Potential Impacts of Biopharming on New Zealand: Results from the Lincoln Trade and Environment Model

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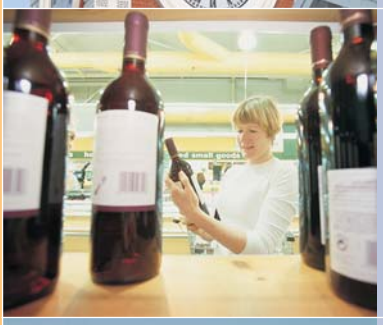

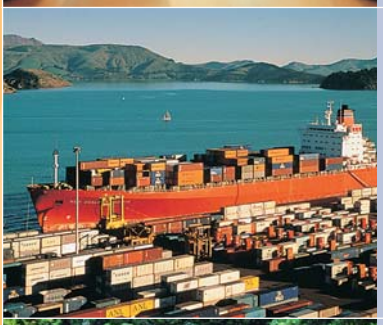

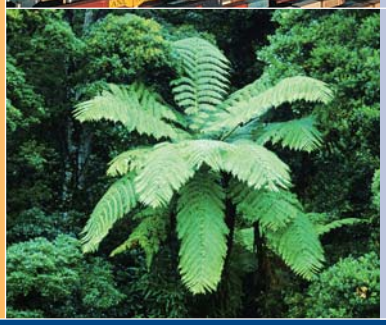

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Preface

This report continues two important research programmes at the AERU. The first programme focuses on the social and economic impacts of new technologies, particularly as they affect food and agriculture. Technologies assessed in prior AERU research include genetic modification, biopharming, various other biotechnologies, and nanotechnology. The second research programme uses a model of international trade in agricultural commodities to evaluate potential economic impacts on New Zealand and other countries. These impacts may result from technological changes and/or policy initiatives. The research reported here quantifies the potential impacts on New Zealand agriculture of adopting a new technology, using the trade model. The results are relevant from both policy and agricultural perspectives.

Professor Caroline Saunders
Director
AERU

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We would like to acknowledge contributions to this research by a number of people. The report is the result of research conducted for the *Constructive Conversations* project, funded by the Foundation for Research, Science and Technology (FRST No. UOCX0221). Joanna Goven leads the project, and has been very helpful in providing ideas and resources for the research reported herein. Research assistance has been provided by Louise Ferguson. Finally, Teresa Cunningham, Deborah O'Connor and Eileen Seymour have provided excellent administrative support for the Lincoln University part of the research project.

The contributions of these people notwithstanding, the final responsibility for the report lies with the authors.

Executive Summary

Biopharming is an agricultural technology on the cusp of commercialisation. The technology uses genetically modified crop plants and animals to produce pharmaceuticals. Biopharm crops are now grown in the United States and Europe, and biopharm animals are being raised in New Zealand and elsewhere. The Agribusiness and Economics Research Unit (AERU) conducted research on the industry in 2006 and 2007 (Kaye-Blake, Saunders, & Ferguson, 2007), finding that 'the necessary information to develop a robust economic analysis of these products is lacking. Much of the information on the relevant dimensions is simply unknown.'

This report builds on the prior AERU study. First, it presents an update on the biopharming industry and the economics literature on it. Secondly, it presents economic modelling to estimate the potential impacts of biopharming in New Zealand. This analysis uses the Lincoln Trade and Environment Model (LTEM) to simulate different market impacts from biopharming and estimate the net economic impacts. Finally, the ramifications of these estimates for biopharming in New Zealand are discussed.

The literature on biopharming has not developed appreciably in the last year or two. There are still a number of unknowns, and its profitability and potential impacts on the wider agricultural sector depend on the pharmaceutical, crop, and region being studied. Consumer reactions appear to be a significant factor. Consumer perceptions of biopharming and the food system are presented in the literature in essentially three ways. One model of perceptions is ecological: it considers the biopharm organism in an agro-ecological environment. A second model is genetic, and focuses on the potential for modified genes to escape the biopharm crop or animal and enter the genome of other organisms. The third model considers how food is produced and the potential for mixing biopharm material with food crops and ingredients in the food industry.

A model of international trade in agricultural commodities – the LTEM – was used to analyse the impact of changes in agricultural markets due to the introduction of biopharming into the dairy sector in New Zealand. The results provided information about the relative sizes of potential economic impacts given different future changes in the markets. Biopharming could have either positive, neutral, or negative impacts on the demand for New Zealand dairy products. In addition, it may be pursued without any impact on the cost structure of the wider dairy sector, but it could impose segregation or similar costs on non-biopharm producers.

A set of scenarios was developed based on these possibilities and modelled. The scenarios included some with no production impact and others with five per cent and 10 per cent increases in production costs. Consumer reactions were modelled with scenarios that included either no change in demand; a 10 per cent increase in demand; or a 10, 20, or 50 per cent reduction in demand. The production and consumption changes were combined into a total of 15 scenarios, including the base scenario.

The modelling results indicated that biopharming could affect agriculture either positively or negatively. The main factor in determine the size and direction of the effect was the change in demand. If demand for dairy products increases (because the products are of higher value and farmers are paid a premium), then the net impact is likely to be positive. If consumers become wary of New Zealand dairy products, then the result is likely to be negative. Of less importance is the imposition of greater costs on the sector for segregation, which created reductions of less than two per cent in agricultural revenues.

The results from the trade modelling provide a baseline for a cost-benefit analysis biopharming. If biopharming results in higher agricultural revenues, then the total economic impact is likely to be positive. If, on the other hand, biopharming causes losses in the agricultural sector, these losses would need to be offset by earnings from the biotechnology or pharmaceutical industries. The modelling results put these potentially lost revenues at between $133 and $3,352 million annually in current dollars.

Chapter 1
Introduction

Biopharming is one of two current technological trajectories in agricultural that could have significant impacts on farming systems, the other being biofuel production. Biopharming, in which pharmaceutical compounds are produced in plant and animal tissue in agricultural systems, is being pursued by several different companies using a variety of production systems. Biopharm crops are already being grown in the open in the United States and Europe, and biopharm animals are already being raised in New Zealand and elsewhere.

Companies and scientists developing this technology are optimistic about its potential, both for improving human health and for producing economic returns. As a distinct, developing technology, however, its economics have been little studied in the academic literature. Only a handful of economic studies exploring the complex impacts of biopharming on the pharmaceutical and agricultural sectors appears in the peer-reviewed literature (e.g., DiMasi, 2007; Elbehri, 2005; Kostandini, Mills, & Norton, 2006), and a few more studies are also available (e.g., GianCarlo, 2006; Wisner, 2005). The Agribusiness and Economics Research Unit (AERU) conducted an extensive literature review and survey of the industry in 2006 and 2007, and amassed a list of extant examples of biopharmed products (Kaye-Blake et al., 2007). The results of that study bear citing here:

> The main result from this examination is that the necessary information to develop a robust economic analysis of these products is lacking. Much of the information on the relevant dimensions is simply unknown. A second result from this work is that the potential value of these products varies tremendously, depending on the overall size of the potential market, control of technology or proprietary information, and other factors. A third concern is adverse reactions in overseas markets. The future impact of consumer concerns is uncertain and contested. (p. 37)

The present research builds on the prior AERU study. First, it presents an update on the biopharming industry and the economics literature on it. Secondly, it presents economic modelling to estimate the potential impacts of biopharming in New Zealand. This analysis used the Lincoln Trade and Environment Model to simulate different market impacts from biopharming and estimated the net economic impacts. Finally, the ramifications of these estimates for biopharming in New Zealand are discussed.

Chapter 2
Update on Biopharming

The AERU published an earlier report (Kaye-Blake et al., 2007) that examined the state of the biopharming industry, the products and companies involved, and economic studies that had been conducted. That report also discussed the nature of New Zealand agriculture and established a framework for considering the potential impacts of biopharming on the country. For a full discussion of the industry and relevant economic issues, the reader is directed to that report.

The present chapter summarises and updates that research. The next section briefly summarises the earlier report to provide context. There then follows an update on the economic research into biopharming. The final section provides empirical motivation for the modelling scenarios analysed in this research.

2.1 Summary of prior study

Biopharming is still in a research stage; it is not a developed industry with commercial products and commercial revenue. Available valuations of products and companies or estimates of economic benefits are not based on market transaction for final products. Instead, those valuations are based on projections of the future market value to be realised from present research.

Economic information on the biopharming industry is difficult to find, and comes largely from two sources: the non-academic press and economic information contained in non-economic publications. Biopharming is one area of a larger industry focused on producing biological compounds of pharmaceutical interest. Biopharming uses genetically modified plants or livestock to produce these compounds, which are then extracted and purified. One such product seemed to be commercially available. These same compounds may also be produced using other non-biopharming technology, such as cell culture, and those compounds are in total worth between US$40 and US$60 billion per year.

One way to assess biopharming is to consider how it differs from other possible ways of producing similar compounds. Prior research has found that biopharming is an improvement on prior technologies in some ways, but also may not perform as well in others. Some of these differences are physical, such as differences in protein yield and structure. Aspects that could significantly affect the economics of biopharming can be divided into supply and demand impacts. On the supply side, interest in biopharming appears to be driven largely by production costs. Costs comparisons ran the gamut, from biopharmed compounds costing one-fiftieth the cost of current methods (Kusnadi, Nikolov, & Howard, 1997) to offering no cost savings at all (Wisner, 2005). On the demand side, there is a public perception that biopharming entails greater risks than current production methods.

A model was developed to estimate the economic potential of biopharming. The model treated each compound as a bundle of characteristics, and related the cost of producing a compound to the costs of the discrete characteristics. More precisely, the difference in cost between a conventional biologic and a biopharmed biologic is a function of the value of the changes in all the characteristics. This model was applied to two products: recombinant human lactoferrin (rhLF) and low-GI (glycaemic index) potatoes. For both products, there was insufficient information to apply the model fully. For the rhLF, it appeared difficult to

earn more than an economically normal profit. There seemed to be several close substitute products and competing technologies, so little opportunity to create a dominant position in the market and earn oligopoly or monopoly profits. Low-GI potatoes, on the other hand, could have clear consumer appeal in the functional foods market, which is a multibillion dollar and expanding market segment (Sloan, 2006). As a functional food, it would have lower regulatory hurdles than a biopharmaceutical. Furthermore, potatoes are a commonly consumed food, and the total market is again a multibillion dollar market.

2.2 Research update

Mewett et al. (2007) reviewed the current state of development of biopharming. They found that 'only a small number of plant-made research and analytical-grade proteins hav[e] reached the commercialisation stage of the product development pipeline' (p. 17). They specified six products – three proteins, two enzymes, and one gene – produced through plant biopharming that have reached commercial production in the US. Of the four companies named as involved in commercialising these compounds, two are in voluntary receivership. As a result, two of the six products may no longer be available. Examining the Australian situation, they found a number of plant-made pharmaceuticals under development but did not describe any in commercial production.

One of the ongoing issues in biopharming is the organism that is used as the platform or bioreactor. Many different species of plants and animals have been used to produce pharmaceutical compounds, at least in research situations. However, one species has been used overwhelmingly for field trials of plants producing pharmaceutical or industrial proteins – maize (Marvier, 2007). Ramessar et al. (2008) examined the case for using maize, and concluded that several characteristics made it the best choice for biopharming. Amongst other traits, the seed is easy to handle and high in protein (so it concentrates the pharmaceutical protein), the plant grows well because of its C4 pathway (most grains use a C3 pathway (Pollan, 2006)), maize is widely consumed and not allergenic, and research has proven it effective for delivering oral vaccines to pigs (Ramessar et al., 2008). On the other hand, a number of researchers have expressed concern with using food crops as bioreactors (e.g., Marvier, 2007; Spok, 2006). They argue that using non-food crops would reduce the risk that biopharm material might enter the food supply.

The focus on maize could be a function of the geographic distribution of biopharming research: maize was by far the most commonly used platform in the US, but safflower and tobacco were the most common crops in Canadian field trials, and maize was second to tobacco in field trials in Europe (Bauer, 2006). Mewett at al. (2007) found that Australian research to commercialise plant-made pharmaceuticals had looked at tobacco, sugarcane, and tomatoes as possible bioreactors. New Zealand research has used animals, such as dairy cattle, as bioreactors (Laible & Wells, 2007). In this vein, animal cloning has been advocated as a way to develop high-value herds of genetically consistent animals (Laible & Wells, 2007).

The economic viability of biopharming generally is still uncertain. Researchers assert that '[p]lants offer …an inexpensive way to produce pharmaceutical proteins' (Ramessar et al., 2008, p. 410), for example, monoclonal antibodies to treat viral diseases (Marasco & Sui, 2007, p. 1432)[1]. There are differences between existing commercial methods for producing

[1] The assertions of Ramessar et al. (2008) and Marasco & Sui (2007) follow many others in describing the economic efficiency of biopharming (see Kaye-Blake et al., 2007). However, Spok (2006) suggested, 'Until

pharmaceutical proteins and biopharming methods (Ramessar et al., 2008), but the economic impacts of those differences have yet to be fully assessed. For the specific case of vaccines delivered through biopharm food, the commercial viability has also not been established (Mewett et al., 2007). For example, growing sufficient quantities of biopharmaceutical crops may be relatively inexpensive, but processing the raw agricultural product to recover the pharmaceutical would account for 80 per cent or more of the costs of production (Ramessar et al., 2008). Current commercial methods of producing biologics face similar issues: growing yeast and bacteria is relatively cheap, but processing according to Good Manufacturing Practice is expensive (Mewett et al., 2007). An additional consideration is that some applications of pharmaceutical proteins, regardless of how they are produced, have encountered challenges in the clinic and in the marketplace (Marasco & Sui, 2007).

The scale of required biopharming production will likely be small. One estimate found that 15,000 acres of safflower would meet worldwide insulin demand in 2012 (Ramessar et al., 2008). Another example considered the production of the human protein vitronectin in GM tobacco: global needs could be met with the production from one glasshouse (Mewett et al., 2007). If animals are used as bioreactors, again the scale is likely to be small, at least initially (Laible & Wells, 2007). This small scale is not surprising, given the overall size of the market for therapeutic proteins, of which biopharming is only one part. Murphy (2007) cited 2004 research valuing the entire market for such proteins at $20 billion (presumably US dollars), with a growth rate of 15 per cent. The 2010 value for the market would thus be approaching $50 billion, although Murphy (2007) cited additional research forecasting the 2010 market value at $140 billion.

The crops used to produce biopharmaceuticals are created using genetic modification and are therefore genetically modified organisms (GMOs). One of the issues surrounding GMOs in agriculture is co-existence, the possibility and difficulties of growing crops for different uses and markets (Fontes, 2007; Miranowski et al., 1999). Earlier research focused on the possibility that GMOs could 'contaminate' organic agriculture (which does not permit the use of GMOs), and concluded that strict segregation was impossible (Fontes, 2007). Instead, thresholds of permissible presence of GM material were advocated (Spok, 2006). By contrast, the development of biopharming appears to have led to calls for stricter segregation (Spok, 2006). The potential health impacts should pharmaceutical crops enter the food supply is one clear concern (Fontes, 2007; Mewett et al., 2007). In addition, concern about protecting the purity of high-value biopharm crops may mean that segregation will also focus on keeping the food crops out of biopharm production (Mewett et al., 2007; Spok, 2006). Researchers believe that biopharm crops can be segregated and contained (Mewett et al., 2007; Murphy, 2007), and point to the current success with segregating food-grade and industrial rapeseed, suggesting that this experience can be transferred to biopharming (Ramessar et al., 2008). The issue of co-existence is particularly acute in 'centres of origin', the geographical areas where particular crop species originate, which still contain genetic diversity for the species and its close relatives (Fontes, 2007).

Where researchers advocate solutions to the issues facing biopharming, they often suggest that greater international cooperation and harmonisation of regulations would be helpful. For example, on the issue of co-existence, Fontes (2007) states, 'It is important that all agricultural sectors – GM, non-GM and organic alike – embrace the concept of coexistence and work together to accommodate each other' (p. 4). Lack of harmonisation would increase the complexity of international trade in food and feed, as exporters worked to meet different standards in different countries (Spok, 2006).

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recently, potential savings in production costs were strongly emphasized, with industry, in the mean time, becoming less optimistic' (p. 75). Spok focused instead on other potential benefits.

The framework for assessing the potentials and risks of biopharming has also received attention. Three main approaches have been discussed (Marvier, 2007). The *precautionary approach* focuses on the risk, so that biopharming would not be allowed to proceed until the producer demonstrated the safety of the production method. A *risk-assessment framework* assesses both the probability of a risk and the magnitude of its potential impact. It attempts to identify the specific impacts and the pathways that could lead to those impacts, and then quantify the probabilities. It also takes the seriousness of the risk into account. Finally, a *cost-benefit analysis* assesses the potential rewards from biopharming and evaluates them against the costs. Such an analysis could include equity considerations, and might also examine the relative costs and benefits of alternative methods of producing the same health outcomes.

2.3 Potential impacts

Biopharming relies in part on natural production systems operating in the open. It is therefore competing for some of the same resources as agriculture and tourism. The agricultural sector depends on the biological resources to produce not only food and fibre for the domestic population but also for a large percentage of the country's exports. Together, agriculture, forestry, and their associated sectors contributed 18 per cent of the country's GDP in 2002/03 (Ministry of Agriculture and Forestry, 2005). In addition, agricultural and silviculture exports accounted for over 60 per cent of merchandise exports (Ministry of Agriculture and Forestry, 2005). International tourism also depends on the country's natural resources, its biology and landscape, benefiting from New Zealand's image as a clean and green destination. Tourism also adds significantly to the country's export earnings. The Tourism Satellite Account (Statistics New Zealand, 2006), which calculates the contribution of tourism to the New Zealand economy, shows a total tourism expenditure of $17.5 billion for the year ending March 2005, contributing nine per cent of gross domestic product. Of this amount, 46 per cent was contributed by international tourists, so that tourism is New Zealand's largest export earner.

The present research focuses in particular on the interactions between biopharming and the rest of agriculture. The potential impacts can be divided into those that affect the supply or production side of the market, and those that affect demand or consumption. The supply side impacts have the potential to affect both pharmaceutical production and the agricultural production of food and fibre. For pharmaceutical production, the cost savings may allow pharmaceutical companies to supply more product, charge lower prices, or do both. Biopharming may also allow pharmaceutical companies to produce new compounds or improve the safety of biologic compounds. However, the main thrust of biopharming in the present and near future is producing currently available compounds at lower cost (Kaye-Blake et al., 2007). The supply side impacts on agriculture are less clear. Biopharming will take resources from other agriculture – land, water, labour, capital, etc. This direct effect is likely to be small because only a small fraction of total arable acreage will be required. Biopharm crops also represent a potential high-value crop for farmers. The value of the crops will depend on several factors, including the market value of the biologic compound, its concentration in the crop, and the costs of extraction. Farmers are likely to be paid a premium to grow biopharm crops, increasing the returns to agriculture. The ultimate size of these premiums will depend on the competition for resources – including farmers' skill – and relative market power. Given the imperfectly competitive structure of the pharmaceutical industry, market power is more likely to favour the pharmaceutical firms than individual farmers. In addition, while premiums may improve the economic performance of specific farms or even specific regions, the size of biopharming relative to the rest of agriculture would dilute the contribution of these premiums to agriculture as a whole.

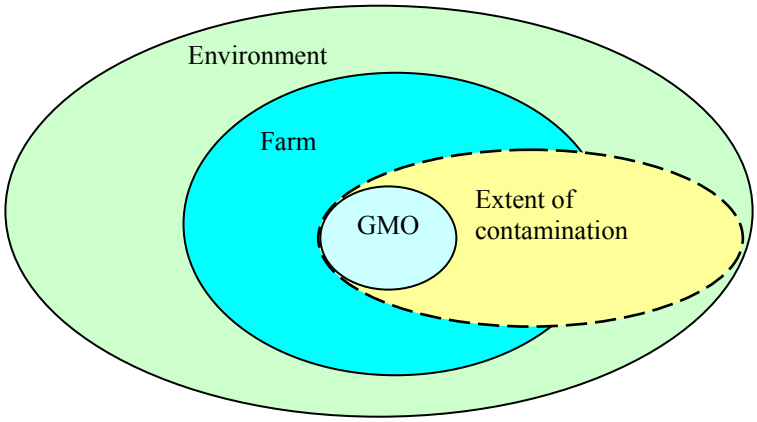
The demand effects of biopharming are also complex and uncertain. On the demand side, it is important to consider the effect that a biopharm crop could have on its conventional counterpart, especially if they are grown in the same region. California farmers, for example, opposed an application by Ventria Bioscience to grow biopharm rice modified with synthetic human genes (Marvier, 2007). They were concerned that any amount of contamination of food rice would pose problems for their customers. Nor are the farmers' concerns unfounded: contamination of the US rice crop with an unapproved GM variety cost the rice growers around $150 million in lost exports to the EU (Marvier, 2007).

A biopharm crop is a hybrid product, with both agricultural and pharmaceutical aspects. There will be demand-side effects for both aspects. For the pharmaceutical compound, the extent to which it is better than existing products will affect demand. The product may have close substitutes, such as similar biologic compounds produced with a different production technique. The economic benefits of biopharming would thus need to be assessed on a case-by-case basis, as they depend on the specific compound. For the agricultural aspect of a crop, the economic impact will depend in large part on consumers' reactions. If consumers perceive that the potential for biopharming to 'contaminate' food crops is high, then the biopharm crop may have significant negative impacts on the wider agricultural sector. Furthermore, if adventitious presence does arise, such that the biopharm crop does appear in the food supply, the demand impacts are likely to depend on consumer perceptions, regulatory behaviour, and private sector management of the incident (Slovic, 2000).

It seems logical to look to the literature on GM food to find indications of how consumers might react to GM biopharm crops. Much of the literature on GMOs has considered consumer reactions, drivers of consumer attitudes, heterogeneity across and within countries, information impacts, economic impacts of demand shifts, and whether consumers are right in their assessments. What appears to have received less attention is how consumers assess the potential for 'contamination' to spread from a GM crop to a non-GM one. The way that consumers understand or make sense of contamination may be important, because it may affect how consumers view potential biopharm contamination and the likelihood of it happening.

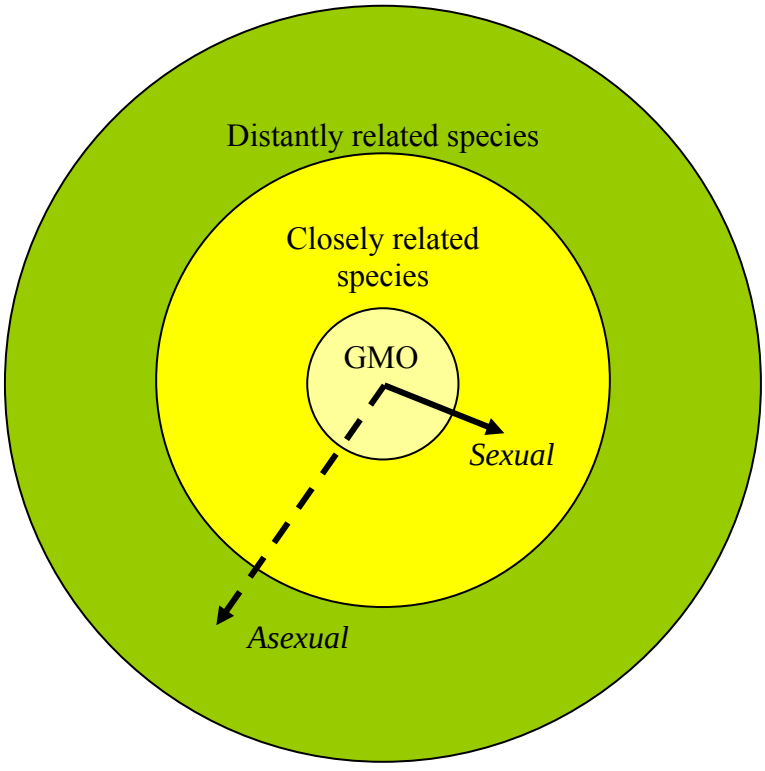
In the literature on GM food and biopharming, three different models appear to underlie how interactions between GMOs and the food system are presented. They are not mutually exclusive, but different models are emphasised in different discussions of the impacts of GMOs. One model is ecological: it considers the GMO as an organism in an agro-ecological environment. This model is shown in Figure 1. The GMO can contaminate the farm's own ecology as well as the surrounding environment, and the contamination is the result of changing or disrupting natural processes. For example, participants in focus groups in Canada were concerned about the possibility of biopharm products entering the food chain through pollen movements or because of wind, insects, or animals (Einsiedel & Medlock, 2005). The extent of the impact can be described by an oval that takes in some part of the farm and, potentially, some surrounding environment.

Figure 1: Ecological model of GMO impacts



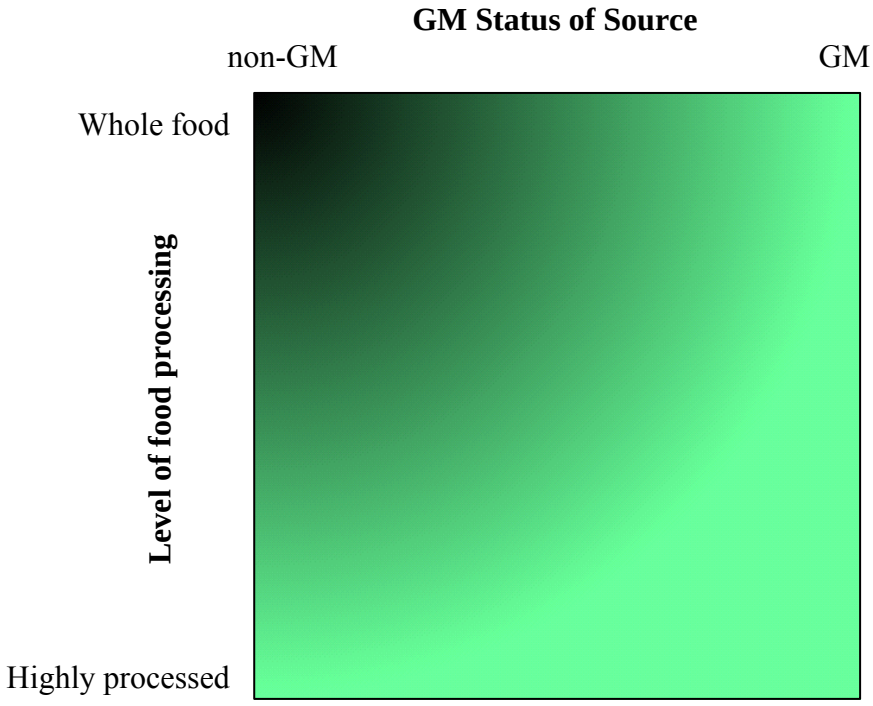
A second mental model is genetic, and focuses on the potential for modified genes to escape the GMO and enter the genome of other organisms. As shown in Figure 2, there are two components to this model. The first component is based on systematic biology, and considers the possibility for transmission of modified genes through sexual reproduction (Fontes, 2007; Mewett et al., 2007). A GMO could cross-breed with a closely related species and the progeny could contain modified genes. This is the basis for concern over the movement of herbicide resistance genes from GM canola to wild mustard, a closely related weed species (Black, 2004). The second component of the genetic model focuses on the potential for genes to escape the GMO through non-sexual means, such as horizontal gene transfer (HGT) (Syvanen, 1994). Research with transgenic plants suggests that HGT happens rarely (Droge, Puhler, & Selbitschka, 1998), but the risk may still be salient for consumers (Wu, 2004). The central question with regard to this model is thus the length of the vector from the GMO into the world of closely and distantly related species, with one vector for each of the two components.

Figure 2: Genetic model of GMO impacts



The third mental model that also arises in discussions of consumer reactions to GMOs, captured in Figure 3, is based on how food is produced (Marvier, 2007; Mewett et al., 2007). The GMO is the source of the modified genetic material, which the consumer experiences not through the organism (as in the environmental model) or its genes (as in the genetic model) but through food products. One important dimension is the extent to which the product is processed. Each extra ingredient adds a possibility of including GM ingredients, and each industrial food ingredient (e.g., high fructose corn syrup) adds to the probability of food ingredients being derived from GM crops, such as soyabeans and maize. Increased processing also increases the possibility of adventitious presence, either of ingredients that were not supposed to be GM, or of unintended ingredients (as when packaging indicates that the product 'may contain nuts'). A second dimension concerns the source of the food. Some sources may be assumed to be GM-free. For example, crops grown in New Zealand are supposed to be free of GMOs (Scandurra, 2007). Other sources are relatively certain to contain GMOs, such as soybeans grown in the US (James, 2005). Both dimensions have gradients from 'certain to be non-GM' to 'definitely contains GMOs'. The gradients are indicated in Figure 3 by shading. The lighter the shading, the more likely a food product is to contain GM material.

Figure 3: Production model of GM status of food



One further aspect of consumer thought that these models do not explicitly capture is the difference between what should happen and what does happen. The difference between the two has shown up in the StarLink incident (Lin, Price, & Allen, 2001-2002), the contamination of US rice with an unapproved variety, and problems with ProdiGene's biopharming activities (Ramessar et al., 2008). Einsiedel & Medlock (2005) found that people made judgements about the safety of biopharming based in part on the idea that

regulators did not have the skill or resources to enforce full compliance with regulations. One view is, as Marvier (2007) notes after reviewing several examples of adventitious presence of GM crops, 'Human error occurs and, frankly, is unavoidable' (p. 61). These concerns around non-compliance and error create uncertainty in all these models, and individuals' assessments of that uncertainty will affect their overall judgement of biopharming.

It should be emphasised that the three figures above are pictorial representations of mental constructs that underlie discussion of the impacts of GMOs on food and agriculture. They do not purport to be complete or mutually exclusive. Genetic and biological impacts of GM crops are occurring simultaneously on farms, and the crops become ingredients that are combined into food products for retail sale. The figures also do not purport to be exact. The sizes and lengths of different components may not exactly conform to the known or perceived impacts of GMOs. However, these mental models – ecological, genetic, and production – are a useful starting point for a discussion of potential impacts of biopharming on consumer perceptions of New Zealand agriculture.

If New Zealand permits biopharming, the consumer impact will depend on the mental models that consumers use to evaluate this development and how the activity responds to any concerns raised. The ecological model will consider the potential impacts on the farm and surrounding ecosystems. The essential question is the size of the dotted oval in Figure 1 and the ability of the biopharming industry to keep the oval as small as possible. That is, measures will be taken to limit the spread of pollen, keep waste products from moving into the wider environment, and demonstrate the safety of the crop for organisms such as butterflies. These measures may convince consumers that the impact oval is really quite small. On the other, some consumers may perceive that the behaviour of an organism – GM or not – in an environment is resistant to control, so that the impact oval remains relatively constant despite the industry's efforts. For these consumers, organisms will always escape control, in a sort of ecological second law of thermodynamics (systems tend towards entropy).

The genetic model provides a different view of the possible spread of biopharm GMOs, this time at the level of the genetic material. Consumers may perceive that the main impact would be through the cross-breeding of biopharm crops with other species, either domestic or wild. In this case, the concern can be allayed by using biopharm crops that do not have sexually compatible relatives in the surrounding environment (Fontes, 2007; Marvier, 2007; Mewett et al., 2007). Perceptions regarding the other method of spread of biopharm genetic material, asexual transfer, may be more difficult to address. If consumers perceive that genetic material can move about in the environment in largely unregulated ways, then any attempt to predict or control these movements would be at best difficult and at worst wishful thinking. This impact is again a sort of entropy, with genetic material always seeking to escape its containment within a specific organism.

The production model is based around uncertainty and probability. Consumers using this sort of mental model are not evaluating a specific crop or its ecosystem, but rather are considering the possibility that GM ingredients could end up in food and whether they would be able to tell. There are two consequences of this model. First, the intentions of biopharm producers do not enter into the assessment. Whether or not the GM material ends up in food is a function of the food system, not the behaviours or intentions of individual producers. The only way to avoid GM food is to buy whole foods from perceived GM-free sources (such as organic farms or countries that do not grow GM crops). Secondly, New Zealand's status along the horizontal axis may be broad-brush and resistant to change. This stickiness is evident in the country's 'clean and green' image. Studies have suggested that New Zealand's agriculture is

not as environmentally friendly as its image suggests, but yet the image persists (Parliamentary Commission for the Environment, 2004). This is akin to the experimentally observed failure in mental processing, failure to update base probabilities. That is, consumers expect New Zealand to be clean and green, and that rule of thumb is stronger than any new information. The rule-of-thumb decisions can cut both ways, however. If a biopharm crop is grown in New Zealand, the country as a whole could become 'one of the GM countries'. Its position along the horizontal axis of Figure 3 would move farther to the right, with a corresponding increase in a perception that New Zealand food is GM food.

The overall impact of a release of a biopharm crop in New Zealand will depend on the mental models that consumers are using to evaluate the release. Both the environmental and genetic models include the possibilities that producers can keep GM material out of the food supply. They also both include the possibility that GM material will escape confinement or control and become part of the wider environment. Given this aspect of both models, it is interesting that the issue of biopharming is actively being framed as one of a technical 'containment or confinement problem' (Spok, 2006, p. 76). That is, the activities of the regulators and industry experts may be in conflict with the mental models that the public are using to make sense of biopharming. Finally, the production model suggests that the overall image of New Zealand is important, but in addition that perceptions that food products are GM can be overcome by focusing on whole foods whose GM status consumers can more clearly evaluate.

As a result of this assessment of potential consumer reactions to the introduction of biopharming, the present research considered the possibility that consumers could have either narrow or wide views of the potential impacts. In the narrow view, biopharming is well monitored and controlled, and biopharm crops are effectively segregated from food. In the wide view, biopharm crops are potentially in the food system, so consumers are less willing to buy New Zealand products. The modelling reported in the next chapter thus included scenarios in which consumers are not concerned as well as scenarios with different levels of consumer concern.

Chapter 3
Method for Analysing Impacts

3.1 Introduction

A model of international trade in agricultural commodities was used to analyse the impact of changes in agricultural markets due to the introduction of biopharming into New Zealand. Economic modelling allows researchers to do three things. First, it provides estimates of the economic effects of specific changes to international agricultural market, which measures the absolute impacts of policies and technological developments. Secondly, researchers can develop many different scenarios and model them. The results provide information about the relative sizes of economic impacts of these different versions of the future. Thirdly, modelling enables researchers to investigate the relative impacts of different elements of a system to identify those elements that are important.

As discussed above, biopharming in New Zealand could have a number of impacts on the agricultural sector, and these impacts could be larger or smaller. Considerable uncertainty surrounds the eventual production, consumption, and regulatory environment of biopharming. Therefore, a number of scenarios were developed to represent several possible futures for New Zealand, and these scenarios were then modelled.

This chapter discusses the method for analysing the potential impacts of biopharming in two parts. The first part presents the model used for the analysis, including the equation structure and the model parameters. The second part describes the scenarios that were developed and the specific techniques for modelling them. The results of the analysis are left to the next chapter.

3.2 The model structure

The model is built on the platform of the Lincoln Trade and Environment Model (LTEM) (Cagatay & Saunders, 2003; Saunders, Moxey, & Roningen, 2001). It is a non-spatial, partial equilibrium model of international agricultural trade developed originally from SWOPSIM (Roningen, 1986; Roningen, Dixit, Sullivan, & Hart, 1991), later VORSIM (Roningen, 2007), and its model structure. It is a synthetic model, based on parameters taken from the literature. The model used for the present research comprises 17 specific countries or regions plus the Rest of the World (ROW), and contains 22 commodities, including three for the oilseed complex and five for the dairy industry. These commodities are considered homogenous with respect to country of origin.

The LTEM can explicitly consider various domestic and border policies, including production quotas, set-aside policies, input and/or output related producer subsidies/taxes, consumer subsides/taxes, minimum prices, import tariffs and quotas, and export subsidies and taxes. The parameters associated with these policies can be modified to simulate policy changes in order to estimate their economic impacts.

The dynamic framework of the LTEM allows the paths of endogenous variables to be assessed through the modelled time period, and a comparative statics analysis can be conducted by comparing different years or the final results of different policies. The model seeks a price equilibrium of a series of production, consumption, and trade equations for each year, solving each year in succession until the final period. The structure of the model is

based on a set of supply and demand equations and one economic identity for each commodity in each country. These are presented below with an explanation following each equation.

$$pp_{ij} = f(WDpp_i, Zs_{ij}, forex) \quad (1)$$

The producer price (*pp*) for a commodity (*i*) in a specific country (*j*) is a function of the world producer price for the commodity ($WDpp_i$); the country's policies, especially producer policies, affecting the commodity (*Zs*); and the exchange rate (*forex*).

$$pcij = g(WDpp_i, Zd_{ij}, forex) \quad (2)$$

The consumer price (*pc*) for a commodity is also related to the world producer price for the commodity, but is additionally affected by the country's policies affecting demand (*Zd*) and the exchange rate (*forex*).

$$qp_{ij} = h(fp_{ij}, Z_j, pp_{ij}, pp_{kj}, qp_{ij,\,t-1}) \quad (3)$$

The level of production of a commodity is influenced by the country's policies (Z_j), the producer price for the commodity, the producer price for other complementary and substitute commodities (pp_{kj}, $k \neq i$), and a one-year production lag term ($qp_{ij,\,t-1}$). In addition, the production equation includes a parameter, fp_{ij}, that can be used to shift productivity from its base levels. This parameter represents changes in production that are exogenous to the model and affect the relationship between prices and quantities, such as introduction of a new cultivar or a new production technology. Because the production equation uses a constant elasticity of substitution functional form, the generated shift is pivotal.

$$qc_{ij} = m_{food}(fc_{ij}, Z_j, pc_{ij}, pc_{kj}, GDP_j, pop_j) \quad (4)$$

The disappearance of a commodity is divided into food, feed, and processing components, with the residual disappearance included in the trade identity (see below). Food demand (*qc*) is modelled as a function of policy variables (*Z*), the consumption price of the commodity, the consumption price of other commodities (pc_{kj}, $k \neq i$), an index of gross domestic product (*GDP*), and the country's population (*pop*). This equation also includes a shift variable, fc_{ij}, which allows exogenous changes to consumption to be modelled.

$$qf_{ij} = m_{feed}(fc_{ij}, Z_j, pc_{ij}, pc_{kj}, qp_{kj}) \quad (5)$$

Some commodities have a feed component of their disappearance. The feed demand of a commodity (*qf*) is based on policy variables, the commodity's own price, and the prices of other commodities (pc_{kj}, $k \neq i$). The feed demand is also affected by the production of livestock commodities, such as beef and dairy products, and these enter directly into the equation. Finally, the feed equation contains a shift variable for exogenous changes to feed consumption.

$$qr_{ij} = m_{proc}(pp_{ij}, pp_{kj}, qr_{ij,\,t-1}) \quad (6)$$

For the oilseed complex, the model contains equations for processing demand. This demand is a function of the commodity's own price, the prices of co-produced products (pp_{kj}, $k \neq i$), and the processing in the prior period ($qr_{ij,\,t-1}$).

$$qe_{ij} = n(qp_{ij}, qc_{ij}, pc_{ij}, qe_{ij,\,t-1}) \quad (7)$$

Commodities have a stock equation to account for changes in inventory. The ending stock of a commodity (*qe*) is based on the quantity produced, the quantity consumed, the consumer price of the commodity, and a lag variable for the prior year's ending stock.

$$qt_{ij} = qp_{ij} - qc_{ij} - qf_{ij} - qr_{ij} - \Delta qe_{ij} \quad (8)$$

The final equation in each country is an identity that sets the amount of trade (*qt*) equal to the quantity produced less consumption, feed uses, processing uses, and the change in ending stocks. This quantity traded, positive in the case of exporting countries and negative in the case of importers, then becomes part of the world trade equation.

The world trade equation sums the quantity traded over all countries and region for each commodity. The model is solved by finding the world producer price ($WDpp_i$, see above) that allows the net world trade to sum to zero, or for total imports to equal total exports. The model is calibrated for the base year of 2004, and then solved for each successive year. In the biopharming research, the model projects impacts out to 2020.

3.3 Scenarios modelled

The trade model was used to assess the potential impacts of biopharming given certain scenarios regarding production and consumption. The first consideration for the modelling was whether to make the pharmaceutical production endogenous to the model. Given the early stage of the technology and the large uncertainties regarding choice of bioreactors, markets, regulations, and other aspects, pharmaceutical production was not included within the model. Instead, the impacts of biopharming *on the agricultural sector* were estimated. These represent impacts *in addition to* the direct economic impacts of the pharmaceutical derived from a biopharming method of production. To illustrate, a therapeutic protein may be able to capture revenue of NZ$100 million. To do this might entail reduction of agricultural production elsewhere or the imposition of greater costs on other producers (for example, segregation costs) of NZ$10 million. The net change in revenue for New Zealand would be NZ$90 million. The modelling described here would be the source of the NZ$10 million number, while the NZ$100 million would be estimated separately from the model.

Extent of biopharming impacts

A key input into the LTEM is the level of uptake of different farming practices. For every country and every commodity, it is possible to specify how much production is conventional and how much uses some other technology. For the present modelling, this variable was used to set a base assumption about the extent to which a country's agriculture was linked to or affected by biopharming. Countries were grouped into three different categories, as shown in Table 1. Several countries were modelled as avoiding biopharming, such as by not licensing biopharming production within their borders. These countries/regions were the EU, Japan, and Norway. Several other countries were modelled as having high uptake of biopharming. These countries would have commercial biopharm crops and would be understood by the international market to allow commercial biopharming. These countries were Canada, Switzerland, and United States. For purposes of this research, it was also assumed that New Zealand had wide adoption of biopharming. The other countries in the LTEM were modelled as having intermediate levels of biopharming adoption. They would neither ban it nor have widespread adoption.

Table 1: Adoption levels of biopharming for LTEM countries/regions

High adoption (90 per cent)	Intermediate adoption (50 per cent)	Low adoption (1 per cent)
Canada	Argentina	European Union (25)
New Zealand	Australia	Japan
Switzerland	Brazil	Norway
USA	China	
	India	
	South Korea	
	Mexico	
	Russian Federation	
	South Africa	
	Turkey	
	Rest of the World	

Production impacts

One way that biopharming could affect agriculture is by its impacts on the supply side or production. Supply impacts are those changes that affect how a product is produced or the efficiency of production. These impacts tend to be technology changes or policy changes that affect the cost of production. One possibility is that biopharming will not have any appreciable impact on the wider agricultural sector. That is, there may be a few niche producers with stringent segregation protocols and high costs, but the only wider impact is a slight reduction in overall production. A second possibility is that the introduction of biopharming creates costs for all producers, with increasing regulation and reporting in order to maintain segregation of food and pharmaceutical crops. In that case, biopharming may cause the cost of production to increase generally. This can be modelled as a shift of the supply curve to the left as the per-unit cost of supplying products increases.

It is important to emphasise that if biopharming leads to farmers growing crops with higher value in the market (absent a technological change in production), this is a demand impact, not a supply impact. That is, farmers may receive a higher price for their products, but the higher price is a result of higher demand for the biopharming crops. A price change is not reflected in a shift of the supply curve.

The prior report on biopharming (Kaye-Blake et al., 2007) examined specific products and applied an economic model to assess their costs and benefits. One such product was human lactoferrin produced in cows' milk. Human lactoferrin has been the target of much biopharming research and commercialisation effort, and biopharming research in New Zealand has specifically examined producing such compounds in cows' milk. To create a realistic scenario and to link this report to the prior one, the modelling was restricted to include just the dairy sector. Other commodities in the model were not modelled as having production (or consumption) impacts.

Taking the possibilities described above into account, this research modelled three supply shifts. The first shift was that biopharming had no impact on the rest of the dairy sector or the wider agricultural sector. In this case, the supply shift variable *fp* (eq. 3) remained at 1.00, the base value, for New Zealand dairy production. Alternatively, the introduction of biopharming could lead to greater costs across the dairy industry. Scenarios were modelled that included a five per cent increase in costs and a ten per cent increase in costs. For these scenarios, *fp* was set to 0.95 and 0.90, respectively, for dairying in New Zealand.

Consumption impacts

The demand side of the LTEM could react positively or negatively to the introduction of biopharming. If farmers began producing pharmaceutical compounds in milk, that milk would be a high-value product. The size of the positive impact on the dairy sector would depend on how much of the dairy sector was given over to biopharming and the size of the premium that farmers were paid for producing biopharm milk. These topics were explored in Kaye-Blake, et al. (2007); the overall finding was that the increase in farm revenues (as opposed to revenue to biopharmaceutical companies) is uncertain but likely to be small. However, there is also the potential for a negative impact. The three models of consumer reactions described above – ecological, genetic, and production – describe different ways that consumer might understand the interaction of biopharming with food farming. If consumers perceive that biopharming is contained, then there is not likely to be a negative consumption effect from embarking on biopharming. On the other hand, these models describe different ways that biopharming might be perceived as 'contaminating' the food supply. If consumers become concerned about the potential for contamination, then negative consumption effects could result. The net consumption impact in the LTEM is the sum of the positive and negative effects.

To model the potential impacts, five different levels for the consumption impact were considered. One possibility is that the positive and negative impacts are so small as to be imperceptible at the level of whole dairy industry. For example, biopharm milk could be a niche product with low premiums, and consumers may not know or care that it is happening. In this case, the demand for milk from areas with biopharming would not be affected, and the shift variable, *fc* (eq. 4) would remain at 1.00, the base level. Another possibility is that the premium paid to farmers for biopharm milk is sufficiently large and/or widespread to boost the demand for the whole industry. In that case, *fc* would shift upwards to reflect the greater demand for dairy products. For the present research, *fc* was changed to 1.10, a 10 per cent increase in demand. This could be the result, for example, of a 100 per cent premium paid to 10 per cent of the industry.

The net impact on the industry could also be negative. Consumers' concern about milk produced in areas where biopharming is permitted could be sufficiently large that demand is reduced, and this reduction is large enough to overwhelm any premium that farmers receive from higher-value biopharm milk. Three different levels of demand reduction were modelled. One level was a relatively modest 10 per cent reduction in demand, modelled by changing *fc* to 0.90. A second level was a larger reduction of 20 per cent, with an *fc* of 0.80. Finally, a very large shift of 50 per cent was also modelled, for which *fc* was set at 0.50.

The way that the LTEM is constructed effected how these consumption shifts were modelled. The increases and decreases in demand affected only that consumption linked to bipharming areas. Consumption linked to areas where biopharming does not occur – the conventional production – did not have direct impacts, although they did have indirect impacts through cross-elasticities with other markets.

Modelled scenarios

Each scenario entailed setting the above production and consumption impacts, given the assumptions about the extent of biopharming impacts, and then simulating international trade in agricultural commodities to the year 2020. In the base scenario, biopharming had no impact on production or consumption, so the shift variables were set to 1.00. In all other scenarios, *fp*, *fc*, or both were changed to simulate the different changes in agricultural markets. The scenarios considered in this modelling were presented in Table 2. Results are presented and discussed in the next chapter.

Table 2: Biopharming scenarios modelling

	Consumption impacts				
Production impacts	10% increase	No change	10% reduction	20% reduction	50% reduction
No change	B01	Base	B06	B09	B13
5% cost increase	B02	B04	B07	B10	B14
10% cost increase	B03	B05	B08	B11	B15

Chapter 4
Results and Discussion

4.1 Modelling results

Each model scenario provided a different estimate of future revenues to the agricultural sector given the use of biopharming in New Zealand (and elsewhere in the world) and specific assumptions about the costs that biopharming creates for the rest of the agricultural sector and consumers' reactions to the new technology. Total revenues to agriculture in New Zealand were calculated for each scenario and compared with results from the base scenario. The net impact could then be expressed as a change from the base. The results are presented in Table 3.

Table 3: Scenario results: change in New Zealand producer returns (%)

	Consumption impacts				
Production impacts	10% increase	No change	10% reduction	20% reduction	50% reduction
No change	2.9	--	-3.0	-6.1	-16.8
5% cost increase	2.1	-0.7	-3.6	-6.7	-17.2
10% cost increase	1.4	-1.4	-4.3	-7.3	-17.6

The first column of result in Table 3 concerns those scenarios in which agricultural revenues are higher as a result of premiums paid for producing biopharm crops. The first of these scenarios examined only a demand increase: biopharm dairy products attracted premium prices for farmers, and no extra costs were imposed on the rest of the sector. The premium prices increased total New Zealand producer returns by 2.9 per cent. Thus, if the country adopted biopharming and the dairy sector attracted the premium modelled – for example, a 100 per cent premium on 10 per cent of milk – then agricultural revenues increased by around three per cent. This increase was reduced as biopharming led to greater costs on the dairy sector. Segregation costs that created a five per cent cost shift reduced the gains to 2.1 per cent; if the costs doubled, then the gains to the sector were 1.4 per cent.

The second column of Table 3 shows the results given no consumption impacts. In these scenarios, biopharming did not change aggregate demand for dairy products. The only impacts were on the costs of production. This column contains the base scenario – no production or consumption impacts. It also contains two further scenarios, one with a five per cent increase in costs and the second with a 10 per cent increase. The first scenario reduced total producer returns in New Zealand by 0.7 per cent, while the second reduced returns by 1.4 per cent. The pivotal shift backwards of the supply curve, representing an increase in costs, moved the equilibrium position of international markets along the original demand curve, leading to reduced production and a higher price. The net effect was a small reduction

in farm revenues. The demand effect in this case was not due to any consumer reactions to biopharming. These solutions had no consumption shifts, so the demand effect was simply a reaction to the reduced supply due to higher production costs.

The next three columns in Table 3 present the model results given negative consumer reactions to the introduction of biopharming. These were net changes in demand, so they include both premiums paid for higher-value dairy products as well as consumer reluctance to consume dairy products from biopharming areas. These three columns present the modelling results given a net 10 per cent, 20 per cent, or 50 per cent reduction in consumer demand for dairy products from countries or areas that allow biopharming. The consumption shifts were considered against the three production impacts. When biopharming had no general impact on the cost of producing dairy products, then the net reduction in producer returns was 3.0 per cent with a 10 per cent reduction in demand, increasing to a 16.8 reduction with a 50 per cent reduction in demand. As production costs increased, producer returns fell further. The largest impact was seen with a 10 per cent increase in costs and 50 per cent reduction in demand, which together produced a fall in producer returns of 17.6 per cent.

4.2 Discussion

The results from a partial equilibrium trade model are best understood not as point estimates of what will happen in the future, but as an indication of tendencies. The several scenarios should be examined together to understand the overall picture of potential impacts.

One general result from these scenarios was that the impacts of cost changes were relatively small compared to those scenarios with no costs impacts. In all scenarios, the impact of increasing the costs of production to accommodate biopharming was less than two per cent of total producer returns to the agricultural sector. This result suggests that if successful development of bipharming in dairy cows required segregation or identify preservation techniques across the whole dairy sector, the cost to the whole sector would not necessarily be high. The findings here are similar to those in prior research regarding productivity increases, although in the opposite direction. Prior research has found that increases in productivity do not necessarily lead to large gains to New Zealand's agriculture, and may even reduce producer revenues (Kaye-Blake, Saunders, Emanuelsson, Dalziel, & Wreford, 2005; Saunders & Cagatay, 2003).

A second general result is that the demand impacts from the introduction of biopharming are larger than the production impacts and will probably determine to size and direction of the net result. If total demand for New Zealand dairy products increases as a result of the production of high-value biopharm products, then the net result is likely to be positive even with increased costs. On the other hand, negative consumer reactions overseas to the introduction of biopharming in New Zealand can be expected to reduce producer returns and shrink the agricultural sector. Again, the importance of consumers' reactions is similar to prior findings.

The mental models discussed in Chapter 2 have a bearing on these results. In the modelling presented here, the assumption was that production and consumption impacts were confined to the dairy sector. The biopharm product was assumed to be something like lactoferrin produced in dairy cows (Kaye-Blake et al., 2007). Biopharming could create additional costs for segregation in the dairy sector, and consumers might have positive or negative reactions to dairy products from New Zealand. These impacts are relatively restricted, given to models of potential reactions presented above. From an ecological standpoint, this approach confines the impacts of biopharming to the product itself without considering the impact on the farm

or wider ecology. One consideration, for example, would be the effluent, which is known to interact with the ecology of the pasture as well as surface water and groundwater. From a genetic standpoint, the impacts described here are probably complete because cows would not be out-crossing with wild bovine species, but they do not preclude greater concern for asexual genetic impacts. Finally, from a production standpoint, consumer could perceive greater impacts than assumed. Commencing biopharming activities in New Zealand could lead to a generalised impression that products from the country are tainted or not to be trusted. In addition, the fact that dairy products are themselves processed and are also included in many processed foods could lead consumers to a belief that biopharm products were leaking into the food system via processing. The three mental models suggest ways in which the assumptions underlying the trade model scenarios regarding potential impacts on the agricultural sector might be too narrow. Consumer concerns could extend to the wider agri-food system or the wider environment. In that case, the impacts could be expected to increase.

The modelling results also provide information relevant to a cost-benefit analysis of biopharming. A biopharming industry could start producing commercial quantities of biologic compounds in New Zealand, which would represent an increase in economic activity in the country and thus a benefit to the economy. If the net impact on the agricultural sector were also positive (as a result of higher payments to farmers), then the overall impact would definitely be positive. If, on the other hand, the net impact on the agricultural sector were negative, the losses to agriculture would represent a cost to introducing biopharming. The overall economic impact would depend on the sum of the costs and benefits. Using the trade modelling results, it is possible to calculate roughly the overall impact on the agricultural sector. According to the Ministry of Agriculture and Forestry, gross agricultural revenue was $19,047 million in 2007 (Ministry of Agriculture and Forestry, 2007, Table 2.4). The result for scenario B04, with no consumption impact and a five per cent increase in costs for the dairy sector, was -0.7 per cent, or $133 million in current dollars at today's level of production. This figure suggests that biopharming would need to generate sufficient revenue to offset agriculture's lost revenue of $133 million annually (in 2007 dollars) to leave the country's economy unaffected as a whole. The greatest impact modelled, scenario B15, leads to a calculation of $3,352 million in lost revenue. Thus, the potential impacts cover a range of values.

Chapter 5
Conclusion

This report has examined the potential impacts of the introduction of biopharming on the New Zealand economy. It summarised a prior report by the authors on this topic (Kaye-Blake et al., 2007), updated it with more recent literature, and systematised the literature by organising consumers' reactions into three mental models. The report then quantified various assumptions regarding technology uptake, production, and consumption, and modelled the net effects of those assumptions on New Zealand agriculture using a model of international trade, the LTEM. Finally, it used the model results to calculate possible economic impacts of biopharming on the agricultural sector.

The general message of the earlier report remains despite the further research that has been conducted. The economic case for biopharming is still uncertain as too many dimensions regarding production of the crop and the biologic are not known. One researcher (Spok, 2006) has suggested that the emphasis on cost reduction had lessened, with current thinking on biopharming shifting to the different types of production and compounds that could result. Nevertheless, the literature still refers to the expected cost-efficiencies of production. In addition, the benefits of new compounds or new methods would need to be quantified in order to develop a full analysis of the economic impacts of biopharming; this quantification is not yet available.

In the face of this uncertainty, a modelling exercise can consider a range of impacts and quantify their possible net effects. The LTEM, a model of international trade in agricultural commodities, was used for this purpose. It estimated the potential impact on agriculture of biopharming; the impacts on the pharmaceutical industry were left for a future analysis. It was assumed, firstly, that New Zealand was one of several countries that decided to pursue biopharming, but that other countries did not. Production of a biopharm product using dairy cows was modelled as having either no effect on the general costs of dairy production or some small impact on those costs. The introduction of biopharming was also assumed to influence demand for dairy products; the net demand impact was modelled as positive, neutral, or negative.

The modelling results indicated that biopharming could affect agriculture either positively or negatively. The main factor in determining the size and direction of the effect was the change in demand. If demand for dairy products increased (because the products were of higher value and farmers were paid a premium), then the net impact was likely to be positive. If consumers became wary of New Zealand dairy products, then the result was likely to be negative. Of less importance was the imposition of greater costs on the sector for segregation of food and biopharm milk. At the cost levels modelled, the impact was a reduction in agricultural revenues of less than two per cent.

The results from the trade modelling provide a baseline for a cost-benefit analysis of the introduction of biopharming. If biopharming results in higher agricultural revenues, then the total economic impact is likely to be positive. If, on the other hand, biopharming imposes costs on the agricultural sector or leads to negative consumer reactions through any of the mental constructs described above, then it would need to offset those costs in order to have a positive economic contribution overall. The size of the offset depends on the size of the production and consumption impacts. The modelling conducted for this research resulted in lost revenues to the agricultural sector of $133 to $3,352 million annually in current dollars.

Figures from Kaye-Blake, et al. (2007) provide a useful comparison: the annual market for a single compound that could be produced with this technology, lactoferrin, was about US$27 million in 2004, while total worldwide sales for 'healthy' and functional foods are around US$25,000 million to US$36,000 million per year. These figures, however, give only an indication. It is still too early to conduct a full, robust cost-benefit analysis or to predict whether the net effect of biopharming on the New Zealand economy would be positive or negative.

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