1. Introduction

Continuously enhancing food production, especially crop production, is one of humankind's primary goals .

However, we live in an era of climate change. **Climate change-induced water scarcity can lead to a 30% or more loss in crop yield** (Gupta et al., 2020). What we need in the fight for food security is to adopt an effective strategy to mitigate water scarcity.

Mechanized land preparation (MLP) can significantly increase the air permeability of the soil and accelerate the decomposition of soil organic matter, contributing to fertile soil development and crop root proliferation. As a result, crops can absorb irrigation water more efficiently.

Therefore, our study investigates the association between MLP adoption and irrigation water productivity (IWP) in the context of rice production in Jiangsu province, China.

1. Introduction

Contributions:

1. We provide the pioneering work to appraise the impact of MLP adoption on IWP.

2. We address the endogeneity issues associated with MLP adoption using an ETR model.

Background

China has successfully fed the 18% of the global population using only 6% of global water resources.

However, water scarcity is turning to be the primary threat to China's food security. Official data suggests that the national total water supply has decreased from 613.12 billion m^3 in 2012 to 602.12 billion m^3 in 2019, while the water consumption of non-agricultural sectors has increased from 222.87 billion m^3 to 233.89 billion m^3 during the same period.

Meanwhile, the MLP penetration of the country seems to have stagnated. Official data reports that the proportion of mechanized tillage area to total planting area only reached 76.50% in 2020 after an average increase of 1.00% per year from 2016.

Literature review

(1) Climate change and water scarcity. As documented by prior literature, global warming and frequent weather variability are two dominating dimensions of climate change that could trigger water scarcity (Sabbaghi et al., 2020; Carracelas et al., 2019; Hristov et al., 2021; Huang et al., 2021; Wang et al., 2021; Zheng et al., 2021).

(2) Pathways for improving agricultural water productivity. Scholars have explored effective pathways for IWP, including **improved irrigation techniques** (Carracelas et al., 2019; Çetin and Kara, 2019; Comas et al., 2018; Parthasarathi et al., 2018), **water-saving farming practices** (Huang et al., 2021; Zhang et al., 2021; Zheng et al., 2021), and **improved crop varieties** (Jing et al., 2021; Kukal et al., 2014; Sánchez et al., 2015).

A crucial fact is that measures to improve water productivity could always be contradictory to food security.

Method

We use the **endogenous treatment regression (ETR) model** to address the observed and unobserved endogeneities associated with MLP adoption. The ETR model can be specified by the following equations.

Stage 1: $MLP_i^* = \gamma_i X_i + \delta_i IV_i + \varepsilon_i,\quad MLP_i = \begin{cases} 1, & if\ MLP_i^* > 0 \\ 0, & otherwise \end{cases}$

Stage 2: $IWP_i = \alpha_i MLP_i + \beta_i X_i + \mu_i$

where MLP_i refers to the status of MLP adoption; IWP_i refers to the IWP ; X_i denotes a vector of independent variables; IV_i refers to the selected instrumental variable.

We synthesize an IV representing the proportion of people using machines for rice land preparation (excluding the respondent) in the sample of a city.

3. Methodology

Data

The data used in our study sourced from a Jiangsu province-targeted survey, the 2021 *China Land Economic Survey* (CLES), conducted and sponsored by Nanjing Agricultural University (Nanjing, China) .

Total sample size: 2,420

We cleaned the data in three steps.

(1) We restricted the sample to the 909 rural samples of rice growers by excluding the 1,511 samples of non-rice growers;

(2) We removed 298 samples with missing values and outliers in rice yield and irrigation water consumption.

(3) We deleted 16 samples reporting abnormal and/or missing values in control variables.

Final samples used in this study: 595

3. Methodology

Table 1 Variable definitions and descriptive statistics

Variables	Definitions	Mean	SD.
Dependent variable			
IWP	Rice yield per unit volume of irrigation water (kg/m^3)	0.60	0.52
MLP adoption	1 if household used machines for land preparation in rice production, 0 otherwise	0.71	0.45
Control variables			
Age	Age of household head (HH) (years)	61.19	10.84
Gender	1 if HH is male, 0 otherwise	0.75	0.43
Education	Educational level of HH (years)	6.91	3.96
Health status	1 if HH reports him/her is in good physical condition, 0 otherwise	0.88	0.33
Household size	Number of people residing in a rural household	3.26	1.76
Elderly ratio	Ratio of the number of residents aged more than 64 years to household size	0.28	0.31
Household income	Total annual household income (1,000 Yuan/capita) [a]	13.71	71.95
Car ownership	1 if rural household owns a car, 0 otherwise	0.48	0.50
Farm size	The total area of the major plot committed to rice production (mu) [b]	7.74	35.69
Soil fertility	1 if HH perceives the cultivated land is fertile, 0 otherwise	0.48	0.50
Natural disaster	1 if the major rice plot experienced natural disasters (e.g., flood and drought) in 2020, 0 otherwise	0.26	0.44
Road condition	The distance from the major rice plot to the nearest cement road (km)	0.25	0.47
Subsidy	1 if rural household receives government planting subsidies, 0 otherwise	0.88	0.32
Northern Jiangsu	1 if household is located in northern Jiangsu, 0 otherwise	0.42	0.50
Central Jiangsu	1 if household is located in central Jiangsu, 0 otherwise	0.40	0.49
Southern Jiangsu	1 if household is located in southern Jiangsu, 0 otherwise	0.18	0.39
City-level MLP ratio	Proportion of people using machines for rice land preparation (excluding the respondent) in the same city	0.64	0.20
Sample size		595	

Note: SD refers to standard deviation; [a] Yuan is a Chinese currency; [b] 1 mu=1/15 hectare.

Table 2 Mean differences in the variables between MLP adopters and non-adopters

	MLP adoption			
Variables	Adopters	Non-adopters	Mean difference	*t*-value
IWP	0.615	0.564	0.051 (0.047)	1.073
Age	60.758	62.260	-1.502 (0.977)	-1.537*
Gender	0.756	0.728	0.028 (0.039)	0.703
Education	7.095	6.462	0.632 (0.357)	1.772**
Health status	0.886	0.855	0.031 (0.030)	1.038
Household size	3.358	3.029	0.329 (0.158)	2.081**
Elderly ratio	0.261	0.311	-0.050 (0.028)	-1.795**
Household income	14.682	11.331	3.351 (6.499)	0.516
Car ownership	0.524	0.370	0.154 (0.045)	3.437***
Farm size	8.372	6.182	2.190 (3.223)	0.680
Soil fertility	0.502	0.410	0.092 (0.045)	2.044**
Natural disaster	0.301	0.150	0.151 (0.039)	3.860***
Traffic condition	0.257	0.215	0.043 (0.042)	1.009
Subsidy	0.905	0.827	0.079 (0.029)	2.715***
Northern Jiangsu	0.393	0.497	-0.104 (0.044)	-2.332**
Central Jiangsu	0.453	0.260	0.192 (0.044)	4.422***
Southern Jiangsu	0.154	0.243	-0.089 (0.035)	-2.570***
City-level MLP ratio (IV)	0.678	0.550	0.128 (0.017)	7.375***
Observations	422	173		

Note: IWP is measured at kg/m^3; household income is measured at 1,000 Yuan/capita; *** < 0.01, ** < 0.05, and * < 0.10.

4.1 Determinants of MLP adoption and its impact on IWP

Table 3 Determinants of MLP adoption and its impact on IWP: ETR model estimates

Variables	MLP adoption	IWP
MLP adoption		0.214 (0.091)**
Age	-0.013 (0.007)*	0.001 (0.003)
Gender	0.106 (0.141)	0.035 (0.058)
Education	0.000 (0.018)	-0.001 (0.006)
Health status	0.200 (0.155)	0.023 (0.068)
Household size	0.071 (0.036)**	-0.009 (0.011)
Elderly ratio	-0.024 (0.241)	0.166 (0.084)**
Household income (ln)	0.077 (0.044)*	-0.024 (0.012)**
Car ownership	0.139 (0.102)	0.076 (0.040)*
Farm size	0.002 (0.002)	0.001 (0.000)***
Soil fertility	0.291 (0.121)**	0.005 (0.042)
Natural disaster	0.536 (0.168)***	-0.045 (0.051)
Traffic condition	-0.065 (0.118)	0.056 (0.062)
Subsidy	0.341 (0.176)*	0.014 (0.049)
Northern Jiangsu	-0.064 (0.157)	0.196 (0.099)**
Central Jiangsu	0.387 (0.189)**	0.029 (0.077)
City-level MLP ratio	1.909 (0.381)***	
Constant	-1.091 (0.436)**	0.191 (0.185)
$\rho_{\mu\varepsilon}$	-0.199 (0.089)***	
VIF test		Mean VIF=1.34
Log-likelihood	-751.629, p=0.000	
Wald χ^2 (df=16)	118.49	
Wald test of exogeneity	$\chi^2(1)=4.73$; Prob>χ^2=0.030	
Observations	595	595

Note: IWP is measured at kg/m^3; Village-level clustered standard errors in parentheses; The reference region is the southern Jiangsu; *** < 0.01, ** < 0.05, and * < 0.10.

4.2 Disaggregated analysis by how farmers access MLP

Table 4 Disaggregated analysis: how the MLP is accessed

Category	IWP	95% Confidence interval
MLP non-adopters	1.229	[1.180, 1.280]
Via only household-owned machine	1.862	[1.770, 1.950]
Via only outsourcing machinery service	1.832	[1.790, 1.870]
Via both household-owned machine and outsourcing service	1.770	[1.610, 1.930]

Note: IWP is measured at kg/m^3.

The predicted IWPs for all the three categories of how farmers access MLP are significantly higher than that of MLP non-adopters.

Nevertheless, how MLP is accessed bears no significant influence on the IWP of rice production.

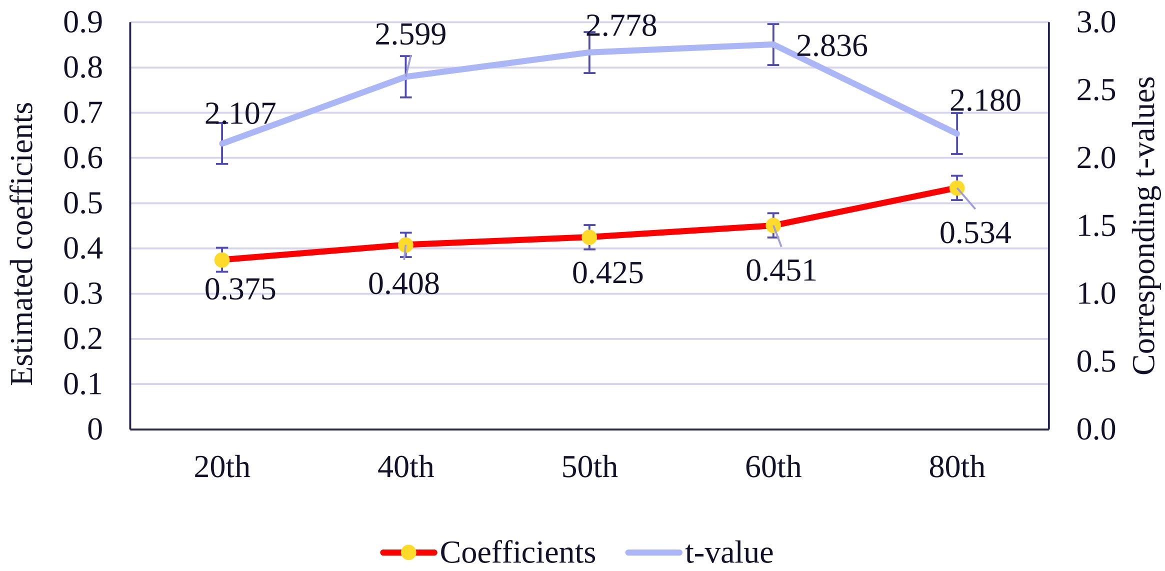
4.2 Disaggregated analysis by regions

Table 5 Disaggregated analysis by regions

Regions	MLP adopters		MLP non-adopters	
	IWP	95% Confidence interval	IWP	95% Confidence interval
Northern Jiangsu	2.134	[2.090, 2.180]	1.416	[1.360, 1.470]
Central Jiangsu	1.642	[1.590, 1.690]	1.050	[0.957, 1.140]
Southern Jiangsu	1.635	[1.570, 1.700]	1.037	[0.953, 1.120]

Note: IWP is measured at kg/m^3.

4.2 Disaggregated analysis: IVQR estimates



Impact of MLP adoption on IWP at the selecetd quantiles: IVQR model estimates

All of the estimated coeffects are statistically significant at least at the 5% level across the selected quantiles (*t*-value is higher than 2).

The impacts of MLP adoption on IWP are monotonically increasing across the selected quantiles, suggesting that farmers having the highest IWP benefit the most from MLP adoption.

In particular, MLP adoption increases IWP, ranging from 0.37 kg/m^3 at the lowest 20th IWP quantile to 0.53 kg/m^3 at the highest 80th IWP quantile.

5. Conclusions and policy implications

5.1 Conclusions

- MLP adoption indeed exerts a significant and positive impact on IWP.
- The IWPs for all MLP access ways are significantly higher than that for MLP non-adopters, whereas the IWP does not vary across the MLP access channels. For MLP adopters and non-adopters, the IWP for the southern Jiangsu category is significantly larger than that of the central and southern Jiangsu categories. Meanwhile, there is no significant differences in IWP between the central and southern Jiangsu categories.
- The results estimated using an IVQR model indicate that the promotion of MLP on IWP increases monotonically per quantile.

5.2 Policy implications

- The government should make more efforts to promote the adoption of MLP in crop cultivation. In practice, the government should authorize more MLP-targeted in-kind and monetary subsidies. Meanwhile, MLP-related training and education through cooperative organizations should also be prioritized to lower the threshold for MLP use.

- China should deepen soil improvement in rural areas: (1) the government should further promote the ongoing soil restoration program to combat soil degradation. (2) the government should provide more incentives (e.g., subsidies and bonuses) for farmers to adopt soil fertility enhancement practices in their crop cultivation.

- Besides, the government should notice the uneven spatial distribution of IWP and lay particular emphasis, such as investments and policy supports, on the vulnerable regions.

Many thanks for your Attention!

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