Baseline***	***Unit***	***Source***
	Taking_hiatus_from_PG[PG_hybrid]		
Leaving PG	Individual Local FF: 0 Individual local WF: 0 Individual hybrid FF: Taking_hiatus_from_PG[PG_hybrid,FarrowtoFinish] Individual hybrid WF: Taking_hiatus_from_PG[PG_hybrid,WeantoFinish] PG hybrid FF: "Re-engaging_in_PG"[PG_hybrid,FarrowtoFinish] PG hybrid WF: "Re-engaging_in_PG"[PG_hybrid,WeantoFinish]	Pig producers / week	
Leaving pig farming	Individual local FF: ("Effect_of_short-term_profits_on_leaving_pig_farming"[Individual_local,FarrowtoFinish]*Pig_producers_in_each_farming_system[Individual_local,FarrowtoFinish])/Time_to_make_a_decision[Individual_local,FarrowtoFinish]+Number_of_new_entrants_leaving[Individual_local,FarrowtoFinish] Individual local WF: ("Effect_of_short-term_profits_on_leaving_pig_farming"[Individual_local,WeantoFinish]*Pig_producers_in_each_farming_system[Individual_local,WeantoFinish])/Time_to_make_a_decision[Individual_local,WeantoFinish]+Number_of_new_entrants_leaving[Individual_local,WeantoFinish] Individual hybrid FF: ("Effect_of_short-term_profits_on_leaving_pig_farming"[Individual_hybrid,FarrowtoFinish]*Pig_producers_in_each_farming_system[Individual_hybrid,FarrowtoFinish])/Time_to_make_a_decision[Individual_hybrid,FarrowtoFinish]+ Number_of_new_entrants_leaving[Individual_hybrid,FarrowtoFinish] Individual hybrid WF: ("Effect_of_short-term_profits_on_leaving_pig_farming"[Individual_hybrid,WeantoFinish]*Pig_producers_in_each_farming_system[Individual_hybrid,WeantoFinish])/Time_to_make_a_decision[Individual_hybrid,WeantoFinish]+Number_of_new_entrants_leaving[Individual_hybrid,WeantoFinish] PG hybrid FF: IF TIME < 156 THEN 0 ELSE Number_of_new_entrants_leaving[PG_hybrid,FarrowtoFinish]+	Pig producers / week	

Structure	*Baseline*	*Unit*	*Source*
	(Pig_producers_in_each_farming_system[PG_hybrid,FarrowtoFinish]*"Effect_of_short-term_profits_on_leaving_pig_farming"[PG_hybrid,FarrowtoFinish])/Time_to_make_a_decision[PG_hybrid,FarrowtoFinish] PG hybrid WF: IF TIME < 156 THEN 0 ELSE Number_of_new_entrants_leaving[PG_hybrid,WeantoFinish]+ (Pig_producers_in_each_farming_system[PG_hybrid,WeantoFinish]*"Effect_of_short-term_profits_on_leaving_pig_farming"[PG_hybrid,WeantoFinish])/Time_to_make_a_decision[PG_hybrid,WeantoFinish]		
Re-entering pig farming	Individual local FF: (Former_pig_producers[Individual_local,FarrowtoFinish]*"Effect_of_profitability_re-entering_pig_farming"[Individual_local,WeantoFinish])/"Time_to_make_a_decision_re-entering" Individual local WF: (Former_pig_producers[Individual_local,WeantoFinish]*"Effect_of_profitability_re-entering_pig_farming"[Individual_local,WeantoFinish])/"Time_to_make_a_decision_re-entering" Individual hybrid FF: ((Former_pig_producers[Individual_hybrid,FarrowtoFinish]/2)*"Effect_of_profitability_re-entering_pig_farming"[Individual_hybrid,WeantoFinish])/"Time_to_make_a_decision_re-entering"+((Former_pig_producers[Individual_hybrid,FarrowtoFinish]/2)*"Effect_of_profitability_re-entering_pig_farming"[Individual_local,FarrowtoFinish])/"Time_to_make_a_decision_re-entering" Individual hybrid WF: (Former_pig_producers[Individual_hybrid,WeantoFinish]*"Effect_of_profitability_re-entering_pig_farming"[Individual_hybrid,WeantoFinish])/"Time_to_make_a_decision_re-entering" PG hybrid FF: (Former_pig_producers[PG_hybrid,WeantoFinish]*"Effect_of_profitability_re-entering_pig_farming"[PG_hybrid,WeantoFinish])/"Time_to_make_a_decision_re-entering" PG hybrid WF: (Former_pig_producers[PG_hybrid,WeantoFinish]*"Effect_of_profitability_re-entering_pig_farming"[PG_hybrid,WeantoFinish])/"Time_to_make_a_decision_re-entering"	Pig producers/ week	
Inflow of pig producers who drop out	Leaving_pig_farming	Producers / week	
Variables			

Structure	Baseline	Unit	Source
Annual profits of all pig producers	IF TIME < 1 THEN 0 ELSE "Cumulative_profits_of_individual_pig_producers_(USD)"/((TIME-208)/52)	US$/year	
Number of highly profitable pig producers	IF Annual_profits_of_pig_producers > 153 THEN Pig_producers_in_each_farming_system ELSE 0	Producers	
Number of litters/year	Local: 1 Hybrid: 2	Litters/ year	SGMB and RG
Seasonal production effects - FF	PULSE(Normal_season_production_rate, 0, 52) +PULSE(High_season_production_rate, 4, 52) +PULSE(High_season_production_rate, 8, 52) +PULSE(Normal_season_production_rate, 12, 52) +PULSE(Normal_season_production_rate, 16, 52) +PULSE(Normal_season_production_rate, 20, 52) +PULSE(Normal_season_production_rate, 24, 52) +PULSE(Normal_season_production_rate, 28, 52) +PULSE(Normal_season_production_rate, 32, 52) +PULSE(Normal_season_production_rate, 36, 52) +PULSE(Normal_season_production_rate, 40, 52) +PULSE(Normal_season_production_rate, 44, 52) +PULSE(Normal_season_production_rate, 48, 52)	Unitless	SGMB
Number of piglets	Local: 8 Hybrid: 12	Piglets/ litter	RG
Local breed disease resilience	0.3	Proportion	RG
Coverage of Good Animal Husbandry Practises	Effect_of_AHWs_on_reducing_mortality+"Effects_of_bio-security_and_hygiene_measure_on_animal_health"	Proportion	RG
Abortion rate	Local: (0.01/(114/7)*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_local,FarrowtoFinish]))+((Disease_outbreak*(1-Local_breed_disease_resilience))*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_local,FarrowtoFinish])) Hybrid: ((0.01/(114/7)*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_hybrid,FarrowtoFinish])))+(Disease_outbreak*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_hybrid,FarrowtoFinish]))	Proportion/ week	RG
Gestation delay	114/7	weeks	RG

Structure	Baseline	Unit	Source
Piglet death rate	Local: ((0.13/6.42)*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_local,FarrowtoFinish]))+((Disease_outbreak*(1-Local_breed_disease_resilience))*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_local,FarrowtoFinish])) Hybrid: ((0.13/6.42)*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_hybrid,FarrowtoFinish]))+(Disease_outbreak*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_hybrid,FarrowtoFinish]))	Proportion/ week	RG
Time to grow	6.42	Weeks	RG
Piglet selling rate	IF Disease_outbreak > 0 THEN 0.1 ELSE 0.5	Proportion	SGMB
Grower death rate	Local: ((0.1/36.4)*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_local,FarrowtoFinish]))+((Disease_outbreak*(1-Local_breed_disease_resilience))*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_local,FarrowtoFinish])) Hybrid: ((0.1/19.3)*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_hybrid,FarrowtoFinish]))+(Disease_outbreak*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_hybrid,FarrowtoFinish]))	Proportion/ week	RG
Time to fatten	Local: 36.4 Hybrid: 19.3	Weeks	RG
Slaughterhouse demand	Inventory_of_live_pigs_in_TRRILD_project_area	Fatteners/ week	
Average breeding time	104	Weeks	SGMB
Death rate breeding stock	Local: ((0.1/104)*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_local,FarrowtoFinish])*(1-Local_breed_disease_resilience))+(Disease_outbreak*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_local,FarrowtoFinish])*(1-Local_breed_disease_resilience)) Hybrid: ((0.1/104)*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_hybrid,FarrowtoFinish]))+(Dise	Proportion/week	

Structure	Baseline	Unit	Source
	ase_outbreak*(1-Coverage_of_Good_Animal_Husbandry_Practises[Individual_hybrid,FarrowtoFinish]))		
Breeding stock gap	(Desired_breeding_stock+Culling_of_breeding_stock)-Breeding_stock	Sows	(Hamza & Rich, 2015)
Indicated breeding stock change rate	IF Growers = 0 THEN 0 ELSE MAX((Breeding_stock_adjustment/Growers), 0)	Unitless	(Hamza & Rich, 2015)
Gap adjustment time	Local: 52 Hybrid: 26	Weeks	SGMB and RG
Desired breeding stock	Production_capacity*"Effect_of_short-term_profits_on_change_in_breeding_stock"	Sows	(Hamza & Rich, 2015)
Production capacity	Pig_producers_in_each_farming_system*Maximum_sows_per_farm	Sows	
Maximum sows/farm	3	Sows	RG
Effect of short-term profits on change in breeding stock	= GRAPH("Short-term_perceived_expected_profit_margin") (-1.000, 0.000), (-0.800, 0.000), (-0.600, 0.000), (-0.400, 0.000), (-0.200, 0.000), (0.000, 0.100), (0.200, 0.200), (0.400, 0.300), (0.600, 0.400), (0.800, 0.500), (1.000, 0.550), (1.200, 0.600), (1.400, 0.650), (1.600, 0.700), (1.800, 0.750), (2.000, 0.800), (2.200, 0.850), (2.400, 0.900), (2.600, 0.950), (2.800, 1.000), (3.000, 1.000)	Unitless	
Normal season production rate	-0.04	Proportion	RG
High season production rate	0.2	Proportion	RG
Seasonal production effect - WF	PULSE(Normal_season_production_rate, 0, 52) +PULSE(Normal_season_production_rate, 4, 52) +PULSE(Normal_season_production_rate, 8, 52) +PULSE(Normal_season_production_rate, 12, 52) +PULSE(Normal_season_production_rate, 16, 52) +PULSE(Normal_season_production_rate, 20, 52) +PULSE(Normal_season_production_rate, 24, 52) +PULSE(Normal_season_production_rate, 28, 52) +PULSE(High_season_production_rate, 32, 52) +PULSE(High_season_production_rate, 36, 52) +PULSE(High_season_production_rate, 40, 52) +PULSE(Normal_season_production_rate, 44, 52) +PULSE(Normal_season_production_rate, 48, 52)	Unitless	
Length of piglet production cycle	Local: 52 Hybrid: 26	Weeks	SGMB and RG
Effect of profit on purchasing piglets	= GRAPH("Short-term_perceived_expected_profit_margin")	Unitless	SGMB

Structure	Baseline	Unit	Source
	(0.000, 0.000), (0.100, 0.000), (0.200, 0.000), (0.300, 0.000), (0.400, 0.000), (0.500, 0.000), (0.600, 0.000), (0.700, 0.100), (0.800, 0.500), (0.900, 0.800), (1.000, 1.000), (1.100, 1.200), (1.200, 1.400), (1.300, 1.600), (1.400, 1.800), (1.500, 2.000), (1.600, 2.200), (1.700, 2.400), (1.800, 2.600), (1.900, 2.800), (2.000, 3.000)		
Time to make a decision	26	Weeks	SGMB
Time to make a decision re-entering	52	Weeks	SGMB
Effect of medium-term profitability on changing pig systems	= GRAPH((expected_profitability_of_pig_systems*Confidence_to_upgrade)) (-1.000, 0.000), (-0.850, 0.000), (-0.700, 0.000), (-0.550, 0.000), (-0.400, 0.000), (-0.250, 0.000), (-0.100, 0.000), (0.050, 0.000), (0.200, 0.177), (0.350, 0.351), (0.500, 0.494), (0.650, 0.600), (0.800, 0.700), (0.950, 0.800), (1.100, 0.887), (1.250, 0.894), (1.400, 0.900), (1.550, 0.900), (1.700, 0.900), (1.850, 0.900), (2.000, 0.900)	Unitless	
Confidence to upgrade	IF Effect_of_knowledge_on_upgrading_decision < 1 THEN 1 ELSE Effect_of_knowledge_on_upgrading_decision	Unitless	

Note: [a] Blank source denotes data or equations which were developed by the Researcher.

Source: Pork VC model

Table C3: Baseline data for farmer finance module

Structure	Baseline	Unit	Source
Stocks			[a]
Cumulative farm profits	0	Kyats	
Savings for financing production costs	0	Kyats/week	
Cumulative profits of individual pig producers (USD)	0	US$	
Cumulative profits of all pig producers (USD)	0	US$	
Feed quality	1	Unitless	
Flows			
Change in profits	Pig_farmer_profits	Kyats/week	
Saving profits for production	IF Change_in_profits < 0 THEN Change_in_profits ELSE Change_in_profits*MIN((Savings_rate+Compulsary_savings_from_MFI), 0.8)	Kyats/week	
Financing	Savings_for_financing_production_costs	Kyats/week	
Change in producer profits	"Weekly_profits_for_indiviudal_producers_(USD)"	US$/week	
Change in all producers' profits	(SUM(Pig_farmer_profits))/Exchange_rate	US$/week	
Change in feed investment	(Desired_feed_quality-Feed_quality)/Time_to_change_feed	Unitless	
Variables			

Structure	***Baseline***	***Unit***	***Source***
Profit margin	IF Total_farm_costs > 0 THEN Total_farm_revenue/Total_farm_costs ELSE 1	Unitless	
Short-term expected profit margin	Profit_margin	Unitless	
Short-term perceived expected profit margin	SMTH1("Short-term_expected_profit_margin", "Time_to_adjust_to_expected_short-term_profits")		
Time to adjust to short-term profits	<u>Local:</u> 52 <u>Hybrid:</u> 26	Weeks	SGMB
Short-term profit margin without upgrading costs	IF TIME > 52 THEN Total_farm_revenue/(Total_farm_costs-Upgrading_loan_repayments) ELSE 1	Unitless	
Short-term perceived profit margin without upgrading costs	SMTH1("Short-term_profit_margin_without_upgrading_costs", "Time_to_adjust_to_expected_short-term_profits")	Unitless	
Savings rate	= GRAPH(Profit_margin) (0.000, 0.800), (0.250, 0.800), (0.500, 0.800), (0.750, 0.800), (1.000, 0.775), (1.250, 0.750), (1.500, 0.700), (1.750, 0.650), (2.000, 0.600), (2.250, 0.550), (2.500, 0.525), (2.750, 0.500), (3.000, 0.500), (3.250, 0.500), (3.500, 0.500), (3.750, 0.500), (4.000, 0.500), (4.250, 0.500), (4.500, 0.500), (4.750, 0.500), (5.000, 0.500)	Proportion	SGMB
Compulsory savings from MFI	0.05*Proportion_of_productive_loans_from_MFI	Proportion	RG
Total farm revenue	<u>Individual:</u> Fattener_revenue+Sow_revenue+Piglet_revenue <u>PG:</u> Fattener_revenue[PG_hybrid,FarrowtoFinish]+Sow_revenue[PG_hybrid,FarrowtoFinish]+Piglet_revenue[PG_hybrid,FarrowtoFinish]+PG_member_rebate[PG_hybrid,FarrowtoFinish]+PG_payment_to_members_for_pigs[PG_hybrid,FarrowtoFinish]	Kyats/week	
Piglet revenue	Selling_piglets*(Piglet_cost-Piglet_marketing_costs)	Kyats/week	
Piglet marketing costs	5000	Kyats/ piglet	SGMB
Sow revenue	(Culling_of_breeding_stock+Panic_selling_breeding_stock)*Culled_sow_price*Fattener_live_weight	Kyats/week	
Fattener revenue	("Farm-gate_price_of_live_pigs_in_target_villages"*Fattener_live_weight*Purchasing_for_slaughter)+("Farm-gate_price_of_live_pigs_in_target_villages"*Panic_selling_growers*Panic_selling_live_weight)	Kyats/week	
Fattener live weight	<u>Local:</u> 35 <u>Individual hybrid:</u> 55 <u>PG hybrid:</u> 55	Viss	SGMB
Culled sow price	"Farm-gate_price_of_live_pigs_in_target_villages"*0.85	Kyats/viss	SGMB
Panic selling live weight	Fattener_live_weight*0.4	Kyats/viss	SGMB

Structure	Baseline	Unit	Source
Farmgate price of live pigs in target villages	Local: Slaughterhouse_price_of_live_pigs_from_Myeik*Debt_pressure[Individual_local]*Local_breed_discount*(1-"Broker_mark-up")*Pig_quality_score[Individual_local] Hybrid: Slaughterhouse_price_of_live_pigs_from_Myeik*Debt_pressure[Individual_hybrid]*(1-"Broker_mark-up")*Pig_quality_score[Individual_hybrid,FarrowtoFinish]*Effect_of_feed_on_hybrid_pig_quality[Individual_hybrid] PG: (Slaughterhouse_price_of_live_pigs_from_Myeik*Debt_pressure[PG_hybrid]*Pig_quality_score[PG_hybrid]*Effect_of_feed_on_hybrid_pig_quality[PG_hybrid])-Collective_transport_costs	Kyats/viss	
Broker mark-up	0.025*Effect_of_transaction_costs	Percentage	SGMB and RG
Effect of transaction costs	= GRAPH(Total_number_of_pigs_available_per_week) (0.00, 1.400), (2.00, 1.260), (4.00, 1.155), (6.00, 1.072), (8.00, 0.996), (10.00, 0.936), (12.00, 0.883), (14.00, 0.830), (16.00, 0.792), (18.00, 0.777), (20.00, 0.777)	Unitless	
Total number of pigs available per week	(Inventory_of_live_pigs_in_TRRILD_project_area[Individual]+Culling_of_breeding_stock[Individual]+Culling_of_breeding_stock[Individual])/Number_of_villages	Pigs/week	
Number of villages	32	Villages	RG
Pig quality score	IF Effect_of_knowledge_on_pig_quality < 1 THEN 1 ELSE Effect_of_knowledge_on_pig_quality	Unitless	RG
Collective transport costs	(5000/Fattener_live_weight[PG])	Kyats/viss	SGMB
Proportion of loan repayments in costs	(Upgrading_loan_repayments+Loan_costs_for_productive_cycle)/Total_farm_costs	Proportion	
Debt pressure	= GRAPH(Proportion_of_loan_repayments_in_costs) (0.0000, 1.000), (0.0500, 0.995), (0.1000, 0.990), (0.1500, 0.985), (0.2000, 0.980), (0.2500, 0.975), (0.3000, 0.970), (0.3500, 0.965), (0.4000, 0.960), (0.4500, 0.955), (0.5000, 0.950)	Unitless	
Effect of feed on pig quality	Feed_quality	Unitless	
Total farm costs	Loan_costs_for_production_cycle+Farm_production_costs+Upgrading_loan_repayments	Kyats/week	
Desired feed quality	= GRAPH("Short-term_perceived_expected_profit_margin") (0.000, 0.8500), (0.100, 0.8500), (0.200, 0.8500), (0.300, 0.8500), (0.400, 0.8500), (0.500, 0.8500), (0.600, 0.8500), (0.700, 0.8500), (0.800, 0.9000), (0.900, 0.9500), (1.000, 1.0000), (1.100, 1.0330), (1.200, 1.0660), (1.300, 1.1000), (1.400, 1.1330), (1.500, 1.1660), (1.600, 1.2000), (1.700, 1.2330), (1.800, 1.2660), (1.900, 1.3000), (2.000, 1.3000)		
Time to change feed	4	Weeks	SGMB
Loan costs for production cycle	IF Production_loan_capital_required <0 THEN 0 ELSE Production_loan_capital_required*(Production_loan_interest_rate)	Kyats/week	

Structure	***Baseline***	***Unit***	***Source***
Production loan capital required	(Farm_production_costs-(HISTORY(Savings_for_financing_production_costs, TIME)-(HISTORY(Savings_for_financing_production_costs, TIME-1))))*Production_cycle_length	Kyats/week	
Production cycle length	Local: 42.82 Hybrid: 25.72	Weeks	SGMB and RG
Average production loan size	IF Pig_producers_in_each_farming_system = 0 THEN 0 ELSE SMTH1(((Production_loan_capital_required)/Pig_producers_in_each_farming_system), 52)	Kyats/week	
Farm production costs	Piglet_purchase_costs+Feed_costs+Other_variable_costs+Breeding_costs	Kyats/week	
Breeding costs	<u>Individual FF:</u> Breeding_stock[Individual]*("Number_of_litters/year"[Individual]/52)*Boar_servicing_costs[Individual_local,FarrowtoFinish] <u>PG FF:</u> ((1-Proportion_of_fertilisation_covered_by_AI_centre)*Breeding_stock[PG_hybrid,FarrowtoFinish]*("Number_of_litters/year"[PG_hybrid,FarrowtoFinish]/52)*Boar_servicing_costs[PG_hybrid,FarrowtoFinish])+((Proportion_of_fertilisation_covered_by_AI_centre)*Breeding_stock[PG_hybrid,FarrowtoFinish]*("Number_of_litters/year"[PG_hybrid,FarrowtoFinish]/52)*AI_costs)	Kyats/week	
Boar servicing costs	<u>Local:</u> 30,000 <u>Hybrid:</u> 45,000	Kyats/ service	SGMB and RG
AI costs	IF Break_even_fee_for_Hyrbid_AI_services < Boar_servicing_costs[Individual_hybrid,FarrowtoFinish] THEN Break_even_fee_for_Hyrbid_AI_services ELSE Boar_servicing_costs[Individual_hybrid,FarrowtoFinish]	Kyats/ service	
Other variable costs	(Watering+Veterinary_services+Shelter_maintenance)*(Growers+Breeding_stock)+Costs_of_AHW_services+"Costs_of_bio-security_and_hygiene_measures"	Kyats/week	
Shelter maintenance	<u>Individual local FF:</u> 46.7 <u>Individual local WF:</u> 27.5 <u>Hybrid FF:</u> 144.3 <u>Hybrid WF:</u> 51.8 <u>PG Hybrid FF:</u> 144.3 <u>PG Hybrid WF:</u> 51.8	Kyats/ week/ pig	SGMB and RG
Veterinary services	<u>Individual local FF:</u> 20 <u>Individual local WF:</u> 11.7 <u>Hybrid FF:</u> 30 <u>Hybrid WF:</u> 19.8	Kyats/ week / pig	SGMB and RG

Structure	*Baseline*	*Unit*	*Source*
Watering	Local: 27.5 Hybrid: 51.5 PG: 51.5	Kyats/ week / pig	SGMB and RG
Costs of AHW services	("AHW_costs/grower"*Growers*Proportion_of_pigs_covered_by_AHW)/Time_to_fatten	Kyats/week	SGMB and RG
AHW costs/grower	4,000	Kyats	RG
Costs of bio-security and hygiene measures	(1000*Growers*"Application_of_bio-security_and_hygiene_measures")/Time_to_fatten	Kyats/week	RG
Piglet purchase costs	Purchased_piglets*Piglet_cost	Kyats/week	
Piglet cost	Local: Slaughterhouse_price_of_live_pigs_from_Myeik*0.65*14 Hybrid: Slaughterhouse_price_of_live_pigs_from_Myeik*18.75	Kyats/week	SGMB and RG
Feed costs	Piglet_feed_costs+Grower_feed_costs+Sow_feed_costs	Kyats/week	
Piglet feed costs	"Feed_costs/piglet"*Piglets	Kyats/week	
Feed costs/piglet	Local: 260.1 Hybrid: 706 PG: 706*(1-PG_discount_for_bulk_ordering)	Kyats/week	SGMB and RG
Grower feed costs	Growers*"Feed_costs/grower"	Kyats/week	
Feed costs/grower	Individual local FF: 700 Individual local WF: 500 Individual hybrid FF: Effect_of_feed_quality_on_costs[Individual_hybrid,FarrowtoFinish] Individual hybrid WF: Effect_of_feed_quality_on_costs[Individual_hybrid,WeantoFinish]*0.65 PG hybrid FF: Effect_of_feed_quality_on_costs[Individual_hybrid,FarrowtoFinish] PG Hybrid WF: (Effect_of_feed_quality_on_costs[PG_hybrid,WeantoFinish]*(1-PG_discount_for_bulk_ordering))*0.65	Kyats/week	SGMB and RG
Sow feed costs	Breeding_stock*"Feed_costs/sow"	Kyats/week	SGMB and RG
Feed costs/sow	Local: 1,212 Hybrid: 9678 PG: 9678*(1-PG_discount_for_bulk_ordering)	Kyats/week	SGMB and RG
PG discount for bulk ordering	0.05	Percentage	RG
Effect of feed quality on costs	=GRAPH(Feed_quality) (0.8500, 5000.0), (0.9000, 5500.0), (0.9500, 6000.0), (1.0000, 6500.0), (1.0500, 7000.0), (1.1000, 7500.0), (1.1500, 8000.0), (1.2000, 8500.0), (1.2500, 9000.0), (1.3000, 9500.0)	Unitless	RG

Note: [a] Blank source denotes data or equations which were developed by the Researcher.
Source: Pork VC model

Table C4: Baseline data for farm investment and credit modules

Structure	*Baseline*	*Unit*	*Source*
Stocks			[a]
Available loan capital from formal lenders	"Initial_capital_injection_(kyat)"	Kyats	
Loan capital in use by pig farmers	0	Kyats	
Upgrading loan capital requirements	0	Kyats	
Number of farmers with investment loans	0	Farmers	
Flows			
Injecting loan capital	Repaying_loan	Kyats/week	
Providing loans	IF Available_loan_capital_from_formal_lenders < 0 THEN 0 ELSE (Farmers_taking_investment_loan[PG_hybrid,FarrowtoFinish]+Farmers_taking_investment_loan[PG_hybrid,WeantoFinish])	Kyats/week	
Repaying loan	DELAY(Providing_loans, MFI_loan_term)	Kyats/week	
Defaulting on production loan	SUM(Default_productive_loan_from_MFI)	Kyats/week	
Defaulting on upgrading loan	SUM(Default_investment_loan_from_MFI)	Kyats/week	
Farmers taking investment loan	Entering_pig_system*"Farm_set-up_costs"	Kyats/week	
Paying off investment loans	DELAY(Farmers_taking_investment_loan, Investment_loan_term)		
Taking loan	Entering_pig_system	Farmers	
Paying off loan	DELAY(Taking_loan, "Investment_loan_term_(PG)")	Farmers	
Variables			
Initial capital injection (kyat)	"Initial_capital_injection_(USD)"*1500	Kyats	
Initial capital injection (USD)	A1: 150000 A1a: 300000	US$	
Medium-term expected profitability of pig systems	(Expected_revenue_with_investment-Expected_cost_with_investment)/Expected_revenue_with_investment ELSE 0	Kyats/week	
Effect of profitability on new entrants leaving pig farming	= GRAPH("Medium-term_expected_profitability_of_pig_systems") (-1.000, 1.000), (-0.800, 0.700), (-0.600, 0.500), (-0.400, 0.300), (-0.200, 0.100), (0.000, 0.000), (0.200, 0.000), (0.400, 0.000), (0.600, 0.000), (0.800, 0.000), (1.000, 0.000)	Unitless	SGMB and RG
Number of new entrants leaving	Effect_of_profitability_on_new_entrants_leaving_pig_farming*Number_of_farmers_with_investment_loans	Farmers/ week	
Default investment loan size	IF Upgrading_loan_capital_requirements = 0 OR Number_of_farmers_with_investment_loans = 0 THEN 0 ELSE (Upgrading_loan_capital_requirements/Number_of_farmers_with_investment_loans)*Number_of_new_entrants_leaving	Kyats	
Default investment loan from MFI	Proportion_of_investment_loans_covered_by_MFI*Default_investment_loan_size	Kyats	
Default production loan size	Average_production_loan_size*(Leaving_pig_farming)	Kyats	

Structure	***Baseline***	***Unit***	***Source***
Default productive loan from MFI	Proportion_of_productive_loans_from_MFI*Default_production_loan_size[PG_hybrid,FarrowtoFinish]	Kyats	
Expected revenue with investment	SMTH1(Total_farm_revenue/Pig_producers_in_each_farming_system, Time_to_adjust_to_revenue_and_costs)	Kyats/week	
Expected costs with investment	SMTH1(((Total_farm_costs-Upgrading_loan_repayments)/Pig_producers_in_each_farming_system)+Loan_costs_for_upgrading, Time_to_adjust_to_revenue_and_costs)	Kyats/week	
Time to adjust to revenue and costs	52	Weeks	
Loan costs for upgrading	-PMT(Upgrading_interest_rate, Investment_loan_term, "Farm_set-up_costs", 0)	Kyats/week	
Farm set-up costs	Shelter+Equipment+Purchase_breeding_sow	Kyats	
Shelter	<u>Local FF:</u> 120000 <u>Local WF:</u> 0 <u>Hybrid FF:</u> 1125000 <u>Hybrid WF:</u> 50000	Kyats	SGMB and RG
Equipment	<u>Local FF:</u> 10000 <u>Local WF:</u> 0 <u>Hybrid FF:</u> 50000 <u>Hybrid WF:</u> 5,000	Kyats	SGMB and RG
Purchase breeding sow	Piglet_cost*4	Kyats	SGMB and RG
Upgrading loan repayments	-PMT(Upgrading_interest_rate,Investment_loan_term, Upgrading_loan_capital_requirements, 0)	Kyats/week	
Money lender interest rate	(0.05*12)/52	Interest/ week	SGMB and RG
MFI interest rate	(0.0246*12)/52	Interest/ week	RG
Capital requirements for farm investments	Upgrading_loan_capital_requirements[FarrowtoFinish]+Upgrading_loan_capital_requirements[WeantoFinish]	Kyats	
Proportion of investment loans covered by MFI	IF Capital_requirements_for_farm_investments = 0 OR Capital_requirements_for_farm_investments < Available_loan_capital_from_formal_lenders THEN 1 ELSE MIN((Available_loan_capital_from_formal_lenders/Capital_requirements_for_farm_investments), 1)	Proportion	
Upgrading interest rate	IF Capital_requirements_for_farm_investments = 0 THEN MFI_interest_rate ELSE ((Money_lender_interest_rate*(1-Proportion_of_investment_loans_covered_by_MFI)*Capital_requirements_for_farm_investments)	Interest/ week	

Structure	Baseline	Unit	Source
	+ (MFI_interest_rate*Proportion_of_investment_loans_covered_by_MFI*Capital_requirements_for_farm_investments))/Capital_requirements_for_farm_investments		
Money lender loan term	52	Weeks	SGMB
MFI loan term	66	Weeks	RG
Investment loan term	IF Capital_requirements_for_farm_investments = 0 THEN MFI_loan_term ELSE ((Money_lender_loan_term*(1-Proportion_of_investment_loans_covered_by_MFI)*Capital_requirements_for_farm_investments)+(MFI_loan_term*Proportion_of_investment_loans_covered_by_MFI*Capital_requirements_for_farm_investments))/Capital_requirements_for_farm_investments	Weeks	
Proportion of productive loans from MFI	IF Available_loan_capital_from_formal_lenders = 0 THEN 0 ELSE MIN(Available_loan_capital_from_formal_lenders/SUM(Production_loan_capital_required), 1)	Proportion	
Productive loan interest rate	((MFI_interest_rate*Proportion_of_productive_loans_from_MFI*SUM(Production_loan_capital_required)) + (Money_lender_interest_rate*(1-Proportion_of_productive_loans_from_MFI)*SUM(Production_loan_capital_required)))/SUM(Production_loan_capital_required)	Interest/ week	

Note: [a] Blank source denotes data or equations which were developed by the Researcher.
Source: Pork VC model

Table C5: Baseline data for knowledge module

Structure	*Baseline*	*Units*	*Source*
Stock			[a]
Farmer technical knowledge	Initial_knowledge_level	Unitless	
Flows			
Gaining knowledge	Learning_rate	Per week	
Forgetting	Farmer_technical_knowledge*(Forgetting_rate/52)	Per week	
Variables			
Initial knowledge level	0.1	Unitless	
Effect of knowledge on upgrading decision	(Farmer_technical_knowledge/Initial_knowledge_level)^(LN(1-"Learning_rate_-_upgrading")/LN(2))	Unitless	Sterman (2000)
Learning rate - upgrading	-0.05	Unitless	RG
Confidence to upgrade	IF Effect_of_knowledge_on_upgrading_decision < 1 THEN 1 ELSE Effect_of_knowledge_on_upgrading_decision	Unitless	

Structure	*Baseline*	*Units*	*Source*
Effect of knowledge on pig quality	(Farmer_technical_knowledge/Initial_knowledge_level)^(LN(1-"Learning_rate_-_quality")/LN(2))	Unitless	Sterman (2000)
Application of bio-security and hygiene measures	IF Effect_of_knowledge_on_upgrading_decision < 1 THEN 1 ELSE Effect_of_knowledge_on_upgrading_decision	Unitless	
Effects of bio-security and hygiene measures on animal health	"Application_of_bio-security_and_hygiene_measures"*0.2	Unitless	
Learning rate - quality	-0.02	Unitless	RG
Forgetting rate	0.05	Annual proportion	
Learning rate	((Percentage_of_farmers_acquiring_knowledge_from_trainings+Proportion_of_farmers_educated_by_peers+Percentage_of_PG_members_acquiring_knowledge_from_training)*Knowledge_gap*Knowledge_absorption_rate)/Time_to_absorb	Unitless	Lie et al. (2018)
Time to absorb	1	Week	
Knowledge absorption rate	0.5	Proportion	RG
Maximum knowledge available	1	Unitless	
Knowledge gap	Maximum_knowledge_available-Farmer_technical_knowledge	Unitless	Lie et al. (2018)
Percentage of farmers acquiring knowledge from trainings	(("Number_of_farmers/training"*Number_of_trainings_per_year)/Total_number_of_pig_farmers)/52	Proportion of farmers	
Percentage of farmers trained by LVBD and civil society	0.05	Annual proportion	RG
Number of farmers/training	Total_number_of_pig_farmers*Percentage_of_farmers_trained_by_LVBD_and_civil_society	Farmers/ training	RG
Number of trainings/year	1	Trainings/ year	RG
Percentage of farmers acquiring knowledge from project training	STEP((("Number_of_farmers/project_training"*"Number_of_project_trainings/year")/52/Number_of_active_PG_members)*"Farmer_training_intervention_on_/_off")-STEP(((("Number_of_farmers/project_training"*"Number_of_project_trainings/year")/52/Number_of_active_PG_members)*"Farmer_training_intervention_on_/_off"), Weeks_of_training_from_project)	Proportion	RG
Number of farmers/project training	25	Farmers	RG
Number of project trainings/year	26	Trainings/ year	RG
Weeks of training from project	156	Weeks	RG
Percentage of farmers acquiring knowledge from PG training	STEP((("Number_of_farmers/PG_training"*"Number_of_PG_trainings/year")/52/Number_of_active_PG_members)*"Farmer_training_intervention_on_/_off")-STEP(((("Number_of_farmers/PG_training"*"Number_of_PG_trainings/year")/52/Number_		

Structure	Baseline	Units	Source
	of_active_PG_members)*"Farmer_training_intervention_on_/_off"),Weeks_of_training_from_PG)		
Number of PG trainings/year	26	Trainings	RG
Weeks of training from PG	1000	Weeks	
Number of farmers/PG training	10	Farmers	RG
Percentage of PG members acquiring knowledge from training	Percentage_of_farmers_acquiring_knowledge_from_project_training+Percentage_of_farmers_acquiring_knowledge_from_PG_training	PG members	
Number of contacts with peer farmers	Individual: 4/52 PG: 12/52	Contacts/ week	SGMB and RG
Number of contacts with technically competent farmers	IF Number_of_farmers = 0 THEN 0 ELSE Number_of_contacts_with_peer_farmers*((Farmer_technical_knowledge*Number_of_farmers)/Number_of_farmers)	Contacts/week	
Number of farmers	Local: Total_number_of_non-PG_pig_farmers Hybrid: Total_number_of_non-PG_pig_farmers PG: Number_of_active_PG_members	Farmers	
Proportion of farmers educated by peers	IF Number_of_farmers = 0 THEN 0 ELSE (Number_of_contacts_with_technically_competent_farmers*Proportion_of_contacts_resulting_in_education)/Number_of_farmers	Proportion	Reinker and Gralla, 2018
Proportion of contacts resulting in education	0.5	Proportion	SGMB

Note: [a] Blank source denotes data or equations which were developed by the Researcher.
Source: Pork VC model

Table C6: Baseline data for collective action module (PG portion)

Structure	Baseline	Units	Source
Stocks			[a]
Active PG[b] members	0	PG members	
Non-active PG members	0	Farmers	
PG cashflow	0	Kyats	
PG savings	0	Kyats	
PG rebates	0	Kyats	
Myeik demand for high-quality wholesale pork	0.01	Proportion	SGMB and RG
Flows			

Structure	Baseline	Units	Source
Joining PG	(PG_forming*Initial_WF_to_FF_ratio)+(Effect_of_PG_capacity_deficit_on_recruiting*Initial_WF_to_FF_ratio)/Time_to_recruit_new_members	Farmers/ week	
Taking hiatus from PG	(Active_PG_members*Effect_of_profits_on_taking_hiatus_from_PG)/Time_to_make_PG_decision	Farmers/ week	
Re-engaging in PG	("Non-active_PG_members"*"Effect_of_profits_on_re-joining_PG")/Time_to_make_PG_decision	Farmers/ week	
Changing farming system	PG WF: IF TIME < 156 THEN 0 ELSE (Active_PG_members[PG_hybrid,WeantoFinish]*"Effect_of_medium-term_profitability_on_changing_pig_systems"[PG_hybrid,FarrowtoFinish])/Time_to_make_a_decision[PG_hybrid,WeantoFinish]	Farmers/ week	
Leaving pig farming (PG)	Leaving_pig_farming[PG_hybrid]	Farmers/ week	
Re-entering PG	PG FF: "Re-engaging_in_PG"[PG_hybrid,FarrowtoFinish]+Changing_farming_system[PG_hybrid,WeantoFinish] PG WF: "Re-engaging_in_PG"[PG_hybrid,WeantoFinish]+"Re-entering_pig_farming"[PG_hybrid,FarrowtoFinish]+"Re-entering_pig_farming"[PG_hybrid,WeantoFinish]	Farmers/ week	
PG Revenue	"PG_revenue_from_high-quality_fattener"[PG_hybrid,FarrowtoFinish]+"PG_revenue_from_high-quality_fattener"[PG_hybrid,WeantoFinish]+ Cashflow_shortfalll+Dividend_payment_to_PO_members	Kyats/ week	
PG costs	PG_payment_to_members_for_pigs[PG_hybrid,FarrowtoFinish]+PG_payment_to_members_for_pigs[PG_hybrid,WeantoFinish]+PG_operating_costs	Kyats/ week	
Allocating rebates to PG members	PG_payment_to_members_for_pigs[PG_hybrid,FarrowtoFinish]+PG_payment_to_members_for_pigs[PG_hybrid,WeantoFinish]+PG_operating_costs	Kyats/ week	
Paying rebates to PG members	PG_rebates	Kyats/ week	
Saving	IF Maximum_flexible_cash > 0 AND PG_savings < Maximum_PG_savings THEN (PG_cashflow/DT-PG_costs)*(MIN((PG_savings_rate+Effect_of_slaughterhouse_profits_on_savings), 1)) ELSE 0	Kyats/ week	
Investing in AHWs	IF Gap_in_AHW_coverage > 0 THEN Gap_in_AHW_coverage*Cost_of_AHW ELSE 0	Kyats	
Investing in AI	IF Gap_in_AI_capacity > 0 THEN Gap_in_AI_capacity*Cost_of_unit_investment_in_AI ELSE 0	Kyats	

Structure	***Baseline***	***Units***	***Source***
Cashflow shortfall	IF PG_cashflow < 0 THEN PG_savings ELSE 0	Kyats	
Investing in PO capacity	MIN(((PG_savings-Cashflow_shortfalll)*Effect_of_slaughterhouse_profits_on_capacity_investment), Slaughterhouse_capacity_gap)	Kyats	
Change in demand for high-quality wholesale pork in Myeik	"Myeik_demand_for_high-quality_wholesale_pork"*"Increase_in_demand_for_high-quality_pork_in_Myeik"	Proportion	
Variables			
Initial number of PG members	640	Pig producers	RG
PG forming	STEP((Initial_number_of_PG_members/Time_to_form_PG*"PG_intervention_on_/_off"),1) - STEP((Initial_number_of_PG_members/Time_to_form_PG*"PG_intervention_on_/_off"), !+Time_to_form_PG)	PG members/ week	
Time to form PG	52	weeks	RG
Initial WF to FF ration	1/6	Proportion	RG
Time to recruit new members	26	Weeks	RG
Effect of PG capacity deficit on recruiting	= GRAPH(Gap_between_production_capacity_and_supply_from_PG) (0.00, 0.0), (5.00, 10.0), (10.00, 20.0), (15.00, 30.0), (20.00, 40.0), (25.00, 50.0), (30.00, 60.0), (35.00, 70.0), (40.00, 80.0), (45.00, 90.0), (50.00, 100.0)	Pig producers/ week	RG
Effect of profits on taking hiatus from PG	= GRAPH(PG_member_profitability_versus_individual_farmers) (0.000, 1.000), (0.200, 0.700), (0.400, 0.400), (0.600, 0.200), (0.800, 0.100), (1.000, 0.000), (1.200, 0.000), (1.400, 0.000), (1.600, 0.000), (1.800, 0.000), (2.000, 0.000)	Unitless	
PG member profitability versus individual farmer	"Short-term_perceived_profit_margin_without_upgrading_costs"[PG_hybrid]/"Short-term_perceived_profit_margin_without_upgrading_costs"[Individual_hybrid]	Unitless	
Time to make PG decision	26	Weeks	
Effect of profit on re-joining PG	= GRAPH(PG_member_profitability_versus_individual_farmers) (1.000, 0.100), (1.100, 0.200), (1.200, 0.400), (1.300, 0.700), (1.400, 1.000), (1.500, 1.000), (1.600, 1.000), (1.700, 1.000), (1.800, 1.000), (1.900, 1.000), (2.000, 1.000)	Unitless	SGMB
Premium for high-quality fattener	0.05	Proportion	RG
PG high-quality fattener price	Farmgate_price_of_live_pigs_in_target_villages*(1+"Premium_for_high-quality_fattener")	Kyats/viss	RG
PG revenue from high-quality fattener	"PG_high-quality_fattener_price"*(Slaughtering_for_premium_cuts+"Slaughtering_for_high-quality_wholesale")*Fattener_live_weight	Kyats	
PG member rebate	PG hybrid FF: IF Paying_rebates_to_PG_members >0 THEN FF_to_WF_ratio*Paying_rebates_to_PG_members ELSE 0 PG hybrid WF:	Kyats/week	

Structure	*Baseline*	*Units*	*Source*
	IF Paying_rebates_to_PG_members >0 THEN (1-FF_to_WF_ratio)*Paying_rebates_to_PG_members ELSE 0		
PG payment to members for pigs	PG_hybrid FF If PG_cashflow > 0 then (Slaughtering_for_premium_cuts+"Slaughtering_for_high-quality_wholesale")*Farmgate_price_of_live_pigs_in_target_villages*Fattener_live_weight Else ((Slaughtering_for_premium_cuts+"Slaughtering_for_high-quality_wholesale")*Farmgate_price_of_live_pigs_in_target_villages*Fattener_live_weight) - (-(PG_cashflow)*(FF_to_WF_ratio) PG_hybrid_WF If PG_cashflow > 0 then (Slaughtering_for_premium_cuts+"Slaughtering_for_high-quality_wholesale")*Farmgate_price_of_live_pigs_in_target_villages*Fattener_live_weight Else ((Slaughtering_for_premium_cuts+"Slaughtering_for_high-quality_wholesale")*Farmgate_price_of_live_pigs_in_target_villages*Fattener_live_weight) - (-(PG_cashflow)*(1-FF_to_WF_ratio)	Kyats/week	
Desired balance	PG_costs*Desired_time_coverage	Kyats	McRoberts (2013)
Desired time coverage	4	Weeks	RG
Maximum flexible cash	PG_cashflow-Desired_balance	Kyats	McRoberts (2013)
PG savings rate	0.1	Proportion	
Maximum PG savings	75000000	Kyats	
PG operating costs	AHW_costs+Management_costs+Technical_support_costs	Kyats	
AHW costs	Cost_of_AHW_refresher_training*Number_of_AHWs	Kyats/week	
Management costs	SMTH1(((Volume_of_fatteners_through_PG)/100*(300000*DT)), 52)	Kyats/week	RG
Technical support costs	SMTH1(((Volume_of_fatteners_through_PG/200)*(200000*DT)), 52)	Kyats/week	RG
Volume of fatteners through PG	"Slaughtering_for_high-quality_wholesale"[PG_hybrid]+Slaughtering_for_premium_cuts[PG_hybrid]+Purchasing_for_slaughter[PG_hybrid]	Pigs/week	
Cost of AHW refresher training	10000/52	Kyats/week	RG
Increase in demand for high-quality pork in Myeik	0.02/52	Proportion / week	RG

Note: [a] Blank source denotes data or equations which were developed by the Researcher. [b] The term "PG" is used in the table, but the same module structure is also used for the Scenario 3 (POs).

Source: Pork VC model

Table C7: Baseline data for collective action module (PO structure)

Structure	*Baseline*	*Units*	*Source*
Stocks			
PO slaughterhouse cashflow	0	Kyats	[a]
Supply line of PO slaughterhouse capacity	0	Pigs slaughtered/ week	
PO slaughterhouse capacity	0	Pigs slaughtered/ week	
PO investment total	0	Kyats	
Strategic partner profits	0	Kyats	
Myeik demand for high-quality pork cuts	0.005	Proportion	RG
Yangon demand for high-quality pork cuts	625	Viss/week	RG
Expected order rate for PG high-quality fatteners	"Wholesale_orders_for_high-quality"+"High-quality_pork_cuts_demand_in_Myeik"	Fatteners/ week	
PO slaughterhouse production capacity	PO_slaughterhouse_capacity	Fatteners/ week	
Slaughterhouse experience level	0	Unitless	
Flows			
Paying dividend	IF Slaughterhouse_maximum_flexible_cash > 0 THEN (PO_slaughterhouse_cashflow/DT)-Slaughterhouse_costs ELSE 0	Kyats/ week	
Slaughterhouse revenue	"Revenue_from_high-quality_pork_cuts_in_Myeik"+"Revenue_from_high-quality_wholesale_pork_in_Myeik"+Revenue_from_standard_wholesale_pork_in_Myeik+"Revenue_from_high-quality_pork_cuts_in_Yangon"+"PO_cashflow_shortfall"	Kyats/ week	
Slaughterhouse costs	Butchering_and_packaging_costs+Marketing_costs+PO_slaughterhouse_production_costs+Pig_purchasing_costs+Transport_costs	Kyats/ week	
Ordering new slaughterhouse capacity	Investing_in_PO_capacity/Unit_cost_of_slaughterhouse_capacity	Pigs slaughtered/ week	
Adding new slaughterhouse capacity	DELAY(Ordering_new_slaugherhouse_capacity, Capacity_acquisition_delay)	Pigs slaughtered/ week	
Slaughterhouse depreciation	PO_slaughterhouse_capacity/Time_to_depreciate	Pigs slaughtered/ week	

Structure	***Baseline***	***Units***	***Source***
Investing by strategic partner	((Strategic_partner_investment/DT)/Unit_cost_of_slaughterhouse_capacity)	Pigs slaughtered/ week	
PO investing in slaughterhouse	Investing_in_PO_capacity	Kyats/week	
Strategic partner change in profits	Dividend_payment_to_strategic_partner*DT	Kyats/week	
Change in demand for high-quality wholesale pork in Myeik	"Myeik_demand_for_high-quality_wholesale_pork"*"Increase_in_demand_for_high-quality"	Proportion/week	
Change in demand for high-quality pork cuts in Myeik	"Increase_in_demand_for_high-quality"*"Myeik_demand_for_high-quality_pork_cuts"	Proportion/week	
Change in demand for high-quality pork cuts in Yangon	Increase_in_Yangon_demand*"Yangon_demand_for_high-quality_pork_cuts"	Proportion/ week	
Change in expected orders for PG fatteners	(("Wholesale_orders_for_high-quality"+"High-quality_pork_cuts_demand_in_Myeik"+"High-quality_pork_product_demand_Yangon")-"Expected_order_rate_for_PG_high-quality_fatteners")/Order_adjustment_time	Fatteners/ week	
Change in PO slaughterhouse production capacity	(Desired_slaughterhouse_proudction_capacity-PO_slaughterhouse_production_capacity)/Time_to_change_sluaghterhouse_production_capacity	Fatteners/week	
Gaining experience	Number_of_carcasses	Unitless	
Variables			
Effect of slaughterhouse profits on savings	= GRAPH(IF Gap_between_production_capacity_and_supply_from_PG > 0 THEN 0 ELSE "Medium-term_slaughterhouse_profit_margin") (0.000, 0.000), (0.100, 0.000), (0.200, 0.000), (0.300, 0.000), (0.400, 0.000), (0.500, 0.000), (0.600, 0.000), (0.700, 0.000), (0.800, 0.000), (0.900, 0.000), (1.000, 0.000), (1.100, 0.100), (1.200, 0.200), (1.300, 0.400), (1.400, 0.500), (1.500, 0.600), (1.600, 0.700), (1.700, 0.800), (1.800, 0.800), (1.900, 0.800), (2.000, 0.800)	Unitless	
Effect of slaughterhouse profits on capacity investment	= GRAPH(IF Gap_between_production_capacity_and_supply_from_PG > 0 THEN 0 ELSE "Medium-term_slaughterhouse_profit_margin") (0.000, 0.000), (0.100, 0.000), (0.200, 0.000), (0.300, 0.000), (0.400, 0.000), (0.500, 0.000), (0.600, 0.000), (0.700, 0.000), (0.800, 0.000), (0.900, 0.000), (1.000, 0.000), (1.100, 0.100), (1.200, 0.400), (1.300, 0.800), (1.400, 1.000), (1.500, 1.000), (1.600, 1.000), (1.700, 1.000), (1.800, 1.000), (1.900, 1.000), (2.000, 1.000)	Unitless	
Dividend payment to PO members	Paying_dividend*Slaughterhouse_profit_split	Kyats	
Dividend payment to strategic partner	(1-Slaughterhouse_profit_split)*Paying_dividend	Kyats	
Slaughterhouse maximum flexible cash	PO_slaughterhouse_cashflow-Slaughterhouse_desired_balance	Kyats	McRoberts (2013)

Structure	*Baseline*	*Units*	*Source*
Slaughterhouse desired balance	Slaughterhouse_costs*Slaughterhouse_desired_coverage_time	Kyats	McRoberts (2013)
Slaughterhouse desired coverage time	4	Weeks	RG
Pig purchasing costs	("PG_revenue_from_high-quality_fattener"[PG_hybrid,FarrowtoFinish]+"PG_revenue_from_high-quality_fattener"[PG_hybrid,WeantoFinish])+(Order_fulfillment_for_standard_wholesale_market_from_PG*Fattener_live_weight[PG_hybrid,FarrowtoFinish]*Farmgate_price_of_live_pigs_in_target_villages[PG_hybrid,FarrowtoFinish])	Kyats/ week	
PO slaughterhouse production costs	(Labour+Electricity+Rent+Licence_fee)*Number_of_carcasses*Effect_of_experience_on_production_costs	Kyats/ week	RG
Labour	1000	Kyats/ carcass	RG
Electricity	23	Kyats/ carcass	RG
Rent	500	Kyats/ carcass	RG
Licence fee	13000	Kyats/ carcass	RG
Number of carcasses	"Slaughtering_for_high-quality_wholesale"[PG_hybrid,FarrowtoFinish]+"Slaughtering_for_high-quality_wholesale"[PG_hybrid,WeantoFinish] +Slaughtering_for_premium_cuts[PG_hybrid,FarrowtoFinish] +Slaughtering_for_premium_cuts[PG_hybrid,WeantoFinish] +Order_fulfillment_for_standard_wholesale_market_from_PG	Carcasses	
Marketing costs	"Marketing_costs/viss"*(Myeik_premium_pork_sales+Yangon_premium_pork_cuts_sales)	Kyats/week	
Marketing costs/viss	100	Kyats/viss	RG
Butchering and packaging costs	"Butchering_and_packaging_costs/viss"*(Myeik_premium_pork_sales+Yangon_premium_pork_cuts_sales)	Kyats/week	
Butchering and packaging costs/viss	200	Kyats/viss	RG
Transport costs	("Myeik_transport_costs/viss"*Myeik_premium_pork_sales)+("Yangon_transport_costs/viss"*Yangon_premium_pork_cuts_sales)	Kyats/week	
Myeik transport costs/viss	50	Kyats/viss	RG
Yangon transport costs/viss	300	Kyats/viss	RG
Yangon premium	0.35	Proportion	RG
Revenue from high-quality pork cuts in Yangon	"Yangon_pork_products_price/viss"*Yangon_premium_pork_cuts_sales	Kyats/week	
Yangon pork cuts price/viss	Government_fixed_pork_price_ceiling*(1+Yangon_premium)	Kyats/viss	RG
Yangon premium pork cuts sales	Number_of_carcasses_allocated_to_Yangon_premium_cuts*Carcass_weight*"Proportion_of_carcass_for_premium_cuts_(Yangon)"	Kyats/week	

Structure	*Baseline*	*Units*	*Source*
Number of carcasses allocated to Yangon premium cuts	(Slaughtering_for_premium_cuts[PG_hybrid,FarrowtoFinish]+Slaughtering_for_premium_cuts[PG_hybrid,WeantoFinish])*(1-Myeik_to_Yangon_ratio)	Carcasses/week	
Number of carcasses allocated to Myeik premium cuts	(Slaughtering_for_premium_cuts[PG_hybrid,FarrowtoFinish]+Slaughtering_for_premium_cuts[PG_hybrid,WeantoFinish])*Myeik_to_Yangon_ratio	Carcasses/ week	
Carcass weight	Fattener_live_weight[PG_hybrid,FarrowtoFinish]*Conversion_ratio	Viss	
Remaining carcass weight for wholesale market	((Number_of_carcasses_allocated_to_Myeik_premium_cuts)*Carcass_weight*(1-"Proportion_of_carcass_for_premium_cuts_(Myeik)"))+(Number_of_carcasses_allocated_to_Yangon_premium_cuts*Carcass_weight*(1-"Proportion_of_carcass_for_premium_cuts_(Yangon)"))	Viss	
Proportion of carcass for premium cuts (Myeik)	0.3	Proportion	RG
Myeik premium pork sales	Number_of_carcasses_allocated_to_Myeik_premium_cuts*Carcass_weight*"Proportion_of_carcass_for_premium_cuts_(Myeik)"	Viss/week	
Revenue from high-quality pork cuts in Myeik	Myeik_premium_pork_sales*"Myeik_pork_cuts_price/viss"	Kyats/week	
Myeik pork cuts price/viss	Government_fixed_pork_price_ceiling*(1+Myeik_premium)	Kyats/viss	
Myeik premium	0.15	Proportion	RG
Myeik premium for wholesale high-quality market	0.1	Proportion	RG
Revenue from high-quality wholesale pork in Myeik	("Slaughtering_for_high-quality_wholesale"[PG_hybrid,FarrowtoFinish]+"Slaughtering_for_high-quality_wholesale"[PG_hybrid,WeantoFinish])*Carcass_weight*(Standard_wholesale_price*(1+"Myeik_premium_for_wholesale_high-quality_market"))	Kyats/week	
Standard wholesale price	Government_fixed_pork_price_ceiling*Price_conversion_wholesale_pork_to_carcass	Kyats	RG
Revenue from standard wholesale pork in Myeik	(Order_fulfillment_for_standard_wholesale_market_from_PG*Carcass_weight*Standard_wholesale_price)+(Remaining_carcass_weight_for_wholesale_market*Standard_wholesale_price)	Kyats/week	
Medium-term slaughterhouse profit margin	SMTH1(PO_slaughterhousee_profit_margin, Time_to_adjust_to_slaughterhouse_profits)	Unitless	
Slaughterhouse capacity gap	IF Gap_between_production_capacity_and_supply_from_PG > 0 THEN 0 ELSE ((Gap_between_production_capacity_and_supply_from_PG*-1)-Supply_line_of_PO_slaughterhouse_capacity)*Unit_cost_of_slaughterhouse_capacity	Fatteners/week	
Unit cost of slaughterhouse capacity	715*1500	Kyats/ fattener	RG
Capacity acquisition delay	12	Weeks	RG
Time to depreciate	30*52	Weeks	RG

Structure	***Baseline***	***Units***	***Source***
Strategic partner investment	Initial_investment_requirement	Kyats	
Minimum slaughterhouse capacity	35	Fatteners/ week	RG
Initial investment requirement	Minimum_slaughterhouse_capacity*Unit_cost_of_slaughterhouse_capacity	Kyats	
Return on strategic partner investment	IF TIME < Slaughterhouse_start_time+52 THEN 0 ELSE (Strategic_partner_profits/Initial_investment_requirement)/((TIME-Slaughterhouse_start_time)/52)*100	Annual percentage	
Slaughterhouse profit split	IF TIME < (Slaughterhouse_start_time+52) THEN 0 ELSE PO_investment_total/(Initial_investment_requirement+PO_investment_total)	Proportion	
Initial production level	5000	Carcasses	
Effect of experience levels on production costs	IF Slaughterhouse_experence_level > 1000 THEN (Slaughterhouse_experence_level/Initial_production_level)^(LN(1-"Learning_curve_effect_-_production_costs")/LN(2)) ELSE 1	Proportion	
Learning curve effect – production costs	0.02	Unitless	
PO slaughterhouse short-term expected profit margin	SMTH1(PO_slaughterhousee_profit_margin, Time_to_adjust_to_Slaughterhouse_profit)	Unitless	
Indicated slaughterhouse capacity utilisation	= GRAPH("PO_slaughterhouse_short-term_expected_profit_margin") (0.000, 0.000), (0.100, 0.000), (0.200, 0.000), (0.300, 0.000), (0.400, 0.000), (0.500, 0.000), (0.600, 0.000), (0.700, 0.300), (0.800, 0.500), (0.900, 0.700), (1.000, 0.800), (1.100, 0.900), (1.200, 0.950), (1.300, 0.975), (1.400, 1.000), (1.500, 1.000), (1.600, 1.000), (1.700, 1.000), (1.800, 1.000), (1.900, 1.000), (2.000, 1.000)	Unitless	RG
Desired slaughterhouse production capacity	Indicated_slaughterhouse_capacity_utlisation*PO_slaughterhouse_capacity	Carcasses/ week	
Time to change slaughterhouse production capacity	1	Week	
Gap between production capacity and supply from PG	PO_slaughterhouse_production_capacity-(SMTH1(Volume_of_fatteners_through_PG, 52))	Fatteners/ week	
PO slaughterhouse profit margin	Slaughterhouse_revenue/Slaughterhouse_costs	Unitless	
Myeik to Yangon ratio	IF "High-quality_fattener_demand_for_Myeik" = 0 THEN 0 ELSE "High-quality_fattener_demand_for_Myeik"/("High-quality_fattener_demand_for_Myeik"+"High-quality_fattener_demand_for_Yangon")	Proportion	
Fatteners ordered for high-quality pork cuts	IF PO_slaughterhouse_production_capacity > "High-quality_fattener_demand_for_Myeik"+"High-quality_fattener_demand_for_Yangon" THEN "High-quality_fattener_demand_for_Myeik"+"High-quality_fattener_demand_for_Yangon" ELSE PO_slaughterhouse_production_capacity	Fatteners/ week	

Structure	*Baseline*	*Units*	*Source*
High-quality wholesale pork order from slaughterhouse	IF "Wholesale_requirement_for_high-quality_fatteners" < (PO_slaughterhouse_production_capacity-"Fatteners_ordered_for_high-quality_pork_cuts") THEN "Wholesale_requirement_for_high-quality_fatteners" ELSE PO_slaughterhouse_production_capacity-"Fatteners_ordered_for_high-quality_pork_cuts"	Fatteners/ week	
Demand for standard wholesale market from PO	PO_slaughterhouse_production_capacity-("Fatteners_ordered_for_high-quality_pork_cuts"+"High-quality_wholesale_pork_order_from_slaughterhouse")	Fatteners/ week	
Proportion of carcass for premium cuts (Yangon)	0.3	Proportion	RG
High-quality fattener demand for Yangon	"Yangon_demand_for_high-quality_pork_cuts"/(Carcass_weight*"Proportion_of_carcass_for_premium_cuts_(Yangon)") ELSE 0	Fatteners/week	
High-quality fattener demand for Myeik	Total_orders_for_live_pigs_in_Myeik*"Myeik_demand_for_high-quality_pork_cuts" ELSE 0	Fatteners/ week	
Order adjustment time	4	Weeks	
Wholesale requirement for high-quality fatteners	Total_orders_for_live_pigs_in_Myeik*"Myeik_demand_for_high-quality_wholesale_pork"	Fatteners/ week	
Increase in demand for high-quality pork in Myeik	0.02/52	Growth/ week	
Increase in Yangon Demand	0.06/52	Growth/ week	

Note: [a] Blank source denotes data or equations which were developed by the Researcher.
Source: Pork VC model

Table C8: Model data for AHW scenario

Structure	*Data*	*Units*	*Source*
Stocks			
Supply line of AHW Capacity	0	AHWs	[a]
Number of AHWs	4	AHWs	SGMB
AHW knowledge	0.1	Unitless	
Flows			
Recruiting new AHWs	IF TIME = 1 THEN (Initial_number_of_AHWs_recruited_by_project-Number_of_AHWs)/DT ELSE (Investing_in_AHWs/Cost_of_AHW)	AHWs/ week	RG
Adding new AHWs	DELAY(Recruiting_new_AHWs, Time_to_train_AHW)	AHWs/ week	
AHWs exiting	Number_of_AHWs*AHW_dropout_rate	AHW/ week	
AHWs gaining knowledge	AHW_learning_rate	Unitless	

Structure	***Data***	***Units***	***Source***
AHWs forgetting	AHW_knowledge*(AHW_forgetting_rate/52)	Unitless	
Variables			
Number of AHWs/project training	IF Number_of_AHWs > 32 THEN 32 ELSE Number_of_AHWs	AHWs/ training	RG
Weeks of AHW training from project/PG	<u>S1: 156</u> <u>S2 and S3:</u> 752	Weeks	
Percentage of AHWs acquiring knowledge from project/PG training	STEP(((("Number_of_AHWs/project_training"*"Number_of_AHW_project_trainings/year")/ 52/Number_of_AHWs)*"AHW_intervention_on_/_off"), 1)- STEP(((("Number_of_AHWs/project_training"*"Number_of_AHW_project_trainings/year")/ 52/Number_of_AHWs)*"AHW_intervention_on_/_off"), 1+Weeks_of_AHW_training_from_project)	Proportion	
Number of AHW project trainings/year	4	Trainings/ year	RG
Percentage of AHWs trained by LVBD and civil society	0.05	Proportion / year	RG
AHW learning rate	((Percentage_of_AHWs_acquiring_knowledge_from_trainings)*AHW_knowledge_gap*AHW _kowledge_absorption_rate)/AHW_time_to_absorb	Unitless	Lie et al (2018)
AHW time to absorb	1	Weeks	
AHW knowledge absorption rate	0.5	Proportion	
AHW knowledge gap	AHW_maximum_knowledge_available-AHW_knowledge	Unitless	
AHW maximum knowledge available	1	Unitless	
AHW forgetting rate	0.05	Proportion	
Time to train AHW	12	Weeks	RG
Gap in AHW coverage	SMTH1((Total_number_of_pigs_in_system/Capacity_of_each_AHW)- (Number_of_AHWs+Supply_line_of_AHW_capacity), 52) ELSE 0	AHWs	
AHW dropout rate	0.1/52	AHWs/ week	RG
Proportion of pigs covered by AHW	IF Number_of_AHWs = 0 THEN 0 ELSE MIN (((Number_of_AHWs*Capacity_of_each_AHW)/Total_number_of_pigs_in_system), 1)	Proportion of pigs	
Capacity of each AHW	140	Pigs	RG
Reduction in disease effects	0.6	Proportion	RG
Effectiveness of AHW	Proportion_of_pigs_covered_by_AHW*AHW_knowledge	Proportion	
Costs of AHW	15,000	Kyats/ AHW	RG
Effect of AHWs on reducing mortality	Effectiveness_of_AHWs*Reduction_in_disease_effects	Proportion	

Note: [a] Blank source denotes data or equations which were developed by the Researcher.
Source: Pork VC model

Table C9: Model data for AI scenario

Structure	*Data*	*Units*	*Source*
Stocks			
Supply line of AI capacity	0	Inseminations /week	[a]
AI capacity	0	Inseminations /week	
AI subsidy required by project	0	US$	
Flows			
Initiating new AI capacity	IF TIME = 1 THEN AI_centre_capacity/DT ELSE Investing_in_AI/Cost_of_unit_investment_in_AI	Inseminations /week	
Increasing Ai capacity	DELAY(Initiating_new_AI_capacity, Time_to_establish_AI_centre)	Inseminations /week	
Declining AI capacity	AI_capacity/Depreciation_of_AI_centre	Inseminations /week	
Requiring AI subsidy	(Project_subsidy_for_AI*Fertilisation_events_covered_by_AI)/1500	US$/week	
Variables			
AI centre capacity	20	Inseminations / week	
Cost of unit investment in AI	112500	Kyats	RG
Time to establish AI centre	26	Weeks	RG
Number of AI workers	AI_capacity/20	Workers	RG
Depreciation of AI centre	30*52	Weeks	RG
Gap in AI capacity	SMTH1(("Total_number_of_fertilisation_events/week"-(AI_capacity+Supply_line_of_AI_capacity)), 52)	Inseminations / week	
Proportion of fertilisation events covered by AI centre	MIN((AI_capacity/"Total_number_of_fertilisation_events/week"), 1)	Proportion	
Fertilisation events covered by AI	Proportion_of_fertilisation_covered_by_AI_centre*"Total_number_of_fertilisation_events/week"	Inseminations /week	
Transport fees	Fertilisation_events_covered_by_AI*3000	Kyats	RG
Labour charges	AI_capacity/20*(15000*7)	Kyats/week	RG
AI veterinary services	(AI_capacity/20)*(6000/52)	Kyats/week	RG
Boar Feed	((AI_capacity/20)*720000)/52	Kyats/week	RG
Boar replacement costs	((500000/20)*AI_capacity)/156	Kyats/week	RG
AI maintenance	(67500/52)	Kyats/week	

Structure	***Data***	***Units***	***Source***
Total costs for AI	Boar_feed+Labour_charges+AI_veterinary_services+AI_maintenance+Transport_fees+Boar_replacement_costs	Kyats	
Break even fee for Hybrid AI services	IF Fertilisation_events_covered_by_AI = 0 THEN 0 ELSE Total_cost_for_AI/Fertilisation_events_covered_by_AI	Kyats/ insemination	
Project subsidy for AI	Break_even_fee_for_Hyrbid_AI_services-AI_costs	Kyats	

Note: [a] Blank source denotes data or equations which were developed by the Researcher.

Source: Pork VC model

Appendix D

Results from sensitivity analysis

Table D1: Comparison of aggregate profits of all pig producers between standard model baseline (disease) and no disease alternative scenario

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	Disease US$	Rank[a]	No disease US$	Rank	Disease US$	Rank	No disease US$	Rank	Disease US$	Rank	No disease US$	Rank
Baseline	842,965		916,551		1,866,956		2,085,929		3,043,266		3,481,062	
Scenario 1: Individual Producers												
S1.A1: Microcredit $150K	1,087,576	1	1,170,958	1	2,380,011	1	2,659,683	1	3,940,949	1	4,476,263	1
S1.A1.2: Microcredit $300K	1,261,361	(1)[b]	1,407,832	(1)	2,877,423	(1)	3,220,144	(1)	4,897,681	(1)	5,578,474	(1)
S1.A2: Training	945,149	3	1,015,575	2[c]	2,089,817	3	2,318,872	2[c]	3,452,985	2	3,869,751	2
S1.A3: AHWs	975,574	2	985,362	4[d]	2,139,809	2	2,228,807	4[d]	3,420,022	3	3,685,918	4[d]
S1.A4: AI	919,824	4	988,827	3[c]	2,027,026	4	2,253,035	3[c]	3,353,877	4	3,751,547	3[c]
S1.A5: Combination	*1,382,303*	*1*	*1,404,149*	*1*	*3,214,879*	*2*	*3,290,741*	*3*	*5,441,792*	*3*	*5,754,571*	*3*
Scenario 2: Producer Groups												
S2.A1: Microcredit $150K	830,903	1	952,552	1	2,171,795	2	2,597,852	1[c]	4,021,996	3	4,747,320	1[c]
S2.A1.2: Microcredit $300K	917,148	(1)	1,057,514	(1)	2,475,852	(1)	2,976,777	(1)	4,692,074	(1)	5,727,066	(1)
S2.A2: Training	800,067	3	917,502	2[c]	2,141,964	3	2,534,206	2[c]	4,062,055	2	4,741,968	2
S2.A3: AHWs	819,634	2	899,542	3[d]	2,210,552	1	2,452,196	3[d]	4,103,582	1	4,536,085	3[d]
S2.A4: AI	769,025	4	885,542	4	2,044,762	4	2,408,630	4	3,812,834	4	4,432,642	4
S2.A5: Combination	*1,022,314*	*3*	*1,097.108*	*3*	*3,199,340*	*3*	*3,495,536*	*2[c]*	*7,063,532*	*2*	*7,730,747*	*2*
Scenario 3: Producer Organisations												
S3.A1: Microcredit $150K	835,051	1	956,715	1	2,754,206	2	3,278,059	1[c]	6,835,205	4	8,539,119	3[c]
S3.A1.2: Microcredit $300K	921,469	(1)	1,061,302	(1)	3,145,440	(1)	3,786,330	(1)	7,730,822	(2)	9,592,528	(2)
S3.A2: Training	804,249	3	921,685	2[c]	2,754,454	3	3,266,382	3	7,153,488	2	8,745,170	2
S3.A3: AHWs	823,966	2	903,711	3[d]	2,955,368	1	3,269,390	2[d]	8,166,828	1	9,079,268	1
S3.A4: AI	773,044	4	889,609	4	2,658,302	4	3,155,488	4	6,890,234	3	8,615,219	4[d]
S3.A5: Combination	*1,026,296*	*2*	*1,100,818*	*2*	*4,033,651*	*1*	*4,418,050*	*1*	*11,205,559*	*1*	*12,049,246*	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D2: Comparison of number of pig producers in highly profitable systems between standard model baseline (disease) and no disease alternative scenario

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	Disease Number	Rank[a]	No disease Number	Rank	Disease Number	Rank	No disease Number	Rank	Disease Number	Rank	No disease Number	Rank
Baseline	379		353		441		401		464		489	
Scenario 1: Individual Producers												
S1.A1: Microcredit $150K	420	1	391	1	539	1	506	1	550	1	668	1
S1.A1.2: Microcredit $300K	477	(1)[b]	447	(1)	635	(1)	634	(1)	636	(1)	811	(1)
S1.A2: Training	399	2	370	2	495	2	448	2	522	2	565	2
S1.A3: AHWs	389	3	366	3	457	3	427	3	507	3	522	3
S1.A4: AI	380	4	353	4	449	4	401	4	483	4	489	4
S1.A5: Combination	*480*	*1*	*449*	*1*	*639*	*2*	*622*	*2*	*710*	*3*	*799*	*2*[c]
Scenario 2: Producer Groups												
S2.A1: Microcredit $150K	343	2	321	1[c]	394	2	385	2	453	2	504	3[d]
S2.A1.2: Microcredit $300K	363	(1)	337	(1)	435	(1)	437	(1)	512	(1)	602	(1)
S2.A2: Training	344	1	321	1	398	1	391	1	474	1	532	1
S2.A3: AHWs	343	2	320	3[d]	378	4	371	4	449	4	507	2[c]
S2.A4: AI	343	2	321	4	389	3	376	3	451	3	502	4
S2.A5: Combination	*397*	*2*	*370*	*3*[d]	*549*	*3*	*554*	*3*	*712*	*2*	*768*	*3*[d]
Scenario 3: Producer Organisations												
S3.A1: Microcredit $150K	343	1	321	1	534	4	541	3[d]	699	4	915	1[c]
S3.A1.2: Microcredit $300K	363	(1)	337	(1)	575	(1)	602	(1)	853	(2)	911	(2)
S3.A2: Training	343	1	321	1	550	2	567	1[c]	751	2	914	2
S3.A3: AHWs	343	1	320	4[d]	556	1	567	1	882	1	915	1
S3.A4: AI	343	1	321	1	540	3	561	4	722	3	911	3
S3.A5: Combination	*399*	*1*	*394*	*2*[c]	*684*	*1*	*691*	*1*	*877*	*1*	*899*	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D3: Comparison of aggregate profits of all pig producers between standard model baseline (disease) and disease and import ban alternative scenario

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	Disease US$	Rank[a]	Disease and import ban US$	Rank	Disease US$	Rank	Disease and import ban US$	Rank	Disease US$	Rank	Disease and import ban US$	Rank
Baseline	842,965		911,040		1,866,956		2,089,426		3,043,266		3,624,170	
Scenario 1: Individual Producers												
S1.A1: Microcredit $150K	1,087,576	1	1,162,223	1	2,380,011	1	2,633,909	1	3,940,949	1	4,663,438	1
S1.A1.2: Microcredit $300K	1,261,361	(1)[b]	1,339,907	(1)	2,877,423	(1)	3,182,722	(1)	4,897,681	(1)	5,824,593	(1)
S1.A2: Training	945,149	3	1,021,180	3	2,089,817	3	2,346,787	3	3,452,985	2	4,165,739	3[d]
S1.A3: AHWs	975,574	2	1,092,817	2	2,139,809	2	2,507,445	2	3,420,022	3	4,373,948	2[c]
S1.A4: AI	919,824	4	989,420	4	2,027,026	4	2,256,803	4	3,353,877	4	4,005,632	4
S1.A5: Combination	*1,382,303*	*1*	*1,497,763*	*1*	*3,214,879*	*2*	*3,821,433*	*3[d]*	*5,441,792*	*3*	*7,123,553*	*3*
Scenario 2: Producer Groups												
S2.A1: Microcredit $150K	830,903	1	907,571	2[d]	2,171,795	2	2,528,161	2	4,021,996	3	5,052,697	3
S2.A1.2: Microcredit $300K	917,148	(1)	999,325	(1)	2,475,852	(1)	2,892,563	(1)	4,692,074	(1)	5,950,515	(1)
S2.A2: Training	800,067	3	878,554	3	2,141,964	3	2,527,423	3	4,062,055	2	5,260,434	2
S2.A3: AHWs	819,634	2	926,013	1[c]	2,210,552	1	2,720,259	1	4,103,582	1	5,919,426	1
S2.A4: AI	769,025	4	848,061	4	2,044,762	4	2,366,537	4	3,812,834	4	4,837,803	4
S2.A5: Combination	*1,022,314*	*3*	*1,146,668*	*3*	*3,199,340*	*3*	*3,943,578*	*2[c]*	*7,063,532*	*2*	*9,734,560*	*2*
Scenario 3: Producer Organisations												
S3.A1: Microcredit $150K	835,051	1	914,652	2	2,754,206	2	3,045,208	3	6,835,205	4	7,762,925	3[c]
S3.A1.2: Microcredit $300K	921,469	(1)	1,006,740	(1)	3,145,440	(1)	3,476,542	(1)	7,730,822	(2)	8,680,824	(2)
S3.A2: Training	804,249	3	885,840	3	2,754,454	3	3,075,180	2[c]	7,153,488	2	8,099,521	2
S3.A3: AHWs	823,966	2	932,227	1[c]	2,955,368	1	3,365,975	1	8,166,828	1	9,398,295	1
S3.A4: AI	773,044	4	852,667	4	2,658,302	4	2,932,816	4	6,890,234	3	7,711,214	4[d]
S3.A5: Combination	*1,026,296*	*2*	*1,152,521*	*2*	*4,033,651*	*1*	*4,512,945*	*1*	*11,205,559*	*1*	*12,699,075*	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D4: Comparison of number of pig producers in highly profitable systems between standard model baseline (disease) and disease and import ban alternative scenario

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	Disease Number	Rank[a]	Disease and import ban Number	Rank	Disease Number	Rank	Disease and import ban Number	Rank	Disease Number	Rank	Disease and import ban Number	Rank
Baseline	379		375		441		443		464		521	
Scenario 1: Individual Producers												
S1.A1: Microcredit $150K	420	1	415	1	539	1	547	1	550	1	643	1
S1.A1.2: Microcredit $300K	477	(1)[b]	473	(1)	635	(1)	653	(1)	636	(1)	757	(1)
S1.A2: Training	399	2	395	2	495	2	504	2	522	2	606	2
S1.A3: AHWs	389	3	392	3	457	3	491	3	507	3	599	3
S1.A4: AI	380	4	375	4	449	4	456	4	483	4	547	4
S1.A5: Combination	*480*	*1*	*508*	*1*	*639*	*2*	*704*	*1*[c]	*710*	*3*	*842*	*2*[c]
Scenario 2: Producer Groups												
S2.A1: Microcredit $150K	343	2	341	3[d]	394	2	412	3[d]	453	2	557	4[d]
S2.A1.2: Microcredit $300K	363	(1)	356	(1)	435	(1)	460	(1)	512	(1)	623	(2)
S2.A2: Training	344	1	343	2[d]	398	1	424	2[d]	474	1	600	2[d]
S2.A3: AHWs	343	2	344	1[c]	378	4	444	1[c]	449	4	665	1[c]
S2.A4: AI	343	2	339	4	389	3	411	4	451	3	566	3[c]
S2.A5: Combination	*397*	*3*	*394*	*2*[c]	*549*	*3*	*608*	*3*	*712*	*2*	*831*	*3*[d]
Scenario 3: Producer Organisations												
S3.A1: Microcredit $150K	343	1	339	3	534	4	549	4	699	4	777	4
S3.A1.2: Microcredit $300K	363	(1)	355	(1)	575	(1)	589	(1)	853	(2)	910	(2)
S3.A2: Training	343	1	340	2	550	2	562	2	751	2	824	2
S3.A3: AHWs	343	1	343	1[c]	556	1	586	1	882	1	847	1
S3.A4: AI	343	1	339	3	540	3	556	3	722	3	804	3
S3.A5: Combination	*399*	*2*	*394*	*2*	*684*	*1*	*702*	*2*[d]	*877*	*1*	*899*	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D5: Comparison of aggregate profits of all pig producers between standard model baseline (disease) and disease with random outbreaks alternative scenario

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	Disease US$	Rank[a]	Random disease US$	Rank	Disease US$	Rank	Random disease US$	Rank	Disease US$	Rank	Random disease US$	Rank
Baseline	842,965		852,195		1,866,956		1,782,994		3,043,266		3,132,999	
Scenario 1: Individual producers												
S1.A1: Microcredit $150K	1,087,576	1	1,109,973	1	2,380,011	1	2,288,328	1	3,940,949	1	3,983,260	1
S1.A1.2: Microcredit $300K	1,261,361	(1)[b]	1,306,491	(1)	2,877,423	(1)	2,762,843	(1)	4,897,681	(1)	4,892,440	(1)
S1.A2: Training	945,149	3	952,911	3	2,089,817	3	2,007,043	3	3,452,985	2	3,528,256	2
S1.A3: AHWs	975,574	2	974,939	2	2,139,809	2	2,083,314	2	3,420,022	3	3,517,354	3
S1.A4: AI	919,824	4	927,105	4	2,027,026	4	1,947,769	4	3,353,877	4	3,439,331	4
S1.A5: Combination	*1,382,303*	*1*	*1,391,133*	*1*	*3,214,879*	*2*	*3,129,359*	*3*[d]	*5,441,792*	*3*	*5,543,415*	*3*
Scenario 2: Producer groups												
S2.A1: Microcredit $150K	830,903	1	850,807	1	2,171,795	2	2,123,141	2	4,021,996	3	4,136,818	3
S2.A1.2: Microcredit $300K	917,148	(1)	948,617	(1)	2,475,852	(1)	2,397,766	(1)	4,692,074	(1)	4,820,992	(1)
S2.A2: Training	800,067	3	817,835	3	2,141,964	3	2,095,628	3	4,062,055	2	4,218,095	2
S2.A3: AHWs	819,634	2	833,417	2	2,210,552	1	2,182,154	1	4,103,582	1	4,226,675	1
S2.A4: AI	769,025	4	785,818	4	2,044,762	4	1,995,047	4	3,812,834	4	3,962,532	4
S2.A5: Combination	*1,022,314*	*3*	1,036,060	*3*	*3,199,340*	*3*	3,237,616	*2*[c]	*7,063,532*	*2*	7,199,273	*2*
Scenario 3: Producer organisations												
S3.A1: Microcredit $150K	835,051	1	854,967	1	2,754,206	2	2,664,583	2	6,835,205	4	7,074,474	4
S3.A1.2: Microcredit $300K	921,469	(1)	952,276	(1)	3,145,440	(1)	3,019,440	(1)	7,730,822	(2)	8,003,267	(2)
S3.A2: Training	804,249	3	821,992	3	2,754,454	3	2,658,014	3	7,153,488	2	7,412,300	2
S3.A3: AHWs	823,966	2	837,589	2	2,955,368	1	2,943,097	1	8,166,828	1	8,389,438	1
S3.A4: AI	773,044	4	789,881	4	2,658,302	4	2,579,189	4	6,890,234	3	7,252,798	3
S3.A5: Combination	*1,026,296*	*2*	*1,039,818*	*2*	*4,033,651*	*1*	*3,995,128*	*1*	*11,205,559*	*1*	*11,418,916*	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D6: Comparison of number of pig producers in highly profitable systems producers between standard model baseline (disease) and disease with random outbreaks alternative scenario

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	Disease Number	Rank	Random disease Number	Rank	Disease Number	Rank	Random disease Number	Rank	Disease Number	Rank	Random disease Number	Rank
Baseline	379		362		441		372		464		484	
Scenario 1: Individual producers												
S1.A1: Microcredit $150K	420	1	402	1	539	1	406	1	550	1	590	1
S1.A1.2: Microcredit $300K	477	(1)[b]	455	(1)	635	(1)	471	(1)	636	(1)	704	(1)
S1.A2: Training	399	2	383	2	495	2	397	3[d]	522	2	548	2
S1.A3: AHWs	389	3	378	3	457	3	422	2[c]	507	3	536	3
S1.A4: AI	380	4	362	4	449	4	370	4	483	4	493	4
S1.A5: Combination	*480*	*1*	*465*	*1*	*639*	*2*	*567*	*2*	*710*	*3*	*763*	*2[c]*
Scenario 2: Producer groups												
S2.A1: Microcredit $150K	343	2	332	1[c]	394	2	365	2	453	2	495	4[d]
S2.A1.2: Microcredit $300K	363	(1)	347	(1)	435	(1)	399	(1)	512	(1)	564	(1)
S2.A2: Training	344	1	332	1	398	1	375	1	474	1	531	1
S2.A3: AHWs	343	2	331	2	378	4	363	4	449	4	504	3[c]
S2.A4: AI	343	2	332	1[c]	389	3	364	3	451	3	508	2[c]
S2.A5: Combination	*399*	*3*	383	*3*	*549*	*3*	525	*3*	*712*	*2*	750	*3[d]*
Scenario 3: Producer organisations												
S3.A1: Microcredit $150K	343	1	332	1	534	4	448	4	699	4	778	4
S3.A1.2: Microcredit $300K	363	(1)	349	(1)	575	(1)	484	(2[d])	853	(2)	894	(2)
S3.A2: Training	343	1	332	1	550	2	472	2	751	2	807	2
S3.A3: AHWs	343	1	332	1	556	1	524	1	882	1	905	1
S3.A4: AI	343	1	332	1	540	3	458	3	722	3	797	3
S3.A5: Combination	*399*	*2*	385	*2*	*684*	*1*	654	*1*	*877*	*1*	897	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D7: Comparisons of aggregate profits of all pig Producers between standard model and increased responsiveness of producers alternative scenario

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	Standard model US$	Rank[a]	Increased responsiveness US$	Rank	Standard model US$	Rank	Increased responsiveness US$	Rank	Standard model US$	Rank	Increased responsiveness US$	Rank
Baseline	842,965		967,396		1,866,956		2,262,879		3,043,266		4,088,431	
Scenario 1: Individual Producers												
S1.A1: Microcredit $150K	1,087,576	1	1,142,024	1	2,380,011	1	2,750,643	1	3,940,949	1	4,936,357	1
S1.A1.2: Microcredit $300K	1,261,361	(1)[b]	1,314,395	(1)	2,877,423	(1)	3,237,446	(1)	4,897,681	(1)	5,719,821	(1)
S1.A2: Training	945,149	3	1,056,005	3	2,089,817	3	2,637,265	2[c]	3,452,985	2	4,870,883	2
S1.A3: AHWs	975,574	2	1,125,296	2	2,139,809	2	2,628,087	3[d]	3,420,022	3	4,642,841	3
S1.A4: AI	919,824	4	1,050,922	4	2,027,026	4	2,526,261	4	3,353,877	4	4,597,437	4
S1.A5: Combination	*1,382,303*	*1*	*1,525,388*	*1*	*3,214,879*	*2*	*3,872,171*	*3[d]*	*5,441,792*	*3*	*7,041,153*	*3*
Scenario 2: Producer Groups												
S2.A1: Microcredit $150K	830,903	1	823,936	2[d]	2,171,795	2	2,496,900	3[d]	4,021,996	3	5,146,235	4[d]
S2.A1.2: Microcredit $300K	917,148	(1)	909,153	(1)	2,475,852	(1)	2,829,716	(1)	4,692,074	(1)	5,860,560	(1)
S2.A2: Training	800,067	3	810,311	3	2,141,964	3	2,607,154	2[c]	4,062,055	2	5,730,216	2
S2.A3: AHWs	819,634	2	838,843	1[c]	2,210,552	1	2,628,380	1	4,103,582	1	5,782,979	1
S2.A4: AI	769,025	4	789,625	4	2,044,762	4	2,473,802	4	3,812,834	4	5,357,445	3[c]
S2.A5: Combination	*1,022,314*	*3*	*1,054,453*	*3*	*3,199,340*	*3*	*4,043,304*	*2[c]*	*7,063,532*	*2*	*9,734,560*	*2*
Scenario 3: Producer Organisations												
S3.A1: Microcredit $150K	835,051	1	833,963	2[d]	2,754,206	2	3,369,973	3	6,835,205	4	9,629,666	4
S3.A1.2: Microcredit $300K	921,469	(1)	917,314	(1)	3,145,440	(1)	3,792,475	(1)	7,730,822	(2)	10,434,776	(2)
S3.A2: Training	804,249	3	820,716	3	2,754,454	3	3,534,568	2[c]	7,153,488	2	10,241,990	2
S3.A3: AHWs	823,966	2	843,614	1[c]	2,955,368	1	3,717,568	1	8,166,828	1	11,739,481	1
S3.A4: AI	773,044	4	796,877	4	2,658,302	4	3,384,639	4	6,890,234	3	10,097,423	3
S3.A5: Combination	*1,026,296*	*2*	*1,060,053*	*2*	*4,033,651*	*1*	*5,385,378*	*1*	*11,205,559*	*1*	*15,715,394*	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D8: Comparisons of number of pig producers in highly profitable systems between standard model and increased responsiveness of producers alternative scenario

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	Standard Model Number	Rank[a]	Increased responsiveness Number	Rank	Standard Model Number	Rank	Increased responsiveness Number	Rank	Standard Model Number	Rank	Increased responsiveness Number	Rank
Baseline	379		469		441		642		464		544	
Scenario 1: Individual Producers												
S1.A1: Microcredit $150K	420	1	534	1	539	1	724	2[d]	550	1	598	3[d]
S1.A1.2: Microcredit $300K	477	(1)[b]	607	(1)	635	(1)	787	(1)	636	(1)	648	(1)
S1.A2: Training	399	2	522	2	495	2	731	1[c]	522	2	615	2
S1.A3: AHWs	389	3	490	3	457	3	690	3	507	3	710	1[c]
S1.A4: AI	380	4	482	4	449	4	665	4	483	4	562	4
S1.A5: Combination	480	1	640	1	639	2	887	2	710	3	847	2[c]
Scenario 2: Producer Groups												
S2.A1: Microcredit $150K	343	2	420	3[d]	394	2	531	4[d]	453	2	554	4[d]
S2.A1.2: Microcredit $300K	363	(1)	447	(1)	435	(1)	580	(1)	512	(1)	594	(2)
S2.A2: Training	344	1	431	1	398	1	570	1	474	1	625	2[d]
S2.A3: AHWs	343	2	416	4[d]	378	4	533	3[c]	449	4	638	1[c]
S2.A4: AI	343	2	428	2	389	3	557	2[c]	451	3	580	3[c]
S2.A5: Combination	397	2	502	3[d]	549	3	746	3	712	2	816	3[d]
Scenario 3: Producer Organisations												
S3.A1: Microcredit $150K	343	1	417	4[d]	534	4	736	4	699	4	843	4
S3.A1.2: Microcredit $300K	363	(1)	445	(1)	575	(1)	771	(1)	853	(2)	846	(2)
S3.A2: Training	343	1	426	1	550	2	764	2	751	2	859	2
S3.A3: AHWs	343	1	418	3[d]	556	1	770	1	882	1	876	1
S3.A4: AI	343	1	425	2[d]	540	3	767	3	722	3	858	3
S3.A5: Combination	399	2	504	2[c]	684	1	929	1	877	1	853	1

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D9: Comparisons of aggregate profits of all pig Producers between standard model and decreased responsiveness of producers alternative scenario

Scenario	Short-term				Medium-term				Long-term			
	Standard model	Rank[a]	Deceased responsiveness	Rank	Standard model	Rank	Decreased responsiveness	Rank	Standard model	Rank	Decreased responsiveness	Rank
	US$		US$		US$		US$		US$		US$	
Baseline	842,965		668,146		1,866,956		1,452,233		3,043,266		2,307,633	
Scenario 1: Individual Producers												
S1.A1: Microcredit $150K	1,087,576	1	934,699	1	2,380,011	1	2,005,429	1	3,940,949	1	3,168,845	1
S1.A1.2: Microcredit $300K	1,261,361	(1)[b]	1,072,282	(1)	2,877,423	(1)	2,338,983	(1)	4,897,681	(1)	3,770,551	(1)
S1.A2: Training	945,149	3	749,994	3	2,089,817	3	1,625,183	3	3,452,985	2	2,550,035	2
S1.A3: AHWs	975,574	2	776,666	2	2,139,809	2	1,665,183	2	3,420,022	3	2,582,775	3
S1.A4: AI	919,824	4	719,588	4	2,027,026	4	1,566,683	4	3,353,877	4	2,502,142	4
S1.A5: Combination	*1,382,303*	*1*	*1,196,188*	*1*	*3,214,879*	*2*	*2,552,802*	*2*	*5,441,792*	*3*	*3,975,661*	*3*
Scenario 2: Producer Groups												
S2.A1: Microcredit $150K	830,903	1	668,883	1	2,171,795	2	1,749,927	1[c]	4,021,996	3	3,068,905	1[c]
S2.A1.2: Microcredit $300K	917,148	(1)	769,833	(1)	2,475,852	(1)	2,047,331	(1)	4,692,074	(1)	3,593,936	(1)
S2.A2: Training	800,067	3	617,434	3	2,141,964	3	1,671,833	3	4,062,055	2	2,870,973	3[d]
S2.A3: AHWs	819,634	2	635,695	2	2,210,552	1	1,714,423	2[d]	4,103,582	1	2,946,162	2[d]
S2.A4: AI	769,025	4	584,941	4	2,044,762	4	1,563,507	4	3,812,834	4	2,691,128	4
S2.A5: Combination	*1,022,314*	*3*	*855,035*	*3*	*3,199,340*	*3*	*2,354,848*	*3*	*7,063,532*	*2*	*4,436,988*	*2*
Scenario 3: Producer Organisations												
S3.A1: Microcredit $150K	835,051	1	675,541	1	2,754,206	2	2,091,096	1[c]	6,835,205	4	4,154,195	2[c]
S3.A1.2: Microcredit $300K	921,469	(1)	773,620	(1)	3,145,440	(1)	2,401,006	(1)	7,730,822	(2)	5,027,338	(1[c])
S3.A2: Training	804,249	3	625,163	3	2,754,454	3	1,984,498	3	7,153,488	2	4,113,148	3[d]
S3.A3: AHWs	823,966	2	638,972	2	2,955,368	1	2,092,213	2[d]	8,166,828	1	4,675,666	1
S3.A4: AI	773,044	4	592,134	4	2,658,302	4	1,869,192	4	6,890,234	3	3,770,819	4[d]
S3.A5: Combination	*1,026,296*	*2*	*858,246*	*2*	*4,033,651*	*1*	*2,783,239*	*1*	*11,205,559*	*1*	*6,862,214*	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D10: Comparisons of number of pig producers in highly profitable systems between standard model and decreased responsiveness of producers alternative scenario

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	Standard model Number	Rank[a]	Decreased responsiveness Number	Rank	Standard model Number	Rank	Decreased responsiveness Number	Rank	Standard model Number	Rank	Decreased responsiveness Number	Rank
Baseline	379		352		441		352		464		352	
Scenario 1: Individual Producers												
S1.A1: Microcredit $150K	420	1	353	1	539	1	375	1	550	1	401	1
S1.A1.2: Microcredit $300K	477	(1)[b]	374	(1)	635	(1)	437	(1)	636	(1)	473	(1)
S1.A2: Training	399	2	352	2	495	2	353	2	522	2	361	2
S1.A3: AHWs	389	3	352	2[c]	457	3	352	3	507	3	353	4[d]
S1.A4: AI	380	4	352	2[c]	449	4	352	3[c]	483	4	354	3[c]
S1.A5: Combination	*480*	*1*	*273*	*3[d]*	*639*	*2*	*415*	*2*	*710*	*2*	*454*	*2*
Scenario 2: Producer Groups												
S2.A1: Microcredit $150K	343	2	278	1	394	2	279	1[c]	453	2	295	1[c]
S2.A1.2: Microcredit $300K	363	(1)	277	(1)	435	(1)	300	(1)	512	(1)	337	(1)
S2.A2: Training	344	1	173	3[d]	398	1	278	2[d]	474	1	290	2[d]
S2.A3: AHWs	343	2	278	1[c]	378	4	278	2[c]	449	4	282	3[c]
S2.A4: AI	343	2	173	3[d]	389	3	278	2[c]	451	3	283	4[d]
S2.A5: Combination	*397*	*2*	*279*	*2*	*549*	*3*	*329*	*3*	*704*	*3*	*407*	*3*
Scenario 3: Producer Organisations												
S3.A1: Microcredit $150K	343	1	278	1	534	4	317	2[c]	699	4	402	3[c]
S3.A1.2: Microcredit $300K	363	(1)	278	(1)	575	(1)	360	(1)	853	(2)	483	(1[c])
S3.A2: Training	343	1	173	3	550	2	316	3[d]	751	2	425	2
S3.A3: AHWs	343	1	278	1	556	1	329	1	882	1	476	1
S3.A4: AI	343	1	173	3	540	3	309	4[d]	722	3	397	4[d]
S3.A5: Combination	*399*	*2*	*280*	*1[c]*	*684*	*1*	*425*	*1*	*877*	*1*	*631*	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D11: Comparison of aggregate profits of all pig producers in ASF outbreak and ASF outbreak with two-year delay alternative scenarios

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	ASF outbreak US$	Rank[a]	Delayed ASF outbreak US$	Rank	ASF outbreak US$	Rank	Delayed ASF outbreak US$	Rank	ASF outbreak US$	Rank	Delayed ASF outbreak US$	Rank
Baseline	401,177		842,965		1,325,393		1,203,111		1,862,715		1,575,269	
Scenario 1: Individual producers												
S1.A1: Microcredit $150K	573,486	3	1,122,532	1[c]	1,150,238	3	1,513,807	2[c]	1,458,516	3	1,883,131	2[c]
S1.A1.2: Microcredit $300K	672,217	(4)[b]	845,630	(4)	999,860	(4)	1,203,111	(4)	1,251,237	(4)	1,578,896	(4)
S1.A2: Biosecurity	976,952	1	1,098,584	2[d]	2,163,755	1	1,927,932	1	3,143,634	1	2,852,429	1
S1.A4: AI	463,054	2	922,472	3	1,356,512	2	1,313,007	3[d]	1,936,144	2	1,724,060	3[d]
S1.A5: Combination	*1,198,247*	*1*	*1,416,822*	*1*	*2,503,514*	*3*	*1,984,487*	*3*	*3,770,806*	*3*	*2,781,030*	
Scenario 2: Producer groups												
S2.A1: Microcredit $150K	295,378	2	822,611	2	1,535,276	2	1,412,896	2	2,224,667	2	1,917,063	2
S2.A1.2: Microcredit $300K	360,194	(2)	910,240	(1)	1,752,904	(2)	1,172,844	(2)	2,759,177	(2)	1,492,302	(4[d])
S2.A2: Training	565,780	1	889,178	1	2,241,898	1	2,001,555	1	4,664,053	1	3,312,393	1
S2.A4: Biosecurity	248,049	3	760,922	3	1,363,685	3	1,250,932	3	2,145,941	3	1,704,329	3
S2.A5: Combination	*738,431*	*3*	*1,013,462*	*2[c]*	*2,044,762*	*2*	*2,603,639*	*2*	*6,299,043*	*2*	*4,525,530*	*2*
Scenario 3: Producer organisations												
S3.A1: Microcredit $150K	309,509	2	791,326	2	2,000,210	2	1,270,684	3[d]	3,199,039	2	1,967,736	3[d]
S3.A1.2: Microcredit $300K	375,956	(2)	891,257	(1)	2,267,309	(2)	1,258,965	(3)	3,484,176	(2)	1,551,461	(4)
S3.A2: Biosecurity	568,575	1	866,111	1	3,009,714	1	2,504,485	1	8,558,098	1	6,756,886	1
S3.A4: AI	250,426	3	729,767	3	1,743,761	3	1,357,976	2[c]	2,813,527	3	2,149,627	2[c]
S3.A5: Combination	*745,336*	*2*	*993,834*	*3[d]*	*3,716,863*	*1*	*3,070,999*	*1*	*10,174,486*	*1*	*8,329,249*	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Table D12: Comparison of number of pig producers in highly profitable systems in ASF outbreak and ASF outbreak with two-year delay alternative scenarios

Scenario	*Short-term*				*Medium-term*				*Long-term*			
	ASF outbreak	Rank[a]	Delayed ASF outbreak	Rank	ASF outbreak	Rank	Delayed ASF outbreak	Rank	ASF outbreak	Rank	Delayed ASF outbreak	Rank
	Number		Number		Number		Number		Number		Number	
Baseline	138		379		441		105		464		112	
Scenario 1: Individual producers												
S1.A1: Microcredit $150K	74	3	352	1[c]	79	3	123	2[c]	51	3	38	3
S1.A1.2: Microcredit $300K	11	(4)[b]	352	1[c]	67	(4)	105	(4)	44	(4)	113	(2[c])
S1.A2: Biosecurity	244	1	352	1	338	1	295	1	251	1	222	1
S1.A4: AI	143	2	352	1[c]	146	2	111	3[d]	109	2	112	2
S1.A5: Combination	*227*	*3*	*365*	*3*	*374*	*2*	*272*	*3[d]*	*276*	*3*	*181*	*3*
Scenario 2: Producer groups												
S2.A1: Microcredit $150K	70	2	343	2	277	2	187	2	140	3	5	2[c]
S2.A1.2: Microcredit $300K	69	(4)	361	(1)	255	(4)	57	(4)	196	(2)	7	(2)
S2.A2: Training	210	1	352	1	283	1	268	1	400	1	201	1
S2.A4: Biosecurity	71	3	343	2[c]	263	3	170	3	166	2	2	3[d]
S2.A5: Combination	*249*	*2*	*394*	*1[c]*	*370*	*3*	*366*	*2[c]*	*495*	*2*	*206*	*2*
Scenario 3: Producer organisations												
S3.A1: Microcredit $150K	70	3	343	1[c]	391	2	57	3[d]	261	2	14	2
S3.A1.2: Microcredit $300K	69	(4)	348	(4)	384	(3)	57	(3)	252	(3)	9	(3)
S3.A2: Biosecurity	211	1	343	1	442	1	380	1	593	1	461	1
S3.A4: AI	71	2	343	1[c]	372	3	193	2[c]	243	3	13	3
S3.A5: Combination	*250*	*1*	*378*	*2[d]*	*504*	*1*	*446*	*1*	*671*	*1*	*520*	*1*

Note: [a] Rank for S1.A5, S2.A5, and S3.A5: Combination refers to the ranking of the three (S1, S2, and S3) institutional scenarios. [b] Value in parentheses denotes that ranking of the sub activity A1.2. [c] indicates rankings that have improved in the alternative scenario compared with the standard model run. [d] indicates rankings that have worsened in the alternative scenario compared with the standard model run.

Source: Pork VC model simulation

Appendix E

Histograms and box plots for results of multi-variate sensitivity analysis

E.1 Histograms for aggregate profits of all pig producers

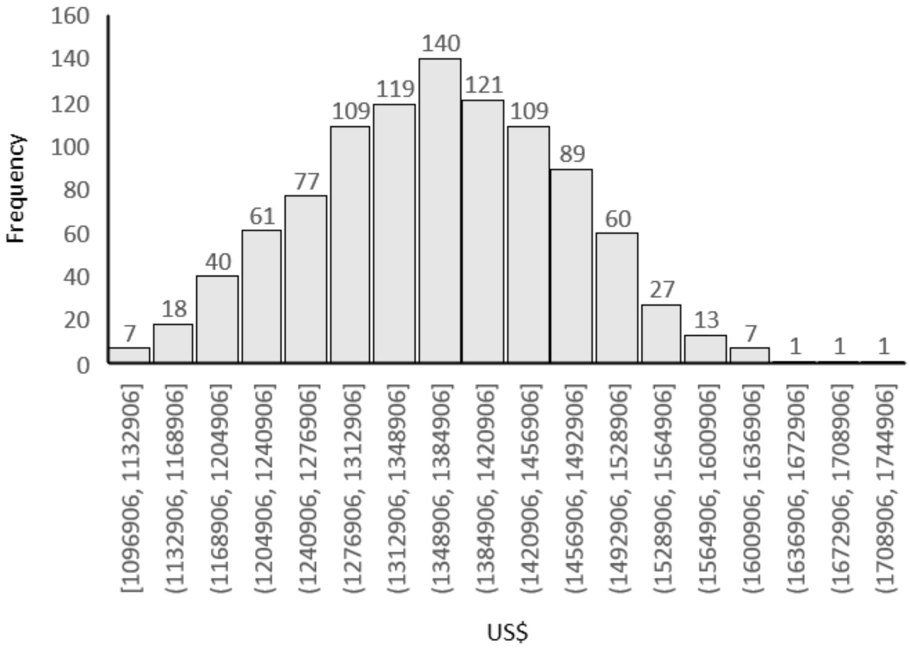

Figure E1: Frequency distribution for S1(individual).A5: short-term aggregate profits of all pig producers
Source: Pork VC model simulation

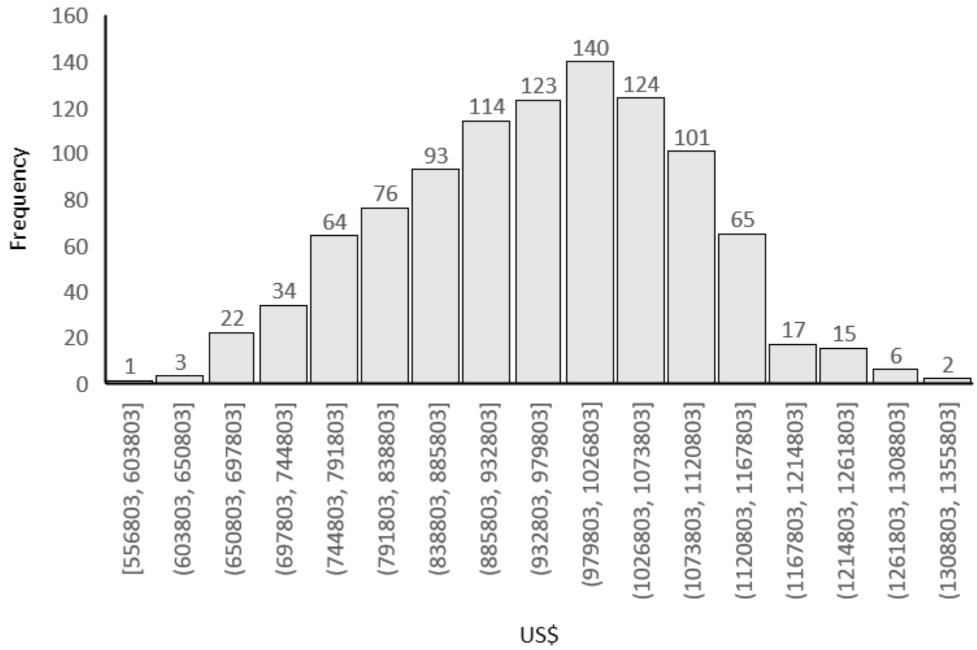

Figure E2: Frequency distribution for S2(PGs).A5: short-term aggregate profits of all pig producers
Source: Pork VC model simulation

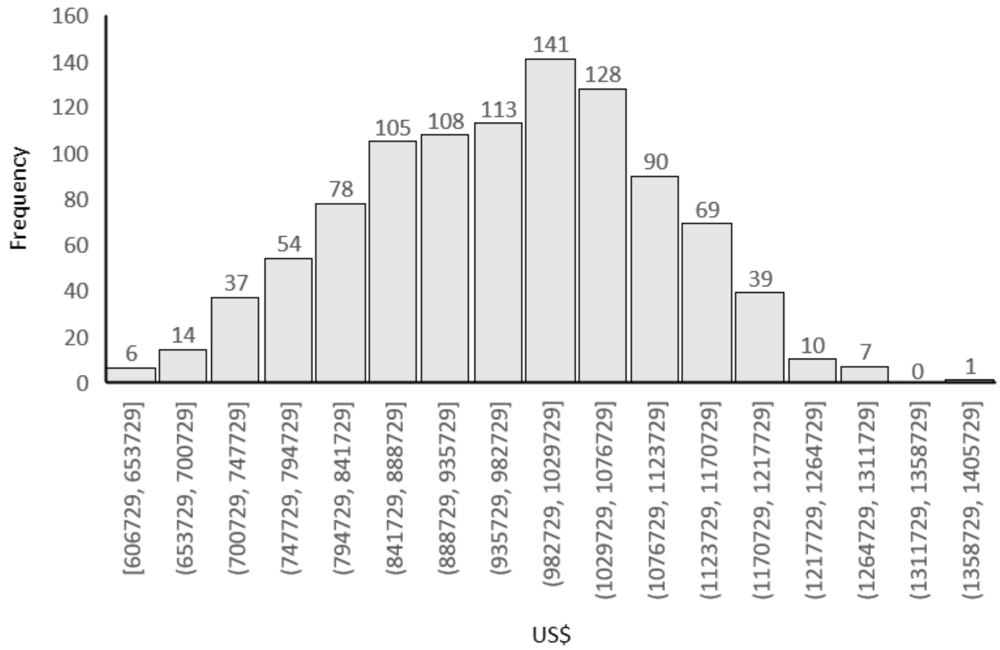

Figure E3: Frequency distribution for S3(POs).A5: short-term aggregate profits of all pig producers
Source: Pork VC model simulation

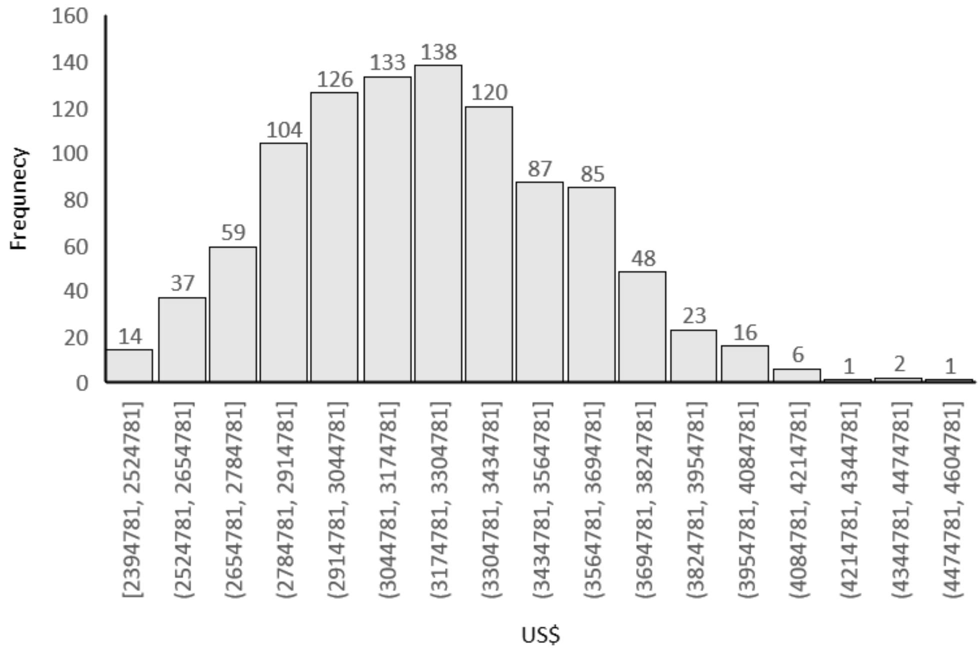

Figure E4: Frequency distribution for S1(individual).A5: medium-term aggregate profits of all pig producers
Source: Pork VC model simulation

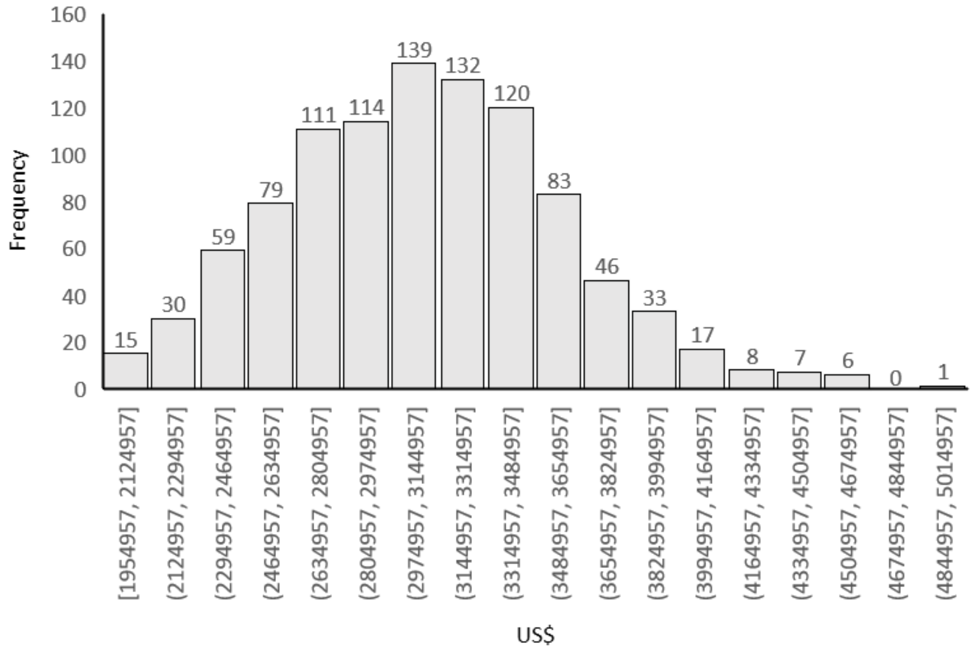

Figure E5: Frequency distribution for S2(PGs).A5: medium-term aggregate profits of all pig producers
Source: Pork VC model simulation

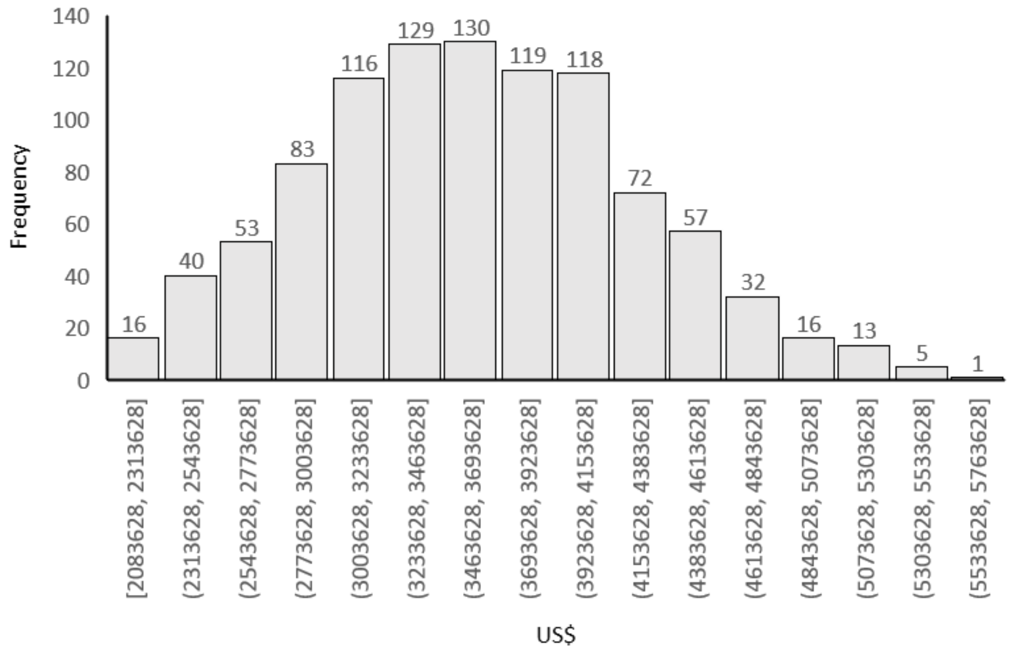

Figure E6: Frequency distribution for S3(POs).A5: medium-term aggregate profits of all pig producers
Source: Pork VC model simulation

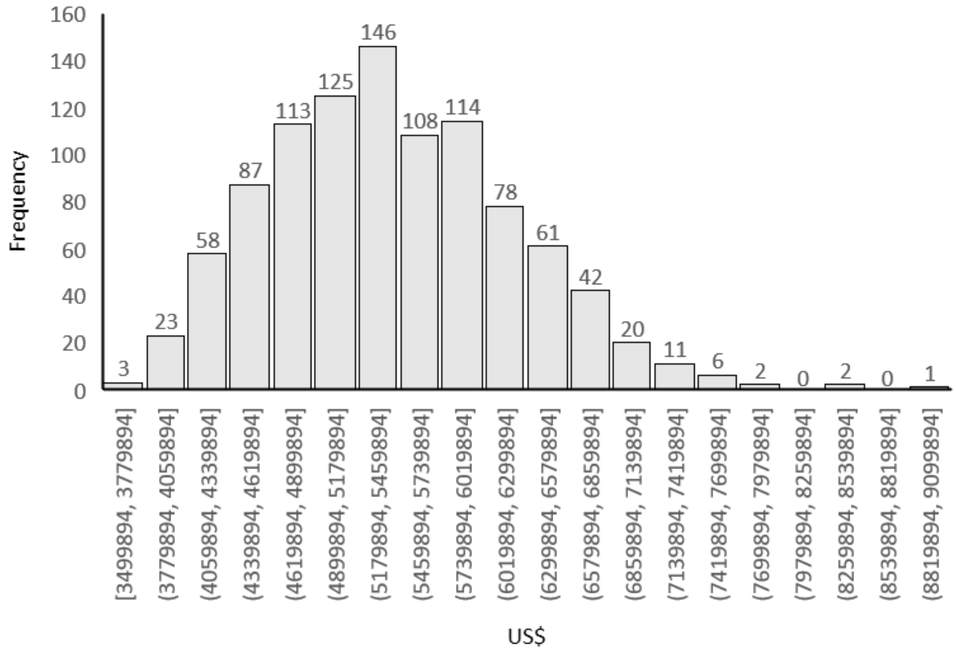

Figure E7: Frequency distribution for S1(individual).A5: long-term aggregate profits of all pig producers
Source: Pork VC model simulation

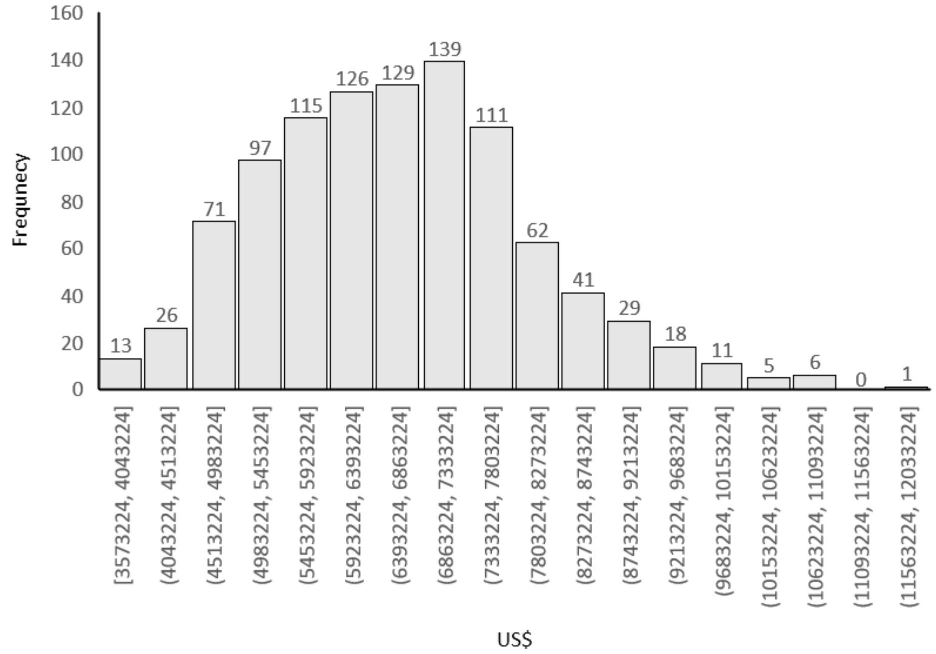

Figure E8: Frequency distribution for S2(PGs).A5: long-term aggregate profits of all pig producers
Source: Pork VC model simulation

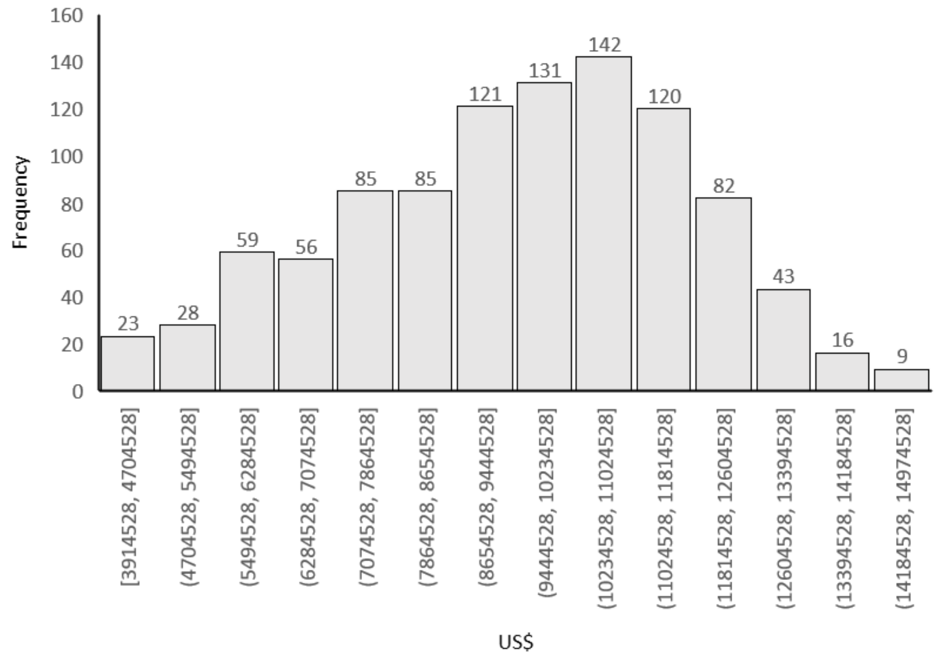

Figure E9: Frequency distribution for S3(POs).A5: long-term aggregate profits of all pig producers
Source: Pork VC model simulation

E.2 Histograms for number of pig producers in highly profitable systems

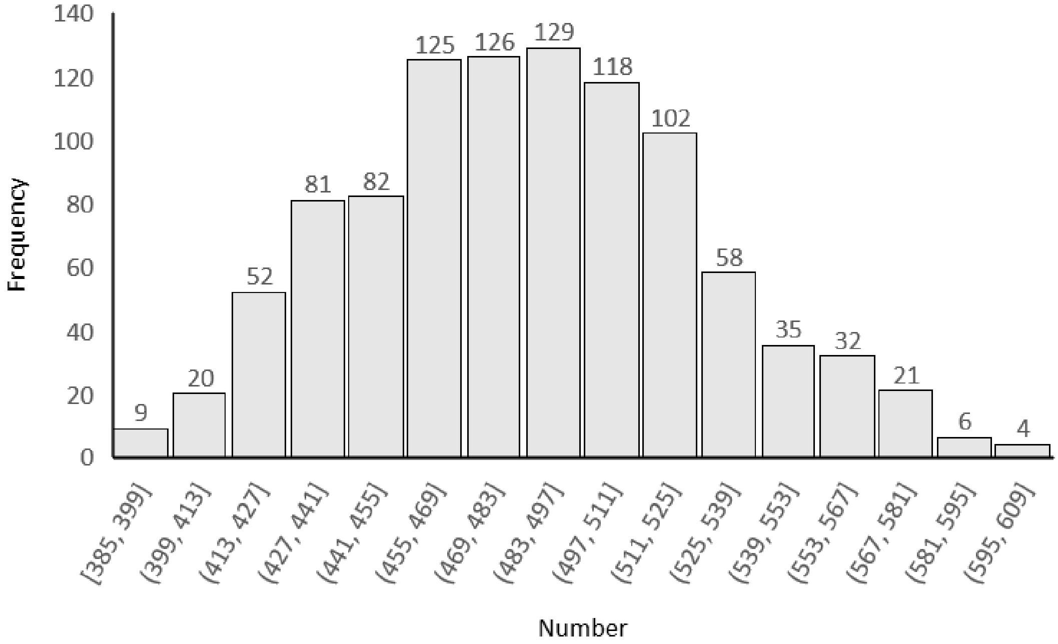

Figure E10: Frequency distribution for S1(individual).A5: short-term number of pig producers in highly profitable systems
Source: Pork VC model simulation

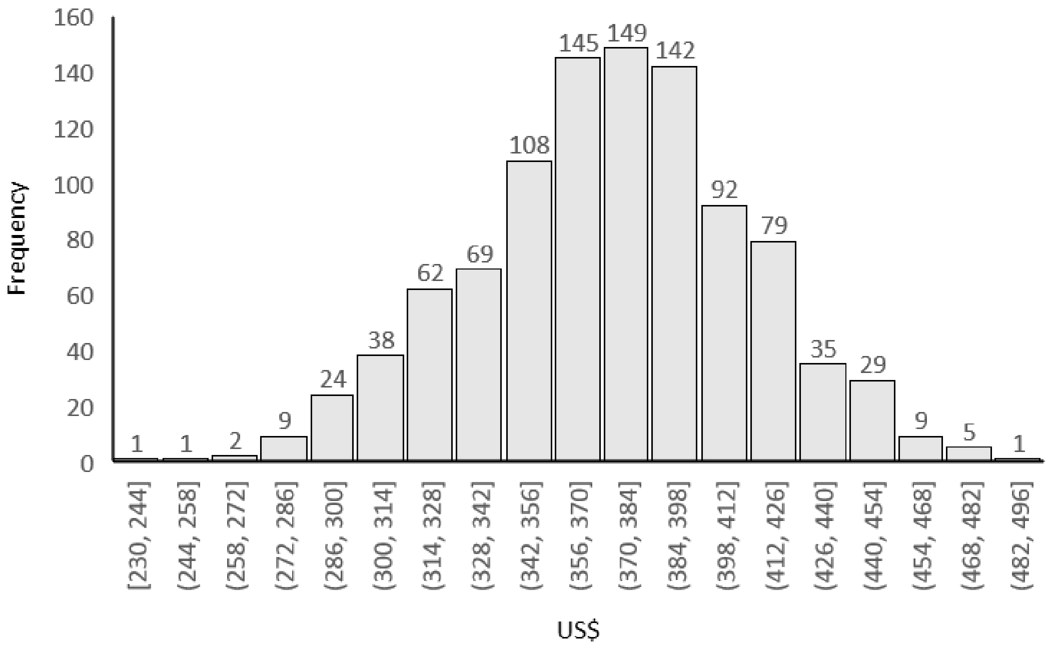

Figure E11: Frequency distribution for S2(PGs).A5: short-term number of pig producers in highly profitable systems
Source: Pork VC model simulation

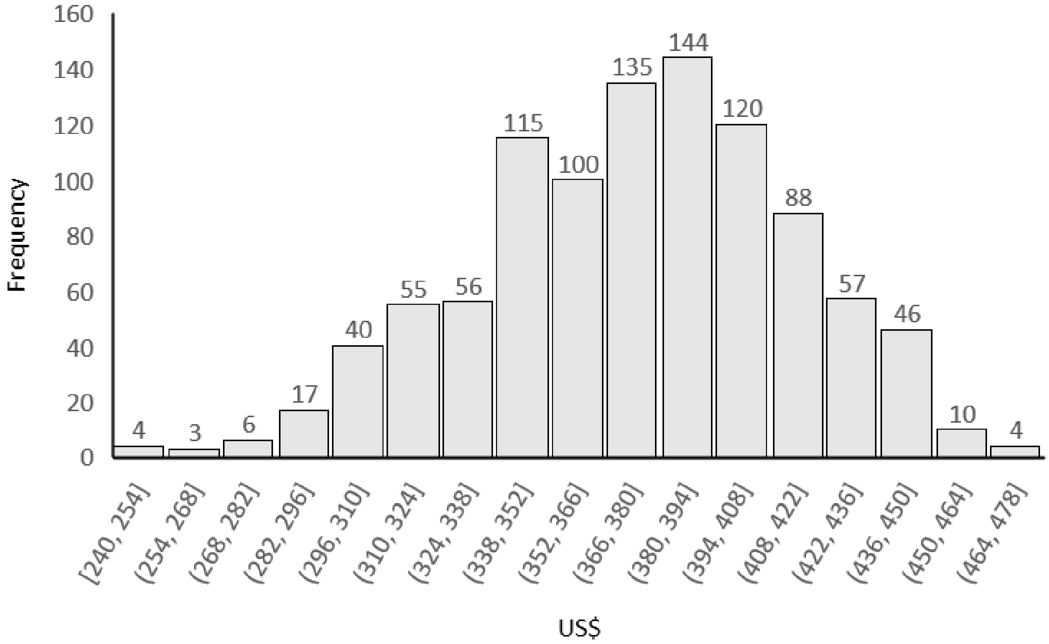

Figure E12: Frequency distribution for S3(P0s).A5: short-term number of pig producers in highly profitable systems

Source: Pork VC model simulation

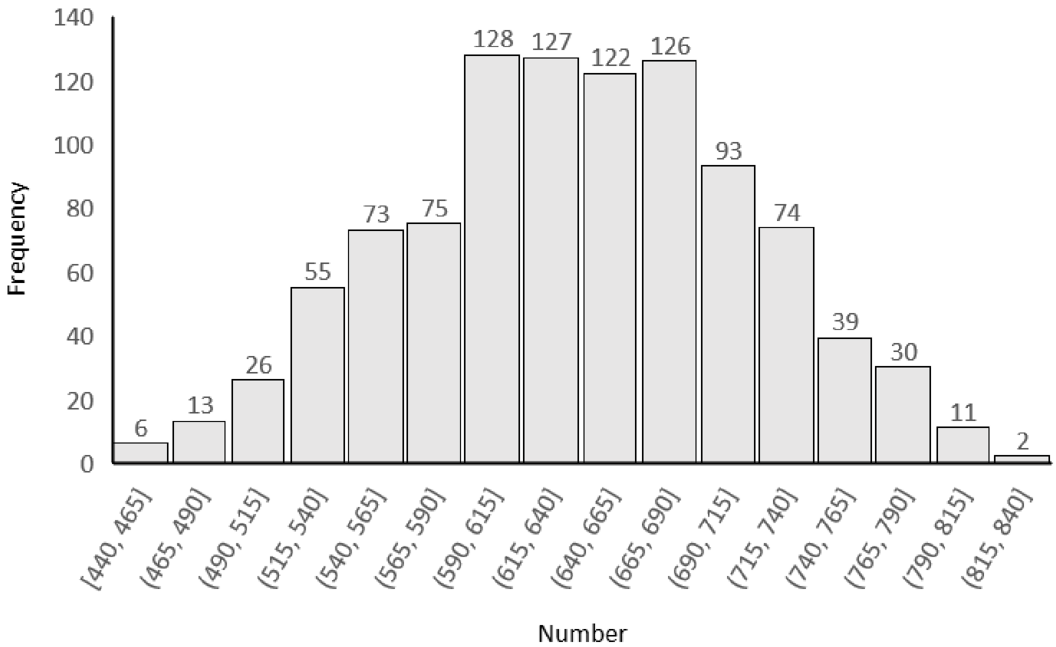

Figure E13: Frequency distribution for S1(individual).A5: medium-term number of pig producers in highly profitable systems

Source: Pork VC model simulation

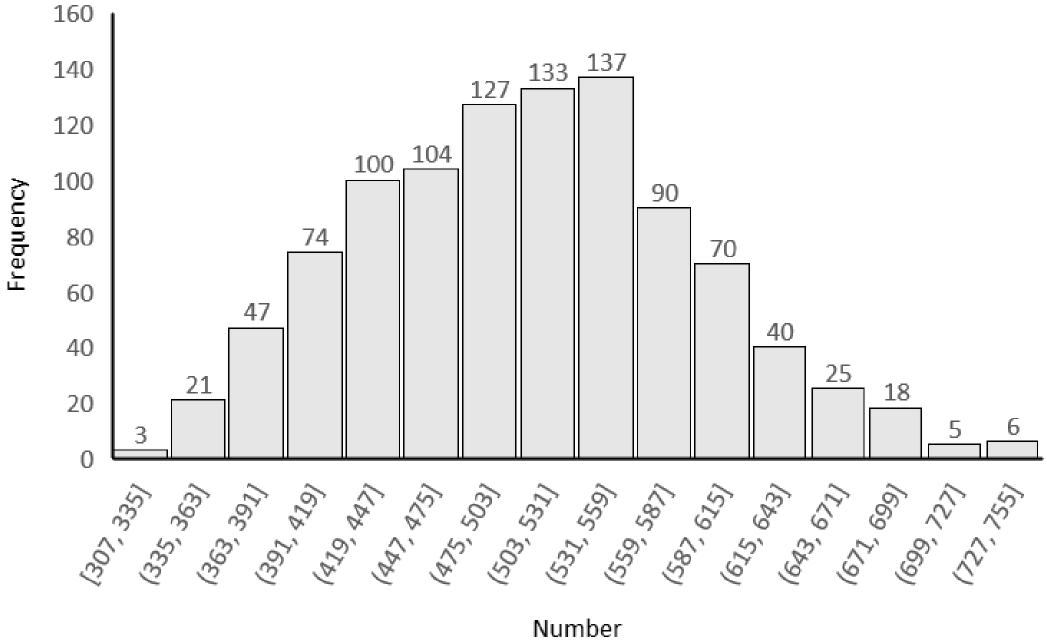

Figure E14: Frequency distribution for S2(PGs).A5: medium-term number of pig producers in highly profitable systems
Source: Pork VC model simulation

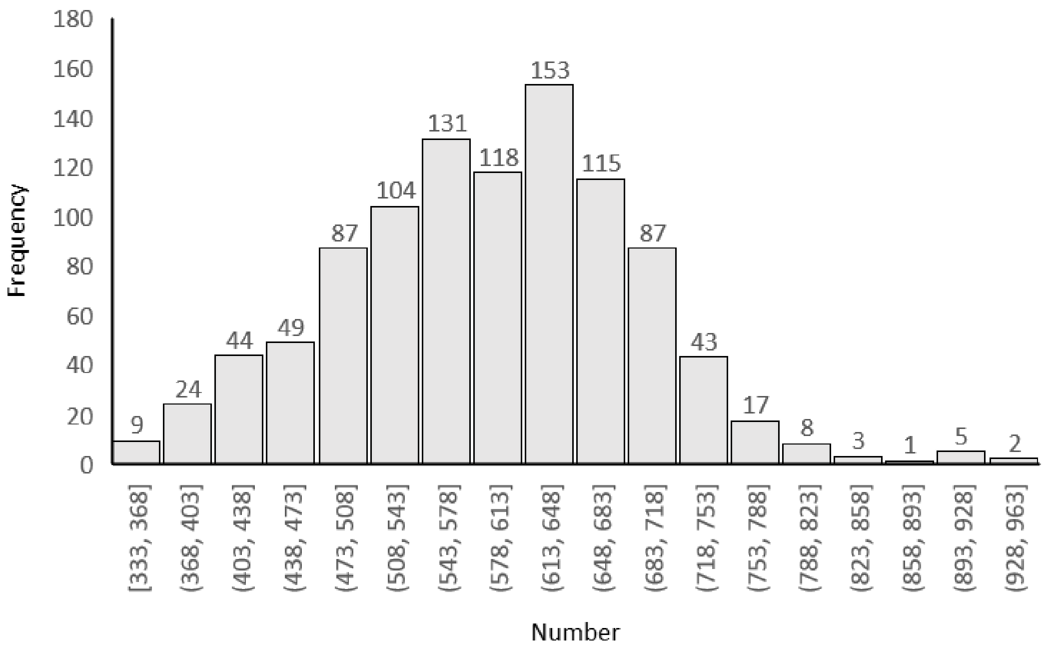

Figure E15: Frequency distribution for S3(POs).A5: medium-term number of pig producers in highly profitable systems
Source: Pork VC model simulation

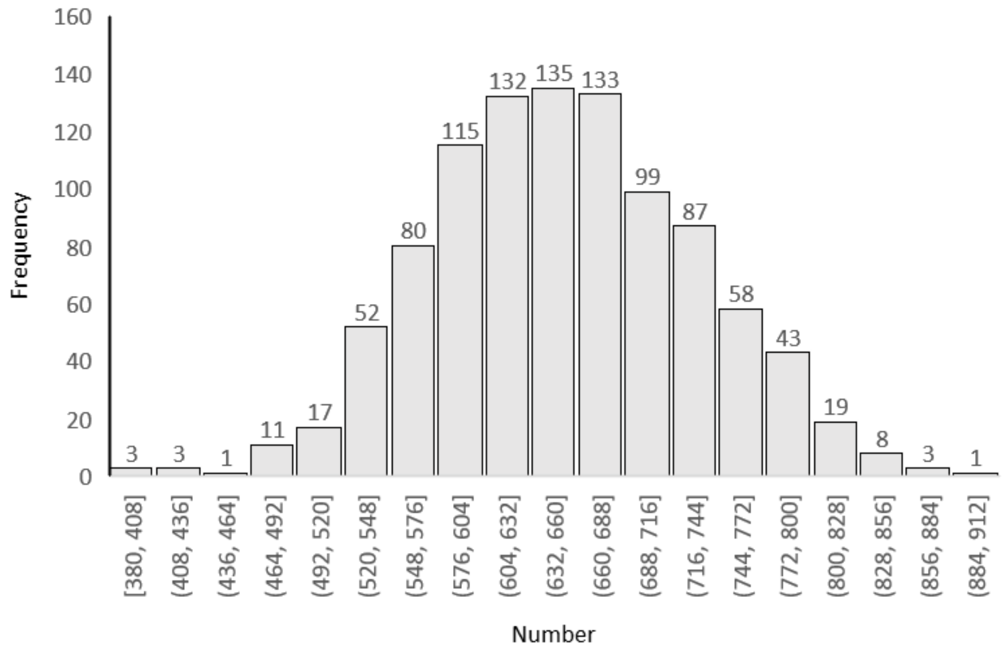

Figure E16: Frequency distribution for S1(individual).A5: long-term number of pig producers in highly profitable systems

Source: Pork VC model simulation

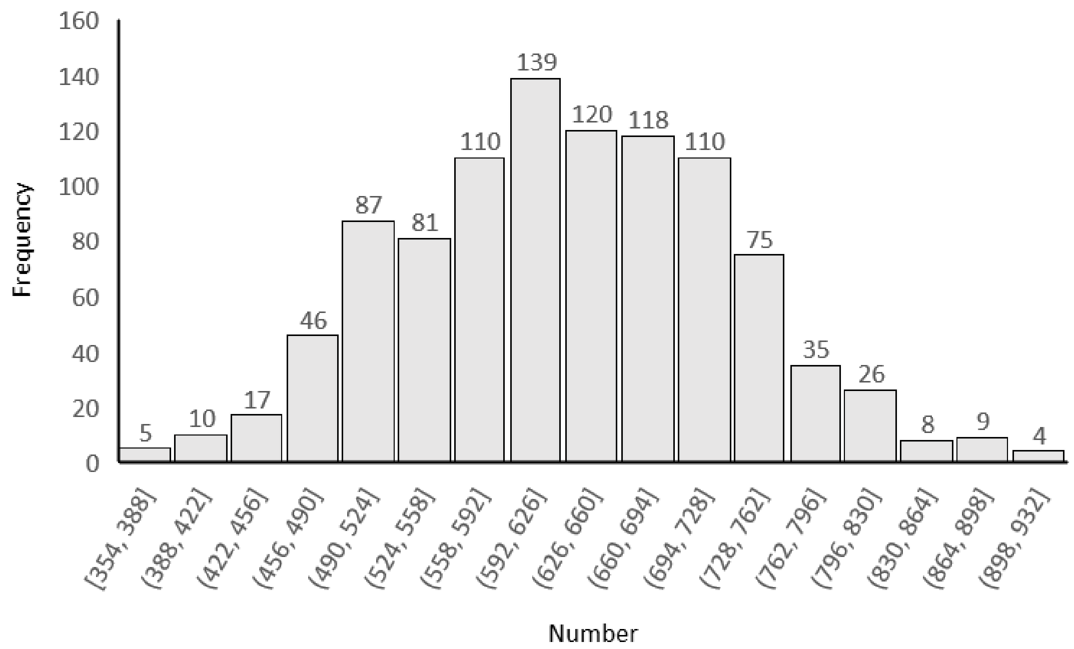

Figure E17: Frequency distribution for S2(PGs).A5: long-term number of pig producers in highly profitable systems

Source: Pork VC model simulation

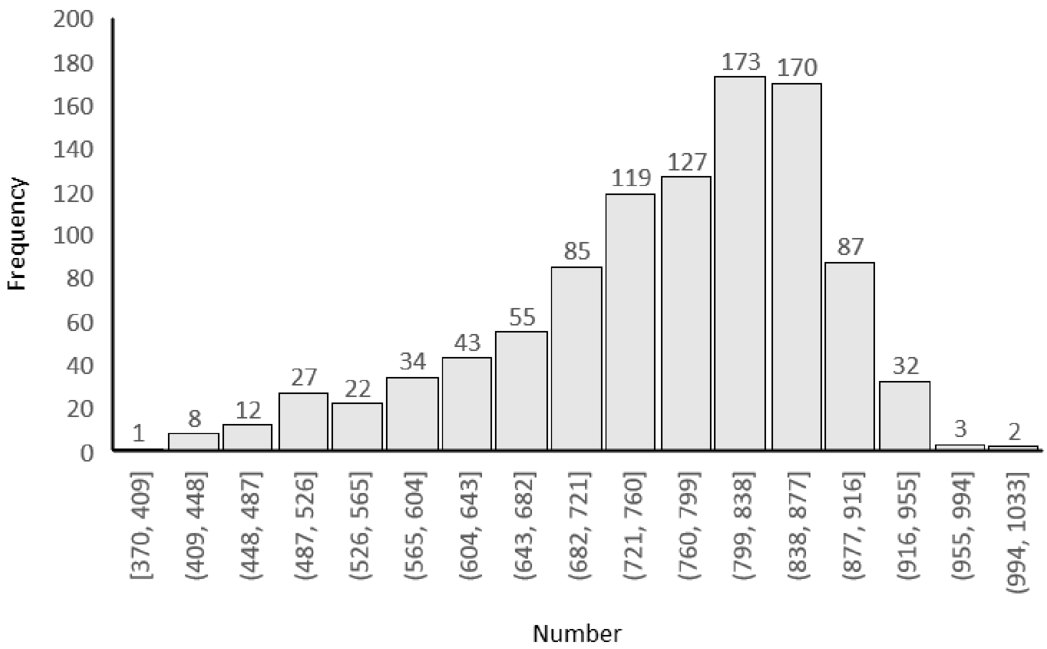

Figure E18: **Frequency distribution for S3(POs).A5: long-term number of pig producers in highly profitable systems**
Source: Pork VC model simulation

E.3 Box plots for aggregate profits for all pig producers

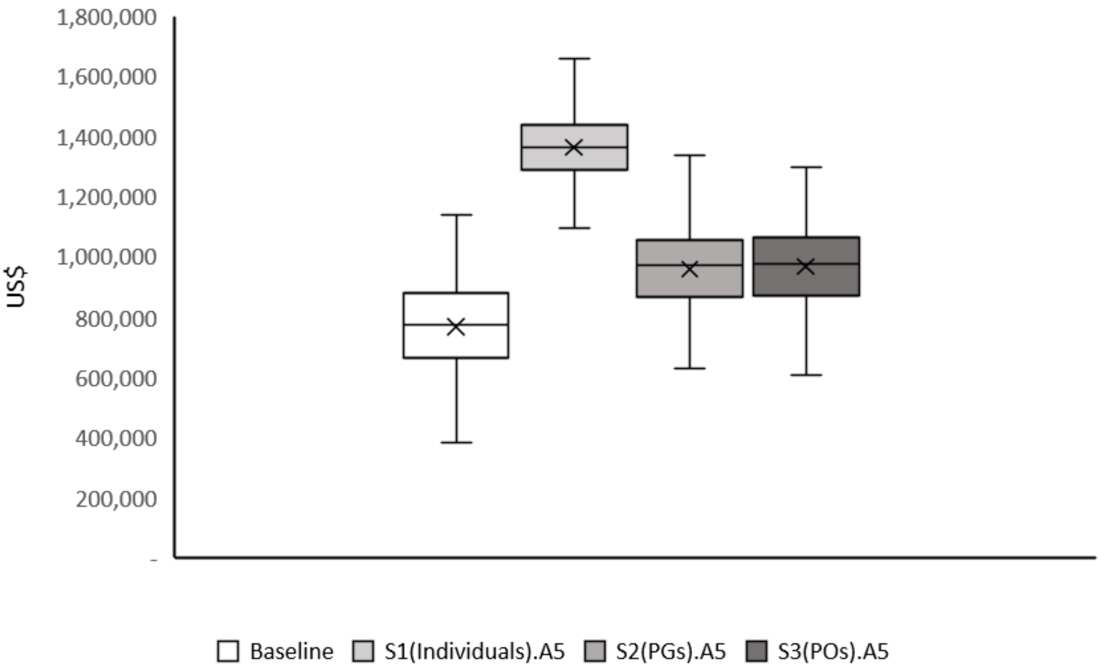

Figure E19: Box plot for short-term aggregate profits of all pig producers
Source Pork VC model simulation

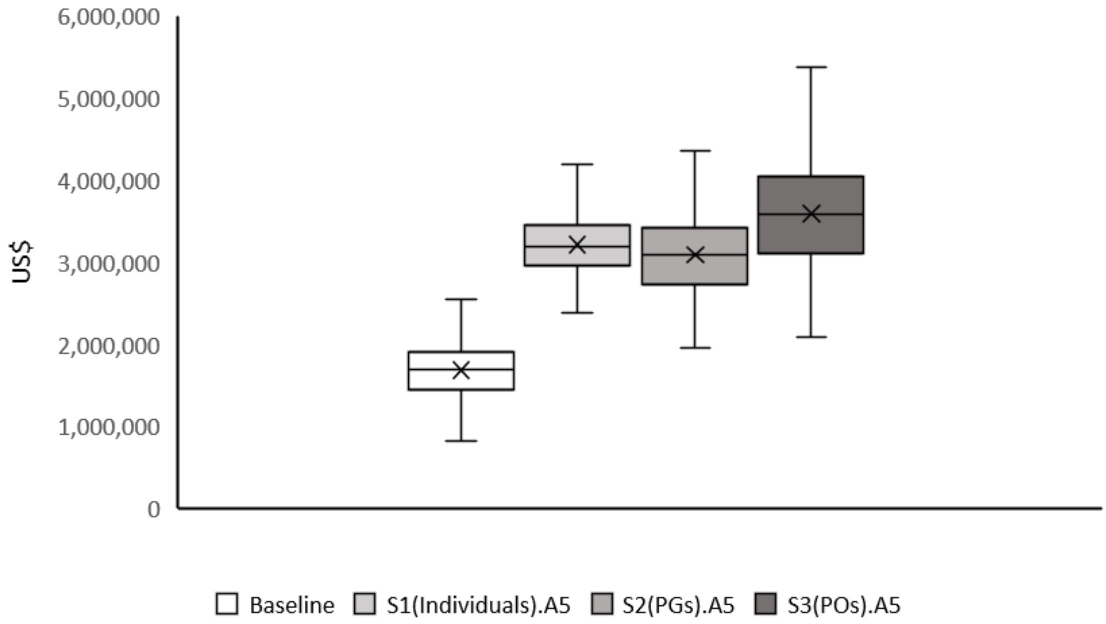

Figure E20: Box plot for medium-term aggregate profits of all pig producers
Source: Pork VC model simulation

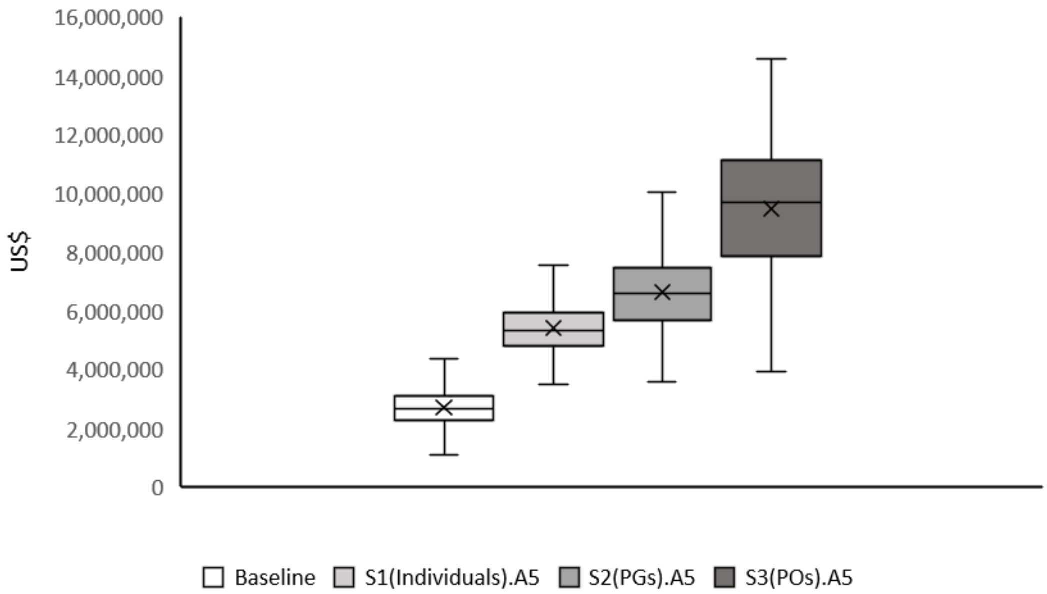

Figure E21: Box plots for long-term aggregate profits of all pig producers
Source: Pork VC model simulation

E.4 Box plots for number of pig producers in highly profitable systems

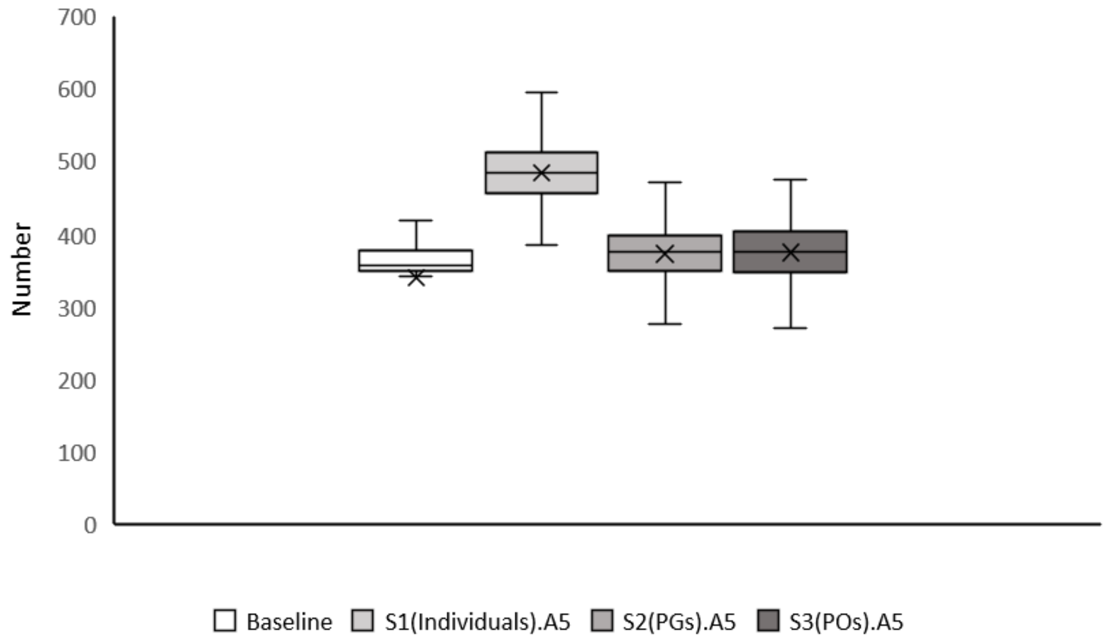

Figure E22: Box plot for short-term number of pig producers in highly profitable systems
Source: Pork VC model simulation

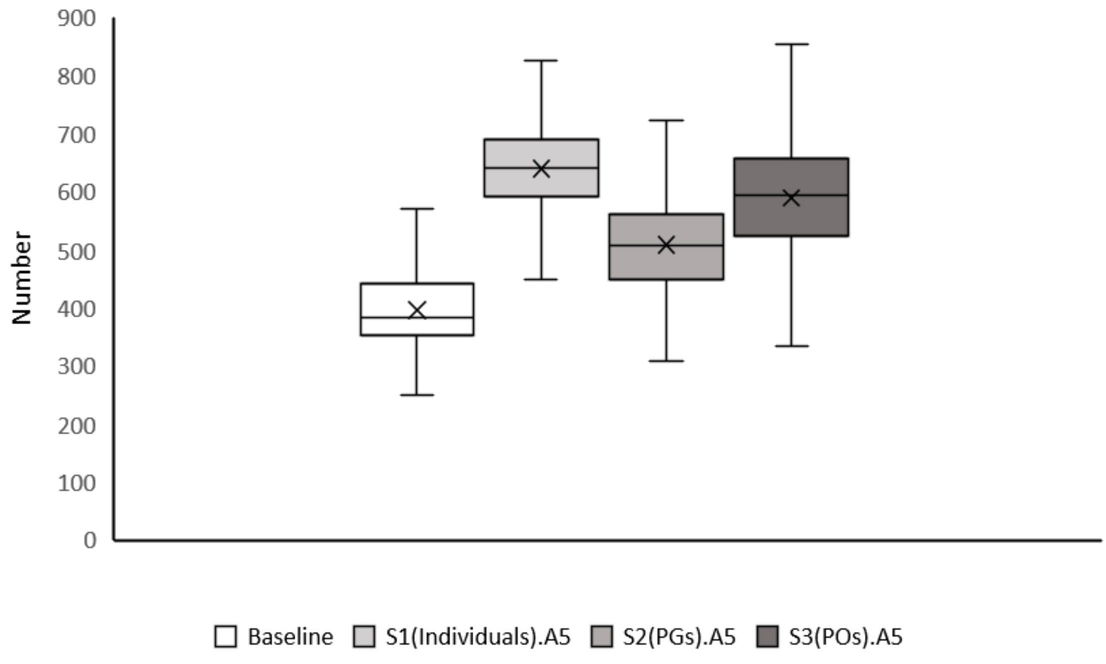

Figure E23: Box plot for medium-term numbers of pig producers in highly profitable systems
Source: Pork VC model simulation

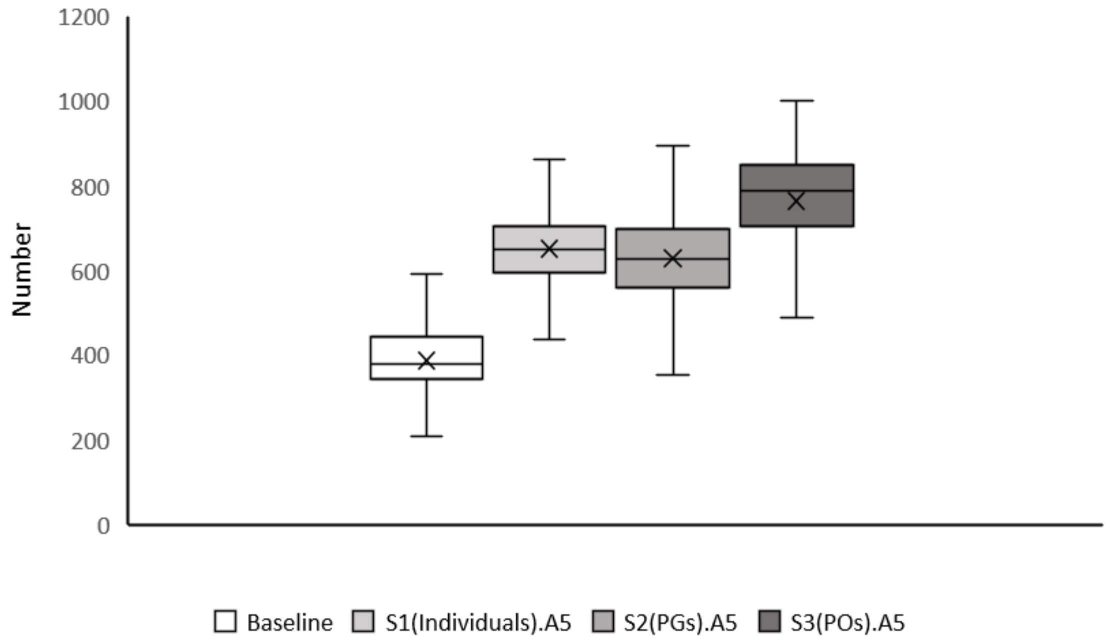

Figure E24: Box plot for long-term numbers of pig producers in highly profitable systems
Source: Pork VC model simulation

Appendix F

Results from multi-variate sensitivity analysis with alternative sample sizes for Latin hypercube sampling technique

Table F1: Comparison of alternative sample sizes on multi-variate sensitivity analysis: aggregate profits of all pig producers in scenario one

Scenario		*Short-term*			*Medium-term*			*Long-term*	
	SA: 1000 US$ [Rank] (CV)	SA: 500 US$ [Rank] % change (CV)	SA: 2000 US$ [Rank] % change (CV)	SA: 1000 US$ (CV)	SA: 500 US$ [Rank] % change (CV)	SA: 2000 US$ [Rank] % change (CV)	SA: 1000 US$ (CV)	SA: 500 US$ [Rank] % change (CV)	SA: 2000 US$ [Rank] % change (CV)
Baseline	768,754 (19%)	767,067 -0.2% (20%)	767,006 -0.2% (20%)	1,684,115 (20%)	1,682,604 -0.1% (21%)	1,680,474 -0.2% (20%)	2,702,188 (24%)	2,699,728 -0.1% (25%)	2,696,448 -0.2% (25%)
Scenario 1: Individual producers									
S1.A1: Microcredit $150K	1,050,763 [1] (10%)	1,049,992 [1] -0.1% (10%)	1,039,667 [1] -1.1% (10%)	2,287,546 [1] (12%)	2,284,208 [1] -0.1% (12%)	2,283,571 [1] -0.2% (12%)	3,707,147 [1] (16%)	3,700,247 [1] -0.2% (17%)	3,698,777 [1] -0.2% (16%)
S1.A1.2: Microcredit $300K	1,243,903 [(1)] (8%)	1,243,208 [(1[a])] -0.1% (8%)	1,230,950 [(1)] -1.0% (8%)	2,792,792 [(1)] (11%)	2,789,949 [(1)] -0.1% (11%)	2,788,587 [(1)] -0.2% (11%)	4,638,498 [(1)] (15%)	4,631,882 [(1)] -0.1% (16%)	4,628,724 [(1)] -0.2% (16%)
S1.A2: Training	865,292 [3] (17%)	864,374 [3] -0.1% (18%)	864,331 [3] -0.1% (18%)	1,923,978 [3] (20%)	1,922,675 [3] -0.1% (20%)	1,967,389 [3] 2.3% (22%)	3,122,299 [3] (25%)	3,117,435 [3] -0.2% (26%)	3,115,492 [3] -0.2% (25%)
S1.A3: AHWs	924,813 [2] (17%)	924,685 [2] 0.0% (17%)	924,565 [2] 0.0% (17%)	2,053,378 [2] (18%)	2,054,337 [2] 0.0% (18%)	2,053,375 [2] 0.0% (19%)	3,283,421 [2] (21%)	3,285,526 [2] 0.1% (22%)	3,284,595 [2] 0.0% (22%)
S1.A4: AI	841,039 [4] (18%)	839,880 [4] -0.1% (18%)	839,877 [4] -0.1% (18%)	1,874,430 [4] (19%)	1,855,051 [4] -1.0% (19%)	1,853,695 [4] -1.1% (19%)	3,024,807 [4] (24%)	3,013,069 [4] -0.4% (24%)	3,011,180 [4] -0.5% (24%)
S1.A5: Combination	*1,365,197 [1]* *(8%)*	*1,365,375 [1]* *0.0%* *(8%)*	*1,365,055 [1]* *0.0%* *(8%)*	*3,218,349 [2]* *(11%)*	*3,220,063 [2]* *0.1%* *(11%)*	*3,219,692 [2]* *0.0%* *(11%)*	*5,411,166 [3]* *(15%)*	*5,413,406 [3]* *0.0%* *(15%)*	*5,413,478 [3]* *0.0%* *(15%)*

Note: SA denotes results from sensitivity analysis with different sample sizes for LHS. SA: 1000 is the standard sensitivity analysis testing that used 1000 sample runs. SA: 500 shows the results with 500 sample runs, and SA: 2000 shows results with 2000 sample runs. The % change figure represents the percentage change in the mean between SA:1000 and SA:500/SA:2000. The coefficients of variation (CV) are provided in brackets below. [a] Value in parentheses denotes that ranking of the sub activity A1.2

Source: Pork VC model simulation

Table F2: Comparison of alternative sample sizes on multi-variate sensitivity analysis: aggregate profits of all pig producers in scenario two

Scenario		*Short-term*			*Medium-term*			*Long-term*	
	SA: 1000 US$ [Rank] (CV)	SA: 500 US$ [Rank] % change (CV)	SA: 2000 US$ [Rank] % change (CV)	SA: 1000 US$ (CV)	SA: 500 US$ [Rank] % change (CV)	SA: 2000 US$ [Rank] % change (CV)	SA: 1000 US$ (CV)	SA: 500 US$ [Rank] % change (CV)	SA: 2000 US$ [Rank] % change (CV)
Baseline	768,754 (19%)	767,067 -0.2% (20%)	767,006 -0.2% (20%)	1,684,115 (20%)	1,682,604 -0.1% (21%)	1,680,474 -0.2% (20%)	2,702,188 (24%)	2,699,728 -0.1% (25%)	2,696,448 -0.2% (25%)
Scenario 2: Producer Groups									
S2.A1: Microcredit $150K	756,258 [1] (18%)	754,511 [1] -0.2% (19%)	755,557[1] -0.1% (18%)	2,046,108 [1] (17%)	2,042,889 [1] -0.2% (17%)	2,044,467 [1] -0.1% (17%)	3,744,576 [2] (20%)	3,737,458 [2] -0.2% (21%)	3,738,483 [2] -0.2% (21%)
S2.A1.2: Microcredit $300K	858,884 [(1)] (14%)	857,070 [(1[a])] -0.2% (15%)	858,007 [(1)] 0.1% (14%)	2,379,672 [(1)] (14%)	2,377,421 [(1)] -0.1% (15%)	2,376,782 [(1)] -0.1% (15%)	4,500,663 [(1)] (18%)	4,492,582 [(1)] -0.2% (19%)	4,493,920 [(1)] -0.1% (19%)
S2.A2: Training	697,972 [3] (24%)	696,177 [3] -0.3% (25%)	697,164 [3] -0.1% (24%)	1,523,724 [3] (22%)	1,949,044 [3] -0.2% (23%)	1,951,779 [3] -0.1% (22%)	3,681,166 [3] (28%)	3,672,487 [3] -0.2% (29%)	3,677,143 [3] -0.1% (29%)
S2.A3: AHWs	728,279 [2] (23%)	727,232 [2] -0.1% (24%)	727,912 [2] -0.1% (23%)	2,025,130 [2] (21%)	2,024,222 [2] 0.0% (22%)	2,024,974 [2] 0.0% (22%)	3,792,198 [1] (27%)	3,797,971 [1] 0.2% (27%)	3,794,880 [1] 0.1% (27%)
S2.A4: AI	671,354 [4] (24%)	669,619 [4] -0.3% (25%)	670,477 [4] -0.1% (25%)	1,832,592 [4] (23%)	1,828,240 [4] -0.2% (24%)	1,830,481 [4] -0.1% (23%)	3,384,251 [4] (28%)	3,378,786 [4] -0.2% (29%)	3,380,161 [4] -0.1% (29%)
S2.A5: Combination	*959,624 [3]* *(14%)*	*958,868 [3]* *-0.1%* *(14%)*	*959,352 [1]* *0.0%* *(14%)*	*3,093,090 [3]* *(16%)*	*3,093,133 [3]* *0.1%* *(16%)*	*3,093,208 [3]* *0.0%* *(16%)*	*6,636,282 [2]* *(20%)*	*6,634,816 [2]* *0.0%* *(20%)*	*6,633,316 [2]* *0.0%* *(20%)*

Note: SA denotes results from sensitivity analysis with different sample sizes for LHS. SA: 1000 is the standard sensitivity analysis testing that used 1000 sample runs. SA: 500 shows the results with 500 sample runs, and SA: 2000 shows results with 2000 sample runs. The % change figure represents the percentage change in the mean between SA:1000 and SA:500/SA:2000. The coefficients of variation (CV) are provided in brackets below. [a] Value in parentheses denotes that ranking of the sub activity A1.2

Source: Pork VC model simulation

Table F3: Comparison of alternative sample sizes on multi-variate sensitivity analysis: aggregate profits of all pig producers in scenario three

Scenario		*Short-term*			*Medium-term*			*Long-term*	
	SA: 1000 US$ [Rank] (CV)	SA: 500 US$ [Rank] % change (CV)	SA: 2000 US$ [Rank] % change (CV)	SA: 1000 US$ (CV)	SA: 500 US$ [Rank] % change (CV)	SA: 2000 US$ [Rank] % change (CV)	SA: 1000 US$ (CV)	SA: 500 US$ [Rank] % change (CV)	SA: 2000 US$ [Rank] % change (CV)
Baseline	768,754 (19%)	767,067 -0.2% (20%)	767,006 -0.2% (20%)	1,684,115 (20%)	1,682,604 -0.1% (21%)	1,680,474 -0.2% (20%)	2,702,188 (24%)	2,699,728 -0.1% (25%)	2,696,448 -0.2% (25%)
Scenario 3: Producer Organisations									
S3.A1: Microcredit $150K	764,261 [1] (18%)	761,688 [1] -0.3% (17%)	763,672[1] -0.1% (18%)	2,404,078 [2] (19%)	2,393,900 [2] -0.4% (19%)	2,405,191 [2] -0.0% (19%)	5,502,402 [3] (27%)	5,469,671 [3] -0.6% (27%)	5,495,395 [2] -0.1% (26%)
S3.A1.2: Microcredit $300K	866,263 [(1)] (14%)	864,270 [(1[a])] -0.2% (14%)	866,553 [(1)] 0.0% (14%)	2,781,791 [(1)] (17%)	2,772,345 [(1)] -0.3% (17%)	2,783,539 [(1)] 0.1% (17%)	6,363,430 [(2)] (25%)	6,327,790 [(2)] -0.6% (24%)	6,369,015 [(2)] 0.1% (24%)
S3.A2: Training	705,498 [3] (23%)	702,959 [3] -0.4% (23%)	705,091 [3] -0.1% (23%)	2,319,272 [3] (23%)	2,308,978 [3] -0.4% (23%)	2,322,470 [3] 0.1% (23%)	5,557,582 [2] (31%)	5,525,537 [2] -0.6% (31%)	5,553,057 [2] -0.1% (31%)
S3.A3: AHWs	736,393 [2] (22%)	734,315 [2] -0.3% (23%)	736,183 [2] -0.0% (24%)	2,484,295 [1] (24%)	2,479,146 [1] -0.2% (24%)	2,481,984 [1] -0.1% (24%)	6,373,854 [1] (32%)	6,363,191 [1] -0.2% (32%)	6,361,785 [1] -0.2% (31%)
S3.A4: AI	679,591 [4] (24%)	676,657 [4] -0.4% (24%)	678,843 [4] -0.1% (24%)	2,204,966 [4] (24%)	2,193,832 [4] -0.5% (24%)	2,205,681 [4] 0.0% (24%)	5,267,707 [4] (32%)	5,245,249 [4] -0.4% (32%)	5,263,411 [4] -0.1% (32%)
S3.A5: Combination	*967,945 [2]* *(14%)*	*965,887 [2]* *-0.2%* *(13%)*	*967,854 [2]* *0.0%* *(14%)*	*3,596,168 [1]* *(18%)*	*3,594,657 [1]* *0.0%* *(18%)*	*3,598,236 [1]* *0.1%* *(18%)*	*9,467,633 [1]* *(24%)*	*9,455,472 [2]* *-0.1%* *(24%)*	*9,473,080 [2]* *0.1%* *(24%)*

Note: SA denotes results from sensitivity analysis with different sample sizes for LHS. SA: 1000 is the standard sensitivity analysis testing that used 1000 sample runs. SA: 500 shows the results with 500 sample runs, and SA: 2000 shows results with 2000 sample runs. The % change figure represents the percentage change in the mean between SA:1000 and SA:500/SA:2000. The coefficients of variation (CV) are provided in brackets below. [a] Value in parentheses denotes that ranking of the sub activity A1.2

Source: Pork VC model simulation

Table F4: Comparison of alternative sample sizes on multi-variate sensitivity analysis: number of pig producers in highly profitable systems in scenario one

Scenario		*Short-term*			*Medium-term*			*Long-term*	
	SA: 1000 Number [Rank] (CV)	SA: 500 Number [Rank] % change (CV)	SA: 2000 Number [Rank] % change (CV)	SA: 1000 Number [Rank] (CV)	SA: 500 Number [Rank] % change (CV)	SA: 2000 Number [Rank] % change (CV)	SA: 1000 Number [Rank] (CV)	SA: 500 Number [Rank] % change (CV)	SA: 2000 Number [Rank] % change (CV)
Baseline	340	341	340	396	394	394	388	388	388
		0.1%	-0.1%		-0.5%	-0.4%		0.0%	0.0%
	(22%)	(20%)	(22%)	(20%)	(21%)	(20%)	(26%)	(27%)	(26%)
Scenario 1: Individual Producers									
S1.A1: Microcredit $150K	407 [1]	407 [1]	407[1]	498 [1]	497 [1]	497 [1]	491 [1]	490 [1]	490 [1]
		-0.2%	-0.1%		-0.2%	-0.2%		-0.1%	-0.3%
	(6%)	(7%)	(6%)	(11%)	(11%)	(11%)	(19%)	(20%)	(19%)
S1.A1.2: Microcredit $300K	465 [(1)]	465 [(1[a])]	465 [(1)]	590 [(1)]	589 [(1)]	589 [(1)]	561 [(1)]	561 [(1)]	560 [(1)]
		-0.1%	-0.1%		-0.2%	-0.2%		-0.1%	-0.2%
	(5%)	(5%)	(5%)	(10%)	(10%)	(9%)	(23%)	(24%)	(24%)
S1.A2: Training	373 [3]	373 [3]	374 [3]	445 [3]	442 [3]	443 [3]	437 [3]	436 [3]	436 [3]
		-0.2%	0.1%		-0.6%	-0.4%		-0.2%	-0.3%
	(17%)	(17%)	(16%)	(20%)	(21%)	(20%)	(25%)	(27%)	(26%)
S1.A3: AHWs	387 [2]	388 [2]	388 [2]	453 [2]	452 [2]	453 [2]	469 [2]	469 [2]	468 [2]
		0.1%	0.1%		-0.1%	0.0%		-0.0%	-0.2%
	(10%)	(10%)	(10%)	(19%)	(20%)	(20%)	(19%)	(20%)	(20%)
S1.A4: AI	343 [4]	344 [4]	343 [4]	405 [4]	402 [4]	403 [4]	400 [4]	399 [4]	400 [4]
		0.2%	-0.2%		-0.6%	-0.4%		-0.3%	0.0%
	(22%)	(22%)	(23%)	(21%)	(22%)	(21%)	(27%)	(28%)	(26%)
S1.A5: Combination	*484 [1]*	*485 [1]*	*485 [1]*	*639 [1]*	*639 [1]*	*639 [1]*	*652 [2]*	*653 [2]*	*651 [2]*
		0.0%	*0.0%*		*0.0%*	*0.0%*		*0.2%*	*-0.1%*
	(8%)	*(9%)*	*(9%)*	*(11%)*	*(12%)*	*(12%)*	*(12%)*	*(13%)*	*(13%)*

Note: SA denotes results from sensitivity analysis with different sample sizes for LHS. SA: 1000 is the standard sensitivity analysis testing that used 1000 sample runs. SA: 500 shows the results with 500 sample runs, and SA: 2000 shows results with 2000 sample runs. The % change figure represents the percentage change in the mean between SA:1000 and SA:500/SA:2000. The coefficients of variation (CV) are provided in brackets below. [a] Value in parentheses denotes that ranking of the sub activity A1.2

Source: Pork VC model simulation

Table F5: Comparison of alternative sample sizes on multi-variate sensitivity analysis: number of pig producers in highly profitable systems in scenario two

Scenario		*Short-term*			*Medium-term*			*Long-term*	
	SA: 1000	SA: 500	SA: 2000	SA: 1000	SA: 500	SA: 2000	SA: 1000	SA: 500	SA: 2000
	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]
		% change	% change		% change	% change		% change	% change
	(CV)	(CV)	(CV)	(CV)	(CV)	(CV)	(CV)	(CV)	(CV)
Baseline	340	341	340	396	394	394	388	388	388
		0.1%	-0.1%		-0.5%	-0.4%		0.0%	0.0%
	(22%)	(20%)	(22%)	(20%)	(21%)	(20%)	(26%)	(27%)	(26%)
Scenario 2: Producer Groups									
S2.A1: Microcredit $150K	309 [1]	307 [1]	307 [1]	361 [2]	360 [2]	360 [2]	406 [2]	404 [2]	405 [2]
		-0.8%	-0.7%		-0.2%	-0.3%		-0.3%	-0.2%
	(17%)	(19%)	(19%)	(16%)	(17%)	(17%)	(20%)	(21%)	(21%)
S2.A1.2: Microcredit $300K	336 [(1)]	335 [(1[a])]	336 [(1)]	410 [(1)]	410 [(1)]	409 [(1)]	466 [(1)]	465 [(1)]	466 [(1)]
		-0.2%	0.2%		-0.2%	-0.3%		-0.4%	-0.1%
	(14%)	(15%)	(13%)	(14%)	(15%)	(15%)	(19%)	(20%)	(20%)
S2.A2: Training	280 [3]	277 [4[c]]	279 [3]	363 [1]	362 [1]	362 [1]	413 [1]	411 [1]	412 [1]
		-0.9%	-0.3%		-0.3%	-0.3%		-0.5%	-0.2%
	(28%)	(30%)	(29%)	(23%)	(23%)	(23%)	(27%)	(28%)	(28%)
S2.A3: AHWs	298 [2]	296 [2]	296 [2]	350 [3]	350 [3]	350 [3]	402 [3]	403 [3]	403 [3]
		-0.7%	-0.7%		0.1%	0.0%		0.2%	0.1%
	(21%)	(22%)	(22%)	(21%)	(21%)	(22%)	(27%)	(28%)	(28%)
S2.A4: AI	280 [4]	278 [3[b]]	278 [4]	349 [4]	349 [4]	349 [4]	386 [4]	384 [4]	385 [4]
		-0.5%	-0.6%		-0.1%	-0.2%		-0.4%	-0.1%
	(27%)	(28%)	(28%)	(21%)	(22%)	(22%)	(27%)	(28%)	(28%)
S2.A5: Combination	*373 [3]*	*372 [3]*	*372 [3]*	*508 [3]*	*508 [3]*	*508 [3]*	*629 [3]*	*628 [3]*	*628 [3]*
		-0.2%	*-0.1%*		*0.0%*	*0.0%*		*-0.2%*	*-0.1%*
	(10%)	*(11%)*	*(11%)*	*(16%)*	*(16%)*	*(16%)*	*(16%)*	*(16%)*	*(16%)*

Note: SA denotes results from sensitivity analysis with different sample sizes for LHS. SA: 1000 is the standard sensitivity analysis testing that used 1000 sample runs. SA: 500 shows the results with 500 sample runs, and SA: 2000 shows results with 2000 sample runs. The % change figure represents the percentage change in the mean between SA:1000 and SA:500/SA:2000. The coefficients of variation (CV) are provided in brackets below. [a] Value in parentheses denotes that ranking of the sub activity A1.2. [b] indicates rankings that have improved in SA: 500 and SA: 2000 compared with SS: 1000. [c] indicates rankings that have worsened in SA: 500 and SA: 2000 compared with SS: 1000.

Source: Pork VC model simulation

Table F6: Comparison of alternative sample sizes on multi-variate sensitivity analysis: number of pig producers in highly profitable systems in scenario three

Scenario		*Short-term*			*Medium-term*			*Long-term*	
	SA: 1000	SA: 500	SA: 2000	SA: 1000	SA: 500	SA: 2000	SA: 1000	SA: 500	SA: 2000
	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]	Number [Rank]
		% change	% change		% change	% change		% change	% change
	(CV)	(CV)	(CV)	(CV)	(CV)	(CV)	(CV)	(CV)	(CV)
Baseline	340	341	340	396	394	394	388	388	388
		0.1%	-0.1%		-0.5%	-0.4%		0.0%	0.0%
	(22%)	(22%)	(22%)	(20%)	(21%)	(20%)	(26%)	(27%)	(26%)
Scenario 3: Producer Organisations									
S2.A1: Microcredit $150K	311 [1]	310 [1]	312 [1]	448 [1]	445 [1]	448 [1]	537 [3]	531 [3]	535 [3]
		-0.3%	0.1%		-0.6%	0.0%		-1.2%	-0.4%
	(18%)	(17%)	(17%)	(20%)	(19%)	(19%)	(36%)	(36%)	(35%)
S2.A1.2: Microcredit $300K	339 [(1)]	338 [(1[a])]	339 [(1)]	499 [(1)]	497 [(1)]	499 [(1)]	599 [(2)]	595 [(2)]	599 [(2)]
		-0.1%	-0.0%		-0.4%	0.1%		-0.6%	0.1%
	(14%)	(12%)	(13%)	(18%)	(17%)	(17%)	(35%)	(35%)	(34%)
S2.A2: Training	284 [3]	284 [3]	285 [3]	447 [2]	444 [3[c]]	447 [2]	565 [2]	559 [2]	564 [2]
		0.0%	0.3%		-0.6%	0.0%		-1.1%	-0.3%
	(28%)	(28%)	(28%)	(24%)	(24%)	(24%)	(34%)	(34%)	(33%)
S2.A3: AHWs	299 [2]	297 [2]	299 [2]	446 [3]	445 [2[b]]	446 [3]	644 [1]	642 [1]	643 [1]
		-0.6%	0.1%		-0.2%	-0.1%		-0.3%	-0.3%
	(21%)	(21%)	(21%)	(24%)	(24%)	(24%)	(26%)	(26%)	(26%)
S2.A4: AI	284 [4]	283 [4]	283 [4]	436 [4]	434 [4]	436 [4]	530 [4]	526 [4]	528 [4]
		-0.2%	-0.3%		-0.6%	0.0%		-0.7%	-0.3%
	(27%)	(27%)	(27%)	(24%)	(24%)	(24%)	(35%)	(36%)	(34%)
S2.A5: Combination	*374 [2]*	*374 [2]*	*374 [2]*	*590 [2]*	*588 [2]*	*589 [2]*	*765 [1]*	*763 [1]*	*765 [1]*
		-0.2%	*-0.0%*		*-0.3%*	*-0.1%*		*-0.2%*	*0.0%*
	(11%)	*(11%)*	*(11%)*	*(17%)*	*(16%)*	*(16%)*	*(15%)*	*(14%)*	*(14%)*

Note: SA denotes results from sensitivity analysis with different sample sizes for LHS. SA: 1000 is the standard sensitivity analysis testing that used 1000 sample runs. SA: 500 shows the results with 500 sample runs, and SA: 2000 shows results with 2000 sample runs. The % change figure represents the percentage change in the mean between SA:1000 and SA:500/SA:2000. The coefficients of variation (CV) are provided in brackets below. [a] Value in parentheses denotes that ranking of the sub activity A1.2. [b] indicates rankings that have improved in SA: 500 and SA: 2000 compared with SS: 1000. [c] indicates rankings that have worsened in SA: 500 and SA: 2000 compared with SS: 1000.

Source: Pork VC model simulation

Appendix G

Information from Plus, Minus, Interesting reflection exercises

Table G1: Results of Plus, Minus, Interesting reflection exercises

Plus (+)	***Minus (-)***	***Interesting (?)***
SGMB 1: Myeik		
- People are very open and talkative - Right people attended, including those who are important and busy - Could refer to agenda on wall to keep workshop on time - Facilitators were able to remain in roles better than in practise workshop	- Questionnaire was 45 minutes, which was overly long - Group of 15 were too large for Layerstack and some did not pay attention to layers which did not relate to their part in the VC - One member tried to dominate the conversation by talking over others and taking a long time to present their opinion - Front of workshop was crowded with three facilitators - Not all participants could see the water level in the water-in-a-bottle script	- Could use coloured water or coke so that people can see better during stock and flow example - Should have more space at front of workshop so facilitators can move easily - Can try having different coloured name tags for VC actors to help distinguish them - Questionnaire translation needs to be reviewed for simplicity - Researcher to take on co-facilitation role
SGMB 1: Palaw		
- Kept to the agenda and followed the allocated time - Facilitators improved in their roles - Participants understood the tools very quickly and we received more information from Layerstack than in Myeik - Palaw NGO staff were very helpful in setting out room and calling participants so they arrived on time	- Pre-workshop preparation was rushed as there was a misunderstanding on who would complete setting up tasks - The Palaw Rice Technical Officer talked more than other participants and dominated the first few layers of Layerstack exercises - Difficult to ask follow-up questions during Layerstack of other workshop participants - Time constraints because of government regulations means we do not have time to prepare in Palaw and have lengthy follow-up conversations	- Participants needed help in writing, especially Karen ethnicity, can ask Palaw NGO staff for assistance - Request Palaw Rice Technical Officer to move to Reference Group - Request Palaw NGO staff to set up workshop and manage lunch booking so we can spend longer informally engaging with participant's post-workshop
SGMB 2: Myeik		
- Good preparation, nothing missing - Completed agenda and kept to time - Open discussion and able to control disagreements between participants	- Facilitators turned their back on participants when writing on board - Need to summarise more often - After lunch four participants left as they had urgent business - Cause-and-consequence exercise was difficult and messy on whiteboard - Some participants are embarrassed to discuss in front of foreigners	- Hard to read participants written words. Need to keep clarifying meaning with them.

Plus (+)	***Minus (-)***	***Interesting (?)***
	- Running out of time because of the need to translate from English-Myanmar-English	
SGMB 2: Palaw		
- Facilitators stuck to their role - Participants are open, honest, and friendly and willing to provide more information - No funnelling of information through the technical officer	- Some participants copy other people's ideas when writing on cards	- Split facilitation in small groups between MBT members
SGMB 3: Myeik		
- Participants are freer to discuss in small groups - Excellent one-on-one discussions with downstream VC actors during breaks and before/after workshops - MBT followed their roles, and collected all the information we needed - Friendly, open, discussion and people listened rather than talking over one another - People who were absent are the ones who expected handouts from the project - Helping people to write their answers on paper means they are more likely to contribute during plenary discussion	- Some people get tired of writing on cards - Ran overtime for lunch, but because participants wanted to keep discussing the VC	- Fewer participants means better discussions, we should do more small-group work - We need to ask more prompt questions along with "Did you understand everything?", "What is missing from this diagram?" - We need to summarise the discussions and ask, "Is this correct, did I capture everything?"
SGMB 3: Palaw		
- Finished on time - Completed every agenda item - Increasingly active participants and good discussions - Participants enjoyed explaining their concept models to each other - New Lead Facilitator did an excellent job	- A new participant joined to substitute a participant that could not attend - MBT distracted by outside phone calls - Some items rushed so that we could finish on time	- The lead Facilitator was unwell, so another MBT stepped in to fill their role
SGMB 4: Myeik		
- Followed our roles - New Lead Facilitator was very active and able to communicate well with participants - Concept model was completed - Almost all participants attended	- Slightly over time for workshop	- Some differences in information between SGMB and RG and Lincoln University Producer Group research team

Plus (+)	*Minus (-)*	*Interesting (?)*
SGMB 4: Palaw		
- Concept model and information completed	- Some participants are restless with reviewing information as nothing new for them - Not easy to keep inviting participants as they are busy, so attendance is declining	
SGMB 5: Myeik		
- Almost all SGMB participants attended - Agree with the model recommendations - More discussions between participants on how they can work together to improve the VC	- Presentation of results by PowerPoint meant that it was difficult to understand for some participants - Results presentation too lengthy - Long gap between workshop four and five, some participants had to be reminded about the concept model	- Present results in simpler format
SGMB 5: Palaw		
- Participants engaged better with simple presentation of key model results and recommendations	- Some participants unable to attend because it was rice harvesting seasons - Technical Officer did not attend as they had relocated overseas - Participants want project to start now, expressed concern at all the consultation but no project activities yet	

Source: Note from the Researcher and the MBT's Notetaker

Appendix H

Spatial group model building questionnaire and results

Table H1: Spatial group model building questionnaire

Spatial Group Model Building Questionnaire က႑ေပါင္းစံုပါဝင္သည့္ (ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္) လုပ္ငန္းရွင္အဖြဲ႕ နမူနာပံုစံ တည္ေဆာက္ျခင္း ေမးခြန္းလႊာ
Background Information ေနာက္ခံ (ကိုယ္ေရးရာဇဝင္) အခ်က္အလက္
Name: အမည္
Date of birth: ေမြးသကၠရာဇ္
Today's date: ေန႕စြဲ
Gender: က်ား/မ
Ethnicity: လူမ်ိဳး
Primary occupation: အလုပ္အကိုင္
Years spent working in primary occupation: လက္ရွိ ဆန္စပါးစိုက္ပ်ိဳးေရး လုပ္ငန္းတြင္ လုပ္ကိုင္ခဲ့သည့္ ႏွစ္အေရအတြက္
Highest education level attained: အျမင့္ဆံုးတက္ေရာက္ခဲ့ေသာ အတန္းပညာေရး

Part A: Value Chain
အပိုင်း(က) တန်ဖိုးမြင့် ထုတ်ကုန်လုပ်ငန်း ကွင်းဆက်

Q.1) I know all the key people in the paddy/pork value chain.
မေးခွန်း-၁) တန်ဖိုးမြင့် ဆန်စပါးစိုက်ပျိုးရေး ထုတ်ကုန် လုပ်ငန်းတွင် ပါဝင်နေသော အဓိကလူ အားလုံးကို ကျွန်ုပ် သိပါသည်။

Please tick your response: ကျေးဇူးပြု၍ သင့်၏အဖြေကို (ရွေးပြီး) အမှန်ခြစ်ပေးပါ။

Strongly agree (ကောင်းကောင်းသိပါသည်)	Agree (သိပါသည်)	Neutral (ကြားနေ)	Disagree (မသိပါ)	Strongly disagree (လုံးဝ မသိပါ)

Q.2) Please list the roles of key people in the paddy/pork value chain you know.
မေးခွန်း-၂) တန်ဖိုးမြင့် ဆန်စပါးစိုက်ပျိုးရေး ထုတ်ကုန်လုပ်ငန်း ကွင်းဆက်တွင် သင်သိသော အဓိကလူများ၏ (အခန်းကဏ္ဍ) တာဝန်ဝတ္တရားများကို ကျေးဇူးပြု၍ ဖော်ပြပေးပါ။

Q.3) There are opportunities to increase my income from paddy/pork.
မေးခွန်း-၃) ဆန်စပါးစိုက်ပျိုးရေး ထုတ်ကုန်လုပ်ငန်းဖြင့် ကျွန်ုပ်၏ ဝင်ငွေတိုးတက်လာဖို့ အခွင့်အလမ်းများ ရှိပါသည်။

Please tick your response: ကျေးဇူးပြု၍ သင့်၏အဖြေကို (ရွေးပြီး) အမှန်ခြစ်ပေးပါ။

Strongly agree (အလွန် ရှိပါသည်)	Agree (ရှိပါသည်)	Neutral (ကြားနေ)	Disagree (မရှိပါ)	Strongly disagree (လုံးဝ မရှိပါ)

Q.4) I understand how different people in the paddy/pork value chain add value to the product.
မေးခွန်း-၄) ဆန်စပါးစိုက်ပျိုးရေး ထုတ်ကုန်လုပ်ငန်းတွေမှာ လုပ်ငန်းကဏ္ဍမတူသူတွေဟာ ထုတ်ကုန်တွေ တန်ဖိုးတက်လာအောင် (ဈေးပိုရအောင်) မည်သို့ လုပ်ဆောင်ကြသည်ကို ကျွန်ုပ် သိပါသည်။

Please tick your response: ကျေးဇူးပြု၍ သင့်၏အဖြေကို (ရွေးပြီး) အမှန်ခြစ်ပေးပါ။

Strongly agree (ကောင်းကောင်းသိပါသည်)	Agree (သိပါသည်)	Neutral (ကြားနေ)	Disagree (မသိပါ)	Strongly disagree (လုံးဝ မသိပါ)

Q.5) I understand the differences in profit people in the paddy/pork value chain make from the value they add to the product
မေးခွန်း-၅) ဆန်စပါးစိုက်ပျိုးရေး ထုတ်ကုန်လုပ်ငန်း လုပ်သူများသည် သူတို့၏ ထုတ်ကုန် တန်ဖိုးတက်အောင် (ဈေးပိုရအောင်) လုပ်ရာတွင် အကျိုးအမြတ် အနည်းအများ မတူညီတာတွေရှိကြတာကို ကျွန်ုပ်သိပါသည်။

Please tick your response: ကျေးဇူးပြု၍ သင့်၏အဖြေကို (ရွေးပြီး) အမှန်ခြစ်ပေးပါ။

Strongly agree (ကောင်းကောင်းသိပါသည်)	Agree (သိပါသည်)	Neutral (ကြားနေ)	Disagree (မသိပါ)	Strongly disagree

				(လံုးဝ မသိပါ)

Q.6) I understand all the types of relationships (friend, contract, cash-buyer, etc.) between the different actors in the paddy/pork value chain.
ေမးခြန္း-၆) ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္ လုပ္ငန္းေတြမွာ လုပ္ငန္းက႑ မတူသူေတြအၾကား (မိတ္ေဆြသူငယ္ခ်င္းျဖစ္သူ၊ စာခ်ဳပ္ျဖင့္လုပ္သူ၊ ေငြလက္ငင္းေပးဝယ္သူ စသျဖင့္) ပတ္သက္ဆက္ႏြယ္မႈပံုစံဘယ္လိုရွိသည္ကို သိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းသိပါသည္)	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree (လံုးဝ မသိပါ)

Q.7) I understand that men and women have different roles in the paddy/pork value chain.
ေမးခြန္း-၇) ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္လုပ္ငန္း လုပ္ေနၾကသည့္ အမ်ိဳးသားႏွင့္ အမ်ိဳးသမီးေတြအၾကား မတူညီတဲ့ အလုပ္တာဝန္က႑ေတြ ရွိေနၾကသည္ကို သိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းသိပါသည္)	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree (လံုးဝ မသိပါ)

Q.8) Please list the main roles women and men have in paddy/pork production.
ေမးခြန္း-၈) ေက်းဇူးျပဳ၍ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္လုပ္ငန္းအတြင္းရွိ အမ်ိဳးသားႏွင့္ အမ်ိဳးသမီးမ်ား၏ အဓိက အခန္းက႑ကို ေဖာ္ျပေပးပါ။

Women's roles အမ်ိဳးသမီးမ်ား၏ အခန္းက႑	Men's roles အမ်ိဳးသားမ်ား၏ အခန္းက႑

Q.9) I know the quality characteristics of paddy/pork products that earn a higher price.
ေမးခြန္း-၉) ေစ်းေကာင္းပိုရသည့္ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္မ်ား၏ အရည္အေသြး လကၡဏာကို ကၽြႏ္ုပ္ သိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းသိပါသည္)	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree (လံုးဝ မသိပါ)

Q.10) I know the volume of paddy/pork products that earn a higher price.
ေမးခြန္း-၁၀) ေစ်းေကာင္းပိုရသည့္ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္မ်ား၏ အေရာင္းအ၀ယ္လုပ္ေနသည့္ ပမာဏကို ကြ်ႏ္ုပ္ သိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းသိပါသည္)	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree (လံုး၀ မသိပါ)

Q.11) I know at what times of year the prices for paddy/pork products are higher.
ေမးခြန္း-၁၁) ဘယ္အခ်ိန္ ဘယ္ရာသီ ဘယ္ကာလေတြမွာ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္ေတြ ပို၍ ေစ်းႀကီးတတ္သည္ (ပို၍ ေစ်းေကာင္းတတ္သည္)ကို ကြ်ႏ္ုပ္ သိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းသိပါသည္)	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree (လံုး၀ မသိပါ)

Q.12) I know what type of paddy/pork products are demanded by consumers.
ေမးခြန္း-၁၂) မည္သည့္ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္မ်ိဳးအမ်ိဳးအစားကို ၀ယ္သူေတြ လိုခ်င္ေနၾကသလဲဆိုတာ ကြ်ႏ္ုပ္ သိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္း သိပါသည္။	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree (လံုး၀ မသိပါ)

Q.13) I have a good understanding of the potential markets for my paddy/pork products.
ေမးခြန္း-၁၃) ကြ်ႏ္ုပ္၏ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္ေတြအတြက္ အလားအလာေကာင္းသည့္ ေစ်းကြက္အေျခအေနမ်ားကို ကြ်ႏ္ုပ္ ေကာင္းေကာင္း သိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းသိပါသည္)	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree (လံုး၀ မသိပါ)

Q.14 I have a good understanding of how the paddy/pork value chain effects (positive and negative) the livelihoods of poorer communities.
ေမးခြန္း-၁၄) တန္ဖိုးျမင့္ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္ လုပ္ငန္းသည္ ဆင္းရဲသားမိသားစုမ်ား၏ (စား၀တ္ေနေရး) လူေနမႈဘ၀အေပၚ မည္သည့္ ေကာင္းက်ိဳး/ဆုိးက်ိဳးမ်ား သက္ေရာက္ေစသည္ကို ကြ်ႏ္ုပ္ ေကာင္းေကာင္း သိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းသိပါသည္)	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree

				(လံုးဝ မသိပါ)

Q.15) The paddy/pork value chain does little harm to the natural environment. (translated: “little” means “almost none”)
ေမးခြန္း-၁၅) တန္ဖိုးျမင့္ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္လုပ္ငန္းသည္ သဘာဝပတ္ဝန္းက်င္ကို ထိခိုက္မႈ မရွိပါ။ (ထိခိုက္မႈ မရွိသေလာက္ပါပဲ။)

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (လံုးဝ မထိခိုက္သေလာက္ပဲ)	Agree (မထိခိုက္ သေလာက္ပဲ)	Neutral (ၾကားေန)	Disagree (ထိခိုက္တယ္)	Strongly disagree (လံုးဝ ထိခိုက္တယ္)

Q.16) I understand how I can improve my paddy/pork products to earn extra income.
ေမးခြန္း-၁၆) အပို ဝင္ေငြတိုးလာေစရန္ ကြ်ႏ္ုပ္၏ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္မ်ားကို မည္သို႔ တိုးတက္ေကာင္းမြန္လာေအာင္ လုပ္ရမည္ကို ကြ်ႏ္ုပ္ သိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းသိပါသည္)	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree (လံုးဝ မသိပါ)

Q.17) I am interested in using new practices in my paddy/pork business.
ေမးခြန္း-၁၇) ဆန္စပါးစိုက္ပ်ိဳးေရး လက္ေတြ႔အသံုးခ် နည္းပညာ လုပ္နည္းလုပ္ဟန္ အသစ္မ်ား အသံုးျပဳျခင္းကို ကြ်ႏ္ုပ္ စိတ္ဝင္စားပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းသိပါသည္)	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree (လံုးဝ မသိပါ)

Q.18) Making improvements to my paddy/pork business is beyond my ability.
ေမးခြန္း-၁၈) ကြ်ႏ္ုပ္၏ ဆန္စပါးစိုက္ပ်ိဳးေရး လုပ္ငန္းကို ပိုမိုတိုးတက္ေကာင္းမြန္လာေအာင္ အဆင့္ျမွင့္တင္ ေဆာင္ရြက္ျခင္းမ်ား (ျပဳလုပ္ဖို႔) ကြ်ႏ္ုပ္ မတတ္ႏိုင္ပါ၊ လက္လွမ္းမမီပါ။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (လံုးဝ မတတ္ႏိုင္ပါ)	Agree (မတတ္ႏိုင္ပါ)	Neutral (ၾကားေန)	Disagree (တတ္ႏိုင္တယ္)	Strongly disagree (ေကာင္းေကာင္း တတ္ႏိုင္တယ္)

Q.19) I have a good understanding of the key challenges to earning more income from the paddy/pork value chain.
ေမးခြန္း-၁၉) တန္ဖိုးျမင့္ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္လုပ္ငန္းျဖင့္ မိသားစုဝင္ေငြ ပိုတိုးလာေအာင္လုပ္ဖို႔ အဓိက စိန္ေခၚမႈမ်ား၊ အခက္အခဲမ်ား၊ အတားအဆီးမ်ားကို ကြ်ႏ္ုပ္ ေကာင္းစြာ သိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းသိပါသည္)	Agree (သိပါသည္)	Neutral (ၾကားေန)	Disagree (မသိပါ)	Strongly disagree (လံုး၀ မသိပါ)

Q.20) Please list the key challenges to earning more income from the paddy/pork value chain.
ေမးခြန္း-၂၀) ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္လုပ္ငန္းျဖင့္ မိသားစုဝင္ေငြ ပိုတိုးလာေအာင္လုပ္ဖို႔ အဓိက စိန္ေခၚမွဳမ်ား၊ အခက္အခဲမ်ား၊ အတားအဆီးမ်ားကို ေကာက္ႏႈတ္ၿပီး ေဖာ္ျပေပးပါ။

Part B: Relationships and Trust
အပိုင္း(ခ) ေပါင္းသင္းဆက္ဆံေရးႏွင့္ ယုံၾကည္မႈ

Q.21) My suppliers/buyers always provide me with the information I require for my business.
ေမးခြန္း-၂၁) ကၽြႏ္ုပ္၏ စီးပြားေရးလုပ္ငန္းအတြက္ လိုအပ္ေသာ သတင္းအခ်က္အလက္မ်ားႏွင့္ ပတ္သက္ၿပီး ကၽြႏ္ုပ္ကို ေရာင္းခ်ေပးေနသူမ်ား/ ကြၽန္ုပ္ထံမွ ဝယ္ယူေနသူမ်ားက ကၽြန္ုပ္အား အၿမဲလိုလို သတင္းမွ်ေဝ ကူညီ ေပးၾကပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (ေကာင္းေကာင္းေပးပါသည္)	Agree (ေပးပါသည္)	Neutral (ၾကားေန)	Disagree (မေပးပါ)	Strongly disagree (လုံး၀ မေပးပါ)

Q.22) All members of the value chain are always fair and honest in their negotiations with me.
ေမးခြန္း-၂၂) ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္ လုပ္ငန္းအတြင္းရွိ အဖြဲ႕ဝင္မ်ားအားလုံးသည္ ကြၽန္ုပ္ႏွင့္ ညွိႏိႈင္းလုပ္ေဆာင္ရာတြင္ (ကၽြန္ုပ္အေပၚ) အၿမဲတမ္း မွ်တမွဳ ရွိၾကပါသည္။ ရိုးသားၾကပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (အေတာ္ မွ်တ ရိုးသားၾကပါသည္)	Agree (မွ်တ ရိုးသားၾကပါသည္)	Neutral (ၾကားေန)	Disagree (မမွ်တ မရိုးသားၾကပါ)	Strongly disagree (လုံး၀ မမွ်တ မရိုးသားၾကပါ)

Q.23) There are specific members of the value chain which are always fair and honest in their negotiations with me.
ေမးခြန္း-၂၃) ကြၽန္ုပ္ႏွင့္ ညွိႏိႈင္းတိုင္ပင္ လုပ္ေဆာင္ရာတြင္ (ကၽြန္ုပ္အေပၚ) အၿမဲတမ္း မွ်တမွဳ ရိုးသားမွဳရွိၾကသည့္ အဖြဲ႕ဝင္မ်ား အထူးသျဖင့္ သတ္သတ္မွတ္မွတ္ ရွိပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (အေတာ္ သတ္သတ္မွတ္မွတ္ရွိပါသည္)	Agree (ရွိပါသည္)	Neutral (ၾကားေန)	Disagree (မရွိပါ)	Strongly disagree (လုံး၀ မရွိပါ)

Please list these members:
ေက်းဇူးျပဳၿပီး အထက္ေဖာ္ျပပါ လုပ္ငန္းရွင္ အဖြဲ႕ဝင္ေတြကို ေဖာ္ျပေပးပါ။

Q.24) Members of the value chain may use opportunities to hurt me financially.
ေမးခြန္း-၂၄) တန္ဖိုးကြင္းဆက္တြင္ပါဝင္ေသာ အဖြဲ႕ဝင္မ်ားသည္ ကြၽန္ုပ္အား စီးပြားေရးအရ ထိခိုက္ေစေအာင္ အခြင့္အလမ္းမ်ား အက်ိဳးအျမတ္မ်ားကို မတရားသျဖင့္ ရယူေနၾကသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (အလြန္ မတရားသျဖင့္ ရယူေနၾကသည္)	Agree (မတရားသျဖင့္ ရယူေနၾကသည္)	Neutral (ၾကားေန)	Disagree (မတရားသျဖင့္ မရယူၾကပါ)	Strongly disagree

				(လံုး၀ မတရားသျဖင့္ မရယူၾကပါ)

Q.25) I only trust specific members of the value chain to give me a fair price for my goods or services.
ေမးခြန္း-၂၅) ကြ်ႏ္ုပ္၏ ထုတ္ကုန္မ်ားအတြက္ သင့္ေတာ္မွ်တေသာ ေစ်းတစ္ခုရရွိဖို႔ လုပ္ငန္းအတြင္းရွိ သတ္မွတ္ထားတဲ့ (လူနည္းစု) အဖြဲ႕၀င္ေတြကိုသာ ကြ်ႏ္ုပ္ ယံုၾကည္လို႔ ရပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (အလြန္ ယံုၾကည္လို႔ ရပါသည္)	Agree (ယံုၾကည္လို႔ ရပါသည္)	Neutral (ၾကားေန)	Disagree (ယံုၾကည္လို႔ မရပါ)	Strongly disagree (လံုး၀ ယံုၾကည္လို႔ မရပါ)

Q.26) There are more benefits for me when I work closely with all members of the value chain.
ေမးခြန္း-၂၆) တန္ဖိုးျမင့္ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္လုပ္ငန္းအတြင္းရွိ အဖြဲ႕၀င္မ်ား အားလံုးႏွင့္ ရင္းရင္းနီးနီး အလုပ္လုပ္သည့္အခါ ကြၽႏ္ုပ္အတြက္ အက်ိဳးအျမတ္ ပိုမ်ားပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (အလြန္ မွန္ပါသည္)	Agree (မွန္ပါသည္)	Neutral (ၾကားေန)	Disagree (မဟုတ္ပါ)	Strongly disagree (လံုး၀ မဟုတ္ပါ)

Q.27) There are more benefits for me when I work closely with specific members of the value chain.
ေမးခြန္း-၂၇) တန္ဖိုးျမင့္ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္လုပ္ငန္းအတြင္းရွိ (ကြ်ႏ္ုပ္) အထူး ခြဲျခား သတ္မွတ္ထားတဲ့ အဖြဲ႕၀င္မ်ားႏွင့္ ရင္းရင္းနီးနီး အလုပ္လုပ္သည့္အခါ ကြၽႏ္ုပ္အတြက္ အက်ိဳးအျမတ္ ပိုမ်ားပါသည္။
Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (အလြန္ မွန္ပါသည္)	Agree (မွန္ပါသည္)	Neutral (ၾကားေန)	Disagree (မဟုတ္ပါ)	Strongly disagree (လံုး၀ မဟုတ္ပါ)

Please list the members of the value chain which you work closely with for increased benefits:
အက်ိဳးအျမတ္တိုးလာဖို႔အတြက္ လုပ္ငန္းမွာ သင္ႏွင့္ နီးကပ္စြာ အလုပ္လုပ္ေနေသာ အဖြဲ႕၀င္မ်ားကို ေက်းဇူးျပဳ၍ ေဖာ္ျပေပးပါ။ (အမည္ထည့္ေရးစရာ မလိုပါ

Q.28) I can depend upon my relationships with specific value chain members when I have a problem with my business.
ေမးခြန္း-၂၈) ကြ်ႏ္ုပ္၏ အလုပ္မွာ အခက္အခဲ ျပႆနာႀကံဳတဲ့အခါ လုပ္ငန္းအတြင္းရွိ သတ္မွတ္ထားတဲ့ အဖြဲ႕၀င္ (အခ်ိဳ႕)နဲ႔ ကြ်ႏ္ုပ္၏ ဆက္ဆံေရးအေပၚ ယံုၾကည္စိတ္ခ် မွီခို အားကိုးလို႔ ရႏိုင္ပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါ။

Strongly agree (အလြန္ မွန္ပါသည္)	Agree (မွန္ပါသည္)	Neutral (ၾကားေန)	Disagree (မဟုတ္ပါ)	Strongly disagree (လံုး၀ မဟုတ္ပါ)

Part C: Effectiveness of SGMB

အပိုင္း(ဂ) ကၽြေပါင္းစံုပါဝင္သည့္ (ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္) လုပ္ငန္းရွင္အဖြဲ႕ နမူနာပံုစံ တည္ေဆာက္ျခင္း၏ အက်ိဳးသက္ေရာက္မွဳ

Q.29) The model that we developed together accurately represents the complex and dynamic processes in the pork/paddy value chain:

ေမးခြန္း-၂၉) မိမိတုိ႔ အတူတကြ ေရးဆြဲခဲ့သည့္ ဤ (ကၽြေပါင္းစံု လုပ္ငန္းရွင္မ်ား ပါဝင္သည့္ ေတြ႕ဆံုေဆြးေႏြးပြဲ) ပံုစံမ်ိဳးသည္ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္လုပ္ငန္းအတြင္း ရွိပ္ေထြးၿပီး အခ်ိန္ႏွင့္အမွ် ေျပာင္းလဲျခင္း ျဖစ္စဥ္မ်ားကို အတိအက် (ကိုယ္စားျပဳ) ေဖာ္ျပေပးသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါရန္။

Strongly agree (အလြန္ မွန္ပါသည္)	Agree (မွန္ပါသည္)	Neutral (ၾကားေန)	Disagree (မဟုတ္ပါ)	Strongly disagree (လံုးဝ မဟုတ္ပါ)

Q.30) What is the most important outcome for you from participating in these workshops?

ေမးခြန္း-၃၀) ဤေဆြးေႏြးပြဲမ်ားတြင္ ပါဝင္ေဆြးေႏြးျခင္းမ်ားမွ သင့္အတြက္ အေရးအၾကီးဆံုး (အေကာင္းဆံုး) အက်ိဳးရလဒ္ (ဘာလဲ) ဘယ္အရာျဖစ္သလဲ။

Please write your response:
ေက်းဇူးျပဳၿပီး သင္၏အေျဖကို ခ်ေရးေပးပါ။

Q.31) The model helps me understand how I can make more income from the value chain:

ေမးခြန္း-၃၁) ဤ (ကၽြေပါင္းစံု လုပ္ငန္းရွင္မ်ား ပါဝင္သည့္ ေတြ႕ဆံုေဆြးေႏြးပြဲ) ပံုစံမ်ိဳးသည္ ဆန္စပါးစိုက္ပ်ိဳးေရး ထုတ္ကုန္ကြင္းဆက္မွ ကြၽ်ႏုပ္ ဘယ္လို ဝင္ေငြပိုရေအာင္ လုပ္ႏိုင္သလဲဆိုတာကို သိရွိနားလည္ေအာင္ ကူညီေပးပါသည္။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါရန္။

Strongly agree (အလြန္ မွန္ပါသည္)	Agree (မွန္ပါသည္)	Neutral (ၾကားေန)	Disagree (မဟုတ္ပါ)	Strongly disagree (လံုးဝ မဟုတ္ပါ)

Q.32) Following my participation in the workshops, I have used what I have learnt to improve my business:

ေမးခြန္း-၃၂) ေတြ႕ဆံုေဆြးေႏြးပြဲမ်ားတြင္ ကြၽ်ႏုပ္ပါဝင္တက္ေရာက္ၿပီးေနာက္ ကြၽ်ႏုပ္ေလ့လာထားေသာအရာမ်ားကို ကြၽ်ႏုပ္၏ လုပ္ငန္း တိုးတက္ ေကာင္းမြန္ဖို႔အတြက္ အသံုးခ်ၿပီးပါၿပီ။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါရန္။

Strongly agree (အလြန္ မွန္ပါသည္)	Agree (မွန္ပါသည္)	Neutral (ၾကားေန)	Disagree (မဟုတ္ပါ)	Strongly disagree (လံုးဝ မဟုတ္ပါ)

Q.33) I have shared with many of my friends / family / business partners what I have learnt from the workshops:

ေမးခြန္း-၃၃) ေတြ႕ဆံုေဆြးေႏြးပြဲမ်ားမွ ကြၽ်ႏုပ္ေလ့လာထားေသာအရာမ်ားကို ကြၽ်ႏုပ္၏ သူငယ္ခ်င္းမိတ္ေဆြမ်ား (သို႔မဟုတ္) ကြၽ်ႏုပ္၏ မိသားစု (သို႔မဟုတ္) ကြၽ်ႏုပ္၏ လုပ္ငန္း လက္တြဲေဖာ္မ်ား အေတာ္မ်ားမ်ားအား ျပန္လည္ ေဝငွ ၿပီးပါၿပီ။

Please tick your response: ေက်းဇူးျပဳ၍ သင္၏အေျဖကို (ေရြးၿပီး) အမွန္ျခစ္ေပးပါရန္။

Strongly agree (အလြန္ မွန္ပါသည္)	Agree (မွန္ပါသည္)	Neutral (ၾကားေန)	Disagree (မဟုတ္ပါ)	Strongly disagree (လံုးဝ မဟုတ္ပါ)

Table H2: Results from pre-spatial group model building questionnaire

Question	*M*	*N*	*S.E*
1. I know all the key people in the VC.	4.07	28	.114
3. There are opportunities to increase my income from paddy/pork.	4.07	28	.114
4. I understand how different people in the VC add value to the product.	3.82	28	.137
5. I understand the differences in profit people in the VC make from the value they add to the product.	3.96	28	.096
6. I understand all the types of relationships (friend, contract, cash-buyer, etc.) between the different actors in the VC.	3.71	28	.161
7. I understand that men and women have different roles in the VC.	4.00	28	.136
9. I know the quality characteristics of products that earn a higher price.	4.14	28	.143
10. I know the volume of products that earn a higher price.	3.93	28	.154
11. I know at what times of year the prices for products are higher.	4.00	28	.154
12. I know what type of products are demanded by consumers.	4.11	28	.119
13. I have a good understanding of the potential markets for my products.	3.82	28	.090
14. I have a good understanding of how the VC effects (positive and negative) the livelihoods of poorer communities.	4.07	28	.050
15. The VC does little harm to the natural environment.	3.29	28	.198
16. I understand how I can improve my products to earn extra income.	3.89	28	.079
17. I am interested in using new practices in my business.	4.39	28	.094
18. Making improvements to my paddy/pork business is beyond my ability.	3.68	28	.193
19. I have a good understanding of the key challenges to earning more income from the VC.	4.11	28	.079
21. My suppliers/buyers always provide me with the information I require for my business.	3.75	28	.175
22. All members of the VC are always fair and honest in their negotiations with me.	3.61	28	.139
23. There are specific members of the VC which are always fair and honest in their negotiations with me.	3.89	28	.079
24. Members of the VC may use opportunities to hurt me financially.	3.32	28	.171
25. I only trust specific members of the VC to give me a fair price for my goods or services.	3.79	28	.173
26. There are more benefits for me when I work closely with all members of the VC.	4.14	28	.160
27. There are more benefits for me when I work closely with specific members of the VC.	3.96	28	.131
28. I can depend upon my relationships with specific VC members when I have a problem with my business.	4.07	28	.102

Note: M refers to the Mean, N refers to the Number of responses, and S.E refers to the Standard Error.
Source: Participant SGMB questionnaires

Table H3: Results from post-spatial group model building questionnaire

Question	*M*	*N*	*S.E*
1. I know all the key people in the VC.	3.62	16	.221
3. There are opportunities to increase my income from paddy/pork.	4.13	16	.085
4. I understand how different people in the VC add value to the product.	4.00	16	.129
5. I understand the differences in profit people in the VC make from the value they add to the product.	4.00	16	.158
6. I understand all the types of relationships (friend, contract, cash-buyer, etc.) between the different actors in the VC.	2.81	16	.228
7. I understand that men and women have different roles in the VC.	4.07	15	.067
9. I know the quality characteristics of products that earn a higher price.	4.13	16	.085
10. I know the volume of products that earn a higher price.	3.50	16	.204
11. I know at what times of year the prices for products are higher.	4.00	16	.158
12. I know what type of products are demanded by consumers.	3.81	16	.164
13. I have a good understanding of the potential markets for my products.	3.44	16	.241
14. I have a good understanding of how the VC effects (positive and negative) the livelihoods of poorer communities.	4.00	16	.129
15. The VC does little harm to the natural environment.	3.31	16	.313
16. I understand how I can improve my products to earn extra income.	4.31	16	.120
17. I am interested in using new practices in my business.	4.50	16	.129
18. Making improvements to my paddy/pork business is beyond my ability.	2.94	16	.249
19. I have a good understanding of the key challenges to earning more income from the VC.	3.94	16	.143
21. My suppliers/buyers always provide me with the information I require for my business.	3.87	15	.165
22. All members of the VC are always fair and honest in their negotiations with me.	3.47	15	.215
23. There are specific members of the VC which are always fair and honest in their negotiations with me.	3.67	15	.126
24. Members of the VC may use opportunities to hurt me financially.	2.67	15	.252
25. I only trust specific members of the VC to give me a fair price for my goods or services.	3.87	15	.165
26. There are more benefits for me when I work closely with all members of the VC.	4.20	15	.107
27. There are more benefits for me when I work closely with specific members of the VC.	3.93	15	.118
28. I can depend upon my relationships with specific VC members when I have a problem with my business.	3.67	15	.159
29. The model that we developed together accurately represents the complex and dynamic processes in the value chain.	4.00	15	.138
31. The model helps me understand how I can make more income from the value chain.	4.13	15	.091
32. Following my participation in the workshops, I have used what I have learnt to improve my business.	3.53	15	.215
33. I have shared with many of my friends/family/business partners what I have learnt from the workshops.	3.67	15	.211

Note: M refers to the Mean, N refers to the Number of responses, and S.E refers to the Standard Error.
Source: Participant SGMB questionnaires