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Quantifying the Economic Performance of Ratoon Rice Production in China: An Endogenous Switching Regression Analysis

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ABSTRACT

Ratoon Rice (RR) has been proposed to be an effective alternative rice system to increase productivity growth and reduce the environmental impact, but data on the economic performance of RR for farmers are limited. A survey of paddy farms was conducted to assess the impact of the adoption of RR in Hubei, China. Endogenous switching regression framework was used to account for observed and unobserved heterogeneity. We analyzed the effect of yield, income, and technical efficiency of RR adoption. Results show that adoption of RR has great impact on yield, income, and technical efficiency. Increase in rice yield (by 5.12%) and rice income (3.74%) was found for RR farmers; increases of yield, income and technical efficiency was also significant if farmers cultivating single rice shifted to RR. Technical efficiency showed a large difference when RR was adopted by farmers cultivating single rice. Small farms and large farms benefit from the adoption of RR. Large farms benefit more yield and income than small farmer, while small farms are more efficient than large farms. Our findings provide meaningful and timely implications for future national programs and policies to promote the implementation of RR in China that aim to promote more sustainable practices and lower environmental impact in agriculture.

Keywords: Impact assessment, Paddy farms, Single rice, Smallholder farmers, Technical efficiency.

INTRODUCTION

China is the world's largest rice producer, contributing nearly 30% of global rice production. As a main staple grain, rice is a primary energy source for most families in China, accounting for 28% global rice consumption (Xin *et al*., 2020). It plays a vital role in food security, and its cultivation is an important source of employment and income for rural household (Gross and Zhao, 2014). Hence, it is particularly important to identify an option that can increase productivity and ensure profitability.

Single-(SR) and Double-season Rice (DR) are the dominant rice systems adopted by farmers in China. With more agricultural input and high labor cost, the ratio of DR to total rice-cultivated area has rapidly dropped (Peng *et al*., 2009).By 2018, SR accounted for 65.14% of the total rice-cultivated area (National Bureau of Statistics of China, 2018). Apparently, the transition of cultivated area from DR to SR may eventually reduce the total rice yield. Further rice yield increases mainly depended on the increase of grain yield per hectare. With the wide application of agricultural chemicals such as fertilizer and pesticides, rice yields per hectare have approached their biophysical potential ceiling (Peng *et al*., 2014). The application of fertilizer in rice production has increased from 58.95 in 1978 to 338.25 kg ha^{-1} in 2018. Accordingly, rice yield increased from 3,978.09 to 7,026.73 kg ha^{-1} (National Bureau of Statistics of China, 2018). However, these agricultural chemicals have been used in

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excess of plant nutritional need and lost to the environment, especially contributing to global warming (Cui *et al*., 2018). The effect, paradoxically, will threat the predicted output in rice production for the next several decades. As Chen *et al*.(2020) predicted, global warming will reduce China's total rice production by 5.0% in 2060 if the present structure of rice cropping systems persists.

RR can be an alternative option for farmers to achieve sustainability in rice production. It is the practices that harvest the first rice crop (main rice) and further obtain a second rice crop from the stubble of the previously harvested crop (Jones, 1993). In China, RR has been widely practiced since 1950 as the result of governmental policy and development of cultivation techniques (Fei *et al*., 2013; Xu *et al*., 2015). Subsequently, its cultivated area quickly declined due to the lack of suitable rice cultivars for RR harvest, varieties with strong ratooning ability, and higher labor requirement(Li *et al*., 2014). But, RR has been proposed as an alternative system for farmers to re-adopt in recent years, because new rice cultivars with high ratooning ability that allows mechanical harvest of main crop, together with better crop and water management, promise both high annual productivity and relatively low labor requirements(Yuan *et al*., 2019).

RR can also serve as an adaptive strategy to climate change and rising temperatures in rice systems. With a warmer climate and extended growing season resulting from climate change, rice farmers will benefit from RR. Rice ratooning is currently practiced as an adaptive strategy of rice systems in many countries, including India, Japan, Philippines, Iran, Pakistan, Brazil, Thailand and the U.S.A., though only in limited areas (Negalur *et al*., 2017). For example, Ziska *et al*.(2018) quantified last 40 years and projected to 2095 changes in air temperature and found an ongoing increase of temperature and growing season length in Mississippi valley. The implementation of ratooning may be an adaptive management that would promote rice production resiliency with warming temperatures.

To increase the adoption of RR, further research is warranted to assess the economic performance in production. Prior studies have found that annual yield in RR is 13% lower compared with DR, but this yield penalty is much smaller compared with the 50% yield reduction when shifting from DR to SR (Yuan *et al*., 2019). If farmers shifted SR into RR, it is possible to compensate the yield reduction associated with the transition from DR to RR. Additionally, RR could lower the cost by a 50% reduction compared with the main rice due to saving in land preparation, labor, water use and agricultural chemicals input (Wang *et al*., 2020). In spite of this, the adoption of RR is relatively low and in limited areas. Explaining farmer' demand for economic benefits in real farming condition can serve as a mean of targeting the development and dissemination of new technology (Wale and Chianu, 2015).

The main objective of the present study was to assess the impact of the transition from SR to RR using farm-level data from Hubei Province, China. The relevance of this study is twofold: Firstly, we try to provide tigorous empirical evidence on the adoption of ratoon rice on rice yield and rice income in China. Most available studies are based on field trial data or simulated data that may not be representative of real farming conditions (Dong et al., 2017). In this study, a survey data of paddy farmers is used to analyze. Second, we explore the technical efficiency of RR production, which is a rice system that has been relatively neglected in the previous literature. Further, assessing the impact of RR adoption can provide potential value for policymakers, thus can be used to identify public interventions to improve productivity of the RR production.

MATERIALS AND METHODS

Econometric Framework

Endogenous Switching Regression Model (ESR)

We want to explore whether the adoption of RR can be an effective choice to enhance farmers' welfare. In real smallholder condition, farm activities before and after adoption of new technology are hardly observed; what is observed is the activities of adopters and non-adopters. However, only comparing the outcome variables (rice yield, rice income, and technical efficiency) between adopters and non-adopters may lead to spurious conclusions, because there may also be differences in other inputs or characteristics. A regression model that includes the adoption decision as treatment variable and other control variables can provide more accurate results (Kabunga *et al*., 2012). Yet, the model only controls observed farm and household characteristic (e.g. gender, education), while these unobserved variables that are responsible for the difference of initial conditions between adopters and non-adopters cannot be directly controlled (Winters *et al*., 2011). Typical unobserved factors such as farmers' innate abilities and other circumstances, may be correlated with the adoption decision and simultaneously affect farmer' welfare. In this case, self-selection into technology adoption is the prominent source of endogeneity, and the net effect of technology adoption may be underestimated or overestimated (Mishra *et al*., 2017).

One way of accounting for such endogeneity is the application of simultaneous equation models (Hausman, 1983). In simultaneous equation models, separate functions for adopters and non-adopters have to be specified, which involve both endogeneity and sample selection at the same time. Endogenous Switching Regression (ESR) is an effective empirical model in this respect in many previous studies (Alene and Manyong, 2007; Coromaldi *et al*., 2015; Jaleta *et al*., 2018). In our study, the ESR approach was applied to estimate the parameters. It first models the adoption decision of farmers with a binary model, and the equations for the outcome variables (rice yield, rice income, and technical efficiency) are modeled for both adoption and non-adoption groups.

Theoretically, the adoption decision is modeled in a random utility framework (Khonje *et al*., 2015). Farmer i will adopt RR when the expected utility from RR (I_{RR}^*) is greater than that from SR (I_{SR}^*).The adoption of new technology is observed as a dichotomous choice: $I_i = 1\ if I_{i,\mathrm{RR}}^* > I_{i,SR}^*$ and $I_i = 0\ if I_{i,\mathrm{RR}}^* < I_{i,SR}^*$. However, I_i^* is not observed, but I_i can be observed by researchers. It can be expressed as follows:

$$I_i^* = Z_i\gamma + \varepsilon_i$$

$$I_i = \begin{cases} 1 & if\ I_{i,RR}^* > I_{i,SR}^* \\ 0 & if\ I_{i,RR}^* < I_{i,SR}^* \end{cases} \quad (1)$$

Where, Equation (1) represents a Probit model to estimate the adoption of a new technology, Z_i is a vector of household, farm, and village characteristics, $\gamma$is a vector of unknown parameter, and ε_i is random error term with $\varepsilon \sim N(0, \sigma^2)$.

Further, two outcome equations are specified to explain the outcome variables (yield and income). Let Y= f(X) represent the relationship between the outcome variable Y (yield and income) and the explanatory variables *X*. Specifically, the two regimes can be estimated as:

Regime 1: $Y_{i,RR} = X_i'\eta_1 + \psi_{i,RR} \quad if\ \delta = 1$ (2a)

Regime 2: $Y_{i,SR} = X_i'\eta_2 + \psi_{i,SR} \quad if\ \delta = 0$ (2b)

Where, Y_i is a vector of outcome variables (yield and income) for adopters and non-adopters (1= RR, 0= SR). $X'$is a matrix of explanatory variables. X' is allowed to overlapp with Z', but at least one variable should be included in Z' but excluded in $X'$to guarantee proper identification (Fuglie and Bosch, 1995). $\eta_i$is a vector of unknown parameters, $\psi_{i,RR}$and $\psi_{i,SR}$are random error terms.

The error terms ε, ψ_{RR} and ψ_{SR} in Equations (1), (2a) and 2(b) are assumed to have a tri-variate normal distribution with zero mean, and follow the covariance matrix(Terza, 1998):

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$$\text{cov}(\varepsilon\ ,\psi_{\text{RR}}\ ,\psi_{SR}) = \begin{vmatrix} \sigma_{\varepsilon}^{2}\sigma_{\varepsilon,\text{RR}}\sigma_{\varepsilon,SR} \\ \sigma_{RR,r}\sigma_{RR}^{2}\sigma_{RR,SR} \\ \sigma_{\text{SR},\varepsilon}\sigma_{\text{SR,RR}}\sigma_{SR}^{2} \end{vmatrix} \quad (3)$$

Where, $\sigma_{\varepsilon}^{2} = var(\varepsilon)$,$\sigma_{RR}^{2} = var(\psi_{\text{RR}})$,$\sigma_{SR}^{2} = var(\psi_{\text{SR}})$,$\sigma_{\varepsilon,\text{RR}} = cov(\varepsilon, \psi_{\text{RR}})$,$\sigma_{\varepsilon,\text{SR}} = cov(\varepsilon, \psi_{\text{SR}})$,$\sigma_{\text{RR,SR}} = cov(\psi_{\text{RR}}, \psi_{\text{SR}})$.$\sigma_{\varepsilon}^{2}$ can be assumed to be equal to 1 as

the coefficient γ is only estimable up to a scale factor (Greene, 2012). Since the error term ε_i is correlated with the error terms $\psi_{i,RR}$ and $\psi_{i,SR}$, the expected values of $\psi_{i,RR}$ and $\psi_{i,SR}$are non-zero(Fuglie and Bosch, 1995). Given these assumptions, the expected values of the truncated error terms $(\varepsilon_{RR}|\ I = 1)$ and $(\varepsilon_{SR}|\ I = 0)$ are

$$\text{E}\left(\varepsilon_{i,RR}\middle|I_i = 1\right) = \sigma_{RR,\eta}\frac{\phi(Z_i\gamma)}{\varphi(Z_i\gamma)} = \sigma_{RR,\eta}\lambda_{\text{i,RR}} \quad (4)$$

$$\text{E}\left(\varepsilon_{i,SR}\middle|I_i = 0\right) = -\sigma_{SR,i}\frac{\phi(Z_i\gamma)}{1-\varphi(Z_i\gamma)} = -\sigma_{SR,\eta}\lambda_{\text{i,SR}} \quad (5)$$

Where, $\lambda_{\text{RR}}$and $\lambda_{\text{SR}}$are the Inverse Mills Ratio (IMR) calculated from the selection function and are included in Equations (2a) and (2b) to correct potential selection bias. $\phi(.)$and$\varphi(.)$are the probability density and cumulative distribution function, respectively.

Treatment Effect

The ESR model can be used to estimate the Average Treatment effect of the Treat (ATT) and the Average Treatment effect of the Untreated (ATU) by comparing the expected outcome variables of RR adopters and SR adopters in in the hypothetical counter factual cases. Following Noltze *et al.*(2013), the conditional expectations for food productivity in the four cases are defined as follows:

RR farmers with adoption (observed):

$$\text{E}\left(\text{Y}_{\text{i,RR}}\middle|I_i = 1\right) = X_i'\eta_1 + \sigma_{RR,\eta}\lambda_{i,RR} \quad (6)$$

RR farmers without adoption (counterfactual):

$$\text{E}\left(Y_{\text{i},SR}\middle|I_i = 1\right) = X_i'\eta_2 + \sigma_{SR,\eta}\lambda_{i,RR} \quad (7)$$

SR farmers without adoption (observed):

$$\text{E}\left(Y_{i,SR}\middle|I_i = 0\right) = X_i'\eta_2 + \sigma_{SR,\eta}\lambda_{i,SR} \quad (8)$$

SR farmers with adoption (counterfactual):

$$\text{E}\left(Y_{i,RR}\middle|I_i = 0\right) = X_i'\eta_1 + \sigma_{RR,\eta}\lambda_{i,SR} \quad (9)$$

Equations (6) and (7) are used to estimate the ATT, and Equations (8) to (9) are employed for estimating the ATU:

$$\text{ATT} = \text{E}(Y_{RR}|I = 1) - \text{E}\ (Y_{SR}|I = 1) \quad (10)$$

$$\text{ATU} = \text{E}(Y_{RR}|I = 0) - \text{E}\ (Y_{SR}|I = 0) \quad (11)$$

2.3. Technical Efficiency : Epsilon-Based Measure Model (EBM)

Technical efficiency shows how production inputs are optimally consumed in a farm (Esfahani *et al*., 2017). In this study, we employed the EBM in order to compare the technological efficiency between adopting RR and otherwise. Tone *et al*.(2010) introduced a hybrid model called Epsilon-Based Measure (EBM). The EBM model combines both radial and non-radial measures in a unified framework and relaxes the assumption that factors should increase or decrease in the same proportion (Cheng *et al*., 2011). The EBM model is defined as follows:

$$\gamma^* = min\theta - \varepsilon_\chi \sum_{i=1}^{m} \frac{w_i^- s_i^-}{x_{i0}}$$

$$\text{s.t.}\ \theta x_0 - X\lambda - s^- = 0\ ;\ Y\lambda \geq y_0\ ;\ \lambda \geq 0\ ;\ s^- \geq 0 \quad (13)$$

Where, γ^* is rice production technical efficiency; θ is the radial efficiency; s_i^- is slack of no-radical input; w_i^- is the weight of input *i* and satisfies$\sum_{i=1}^{m} w_i^- = 1$; ε_χ indicates the relative importance of the non-radial slacks over the radial θ. Note that in the context of this study, input includes the expenses of seeds, fertilizers, pesticides, irrigation, and machinery per hectare. On the

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other hand, output refers to the total yield per hectare in one year.

Data Collection

This study was carried out in Hubei Province, located in the central part of China. With 2.37 million hectares rice paddy field, rice yields of Hubei Province accounted for 10% of the total in China (NBS, 2018). It is characterized by a subtropical monsoon climate with an average temperature of 3-7℃ in January and 26-29℃ in July, average annual precipitation of 900-1500 mm. Traditionally, SR is the most common production system in Hubei Province, while RR planted area has rapidly increased in recent years as the result of governmental policy and improvement of cultivation techniques. By 2018, 200 thousand hectares paddy field has been planted with RR in Hubei Province (He *et al*., 2019). Thus, Hubei Province is a typical area that RR and SR can be cultivated.

We conducted a farming household survey between the month of July and August in 2018. The survey area included 9 counties: Qichun, Wuxue, Xianning, Honghu, Jianli, Jiangling, Shayang, Xiantao, and Xiaogan. These counties covered three predominant paddy regions in Hubei Province, namely, central region with single rice, Jianghan plain with single-and-double-crop rice, and northeast region with Hubei Japonica rice. The questionnaire included questions about the household's basic information (e.g., income, education, housing and health status), input and output of rice production, and their perceptions and practices of growing RR.

The required sample size was determined before collecting the initial data. A Multi-stage random sampling method was used to ensure each individual in the abovementioned regions had the same probability of being chosen at any stage in the sampling process. First, two or three towns were randomly selected from the above 9 countries in Hubei Province. Then, two villages were randomly selected from each town; finally, about 30 households were randomly selected in each village. The inclusion criteria were set such that only households that exclusively specialized in rice production in 2017 were surveyed. The required sample size was estimated using the following formula:

$$n = \frac{Z^2 p(1-p)}{E^2}$$

Where, n is the required sample size, Z is the t value at 95% confidence level from the standard normal distribution, p represents the standard of deviation (0.5), and E is the acceptable error ($\pm$1.641%). The permissible error in the sample size was defined to be 5 for 95% confidence (Mousavi-Avval *et al*., 2011). Including incomplete responses and outliers, we surveyed 1,290 farmers. After removing the inconsistence and missing values, the final sample in our research was 1,284 households (616 RR and 668 SR farmers) were randomly selected for the analysis.

RESULTS

Description of Sample

Table 1 shows that 47.98% of sample households cultivate RR, and 50.02% grow SR. More than 90% of the heads of sampled households were male for both RR and SR production. It was no surprise that the decision of agricultural production was still mainly made by the male head in rural Chinses families (Khairullah and Khairullah, 2013). The average age for the heads of households growing RR and SR were 59.06 and 57.88 years, respectively. The average years of schooling for farmers in RR and SR production, were about 6 years, which is in line with the reported average years of education in rural China. As for labor force participation, on average, two members of the households are involved in farming-related activities. This is consistent with the age structure and labor force participation of

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Table 1. Summary statistics and mean comparison of RR and SR farmers, China.

Variables	Means (SD)			Mean diff
	All(n= 1443)	SR (n= 668)	RR (n= 616)	
Total returns				
Rice yield (kg ha^{-1})	10013.14 (3172.61)	7926.33 (1983.22)	12276.11 (2621.67)	4349.78***
Income from rice (Yuan ha^{-1})	22791.52 (8082.05)	17592.73 (4460.37)	28429.17 (7314.35)	10836.44***
Farm input level				
Seed (kg ha^{-1})	29.84 (16.19)	28.85 (18.13)	30.87 (13.80)	2.02***
Seed price (Yuan ha^{-1})	77.09 (33.72)	79.93 (35.31)	74.10 (31.72)	-5.80***
Fertilizer (kg ha^{-1})	299.49 (132.96)	356.47 (104.18)	444.71 (144.51)	88.24***
Fertilizer price (Yuan ha^{-1})	7.64 (2.44)	8.03 (2.45)	7.23 (2.37)	-0.80***
Pesticide (kg ha^{-1})	45.01 (25.01)	42.78 (23.34)	47.36 (26.48)	4.56***
Pesticide price (Yuan ha^{-1})	45.35 (8.56)	45.53 (9.15)	45.15 (7.89)	0.38
Total labor (h ha^{-1})	375.73 (164.43)	346.13 (189.41)	406.81 (126.07)	60.67***
Household characteristics				
Gender of household head(1= Male, 0= Female)	0.92 (0.26)	0.89 (0.31)	0.96 (0.20)	4.37***
Age of household head	58.45 (9.75)	57.88 (10.23)	59.06 (9.17)	2.18***
Education level	6.28 (3.50)	6.24 (3.57)	6.31 (3.42)	0.36
Decision-maker in rice production (1= Yes, 0= No)	0.94 (0.24)	0.93 (0.26)	0.95 (0.22)	1.84*
Farming labor in family	2.02 (0.95)	2.05 (1.05)	1.99 (0.83)	1.05
Member in cooperative (1= Yes, 0= No)	0.45 (0.50)	0.29 (0.45)	0.63 (0.48)	0.34***
Instruments				
Government extension(1= Yes, 0= No)	0.38 (0.49)	0.23 (0.42)	0.54 (0.49)	0.31***
Farmer to farmer extension (1= Yes, 0= No)	0.73 (0.44)	0.61 (0.49)	0.86 (0.35)	0.25***

* Significant at the 10% level; ** Significant at the 5% level, *** Significant at the 1% level.

rural China in agricultural sector, where more individuals in rural areas are engaged in off-farm employment, and the young prefer to immigrate to urban settings (Guo *et al*., 2015). Farmers tend to grow RR when the head of household is a member of an agricultural cooperative organization. In RR group, 63% of farmers participated in the cooperative, which is obviously higher than that in SR group. The average rice cultivated area (1.74 hectare) is smaller for those cultivating RR compared to the average rice cultivated area (2.24 hectare) of those cultivating SR. Additionally; farmers with access to agricultural information were more prone to grow RR. Also, 63% of farmers obtained information from government for RR group, while the percentage for SR

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group was only 23%. A similar result was observed if households obtained variety information from other farmers.

Rice yield and income under the two rice production systems is presented in Table 1.The average of rice yield of RR (12,276.11 kg ha^{-1}) was significantly higher than the yield of SR (7,296.33 kg ha^{-1}). Similarly, rice income derived from RR production (28,429.17 Yuan ha^{-1}) appeared to be significantly higher than SR production (17,592.73 Yuan ha^{-1}). The yield and income in RR production were 54.88 and 61.60% higher than growing SR, respectively. As for the farm input, the amount of seed, fertilizer, pesticide, and labor used in RR production was statistically significant and different from those used in SR production. The increase in seed, fertilizer, pesticide, and labor was 7.0, 24.75, 17.53, and 10.71%, which is lower than the increase in yield and income.

Rice Yield Effect

The result for the yield effect of RR adoption is presented in Table 2. Double-log specification is found to fit the estimation. The Wald χ^2test significantly rejects the assumption that the selection equation and the outcome equation are independent from each other, because$\rho_{\varepsilon\psi_{RR}}$ and $\rho_{\varepsilon\psi_{SR}}$are non-zero, and $\rho_{\varepsilon\psi_{SR}}$is significantly positive. This indicates that the estimation without any correction would lead to biased results. In selection equation, we control for the difference in farm inputs, socio-economic and demographic explanatory variables. Further, to make the proper identification, the outcome functions should contain all of the above explanatory variables and, at least, one instrumental variable (Lokshin and Sajaia, 2004). The instrumental variable affects farmers' adoption decision but should not impact the outcome variables. In the context of this study, outcome variables are rice yield, rice income and technical efficiency. Before adopting new technology, farmers must have access to information about them. Extension services from government and immediate peers are the main means to obtain information about new technology(Abdoulaye *et al*., 2018; Shahpasand, 2020). Thus, government extension and farmer-to-farmer extension are selected as the instrumental variables in our study.

The result of selection equation for ERS model is presented in the second column of Table 2. The important determinants affecting the adoption of RRat farm input level are fertilizer quantity and total labor. With respect to the socio-economic and demographic factors, membership in a cooperative significantly increases the probability of RR adoption due to the available production and sales services. Farm size has a positive relevance for RR adoption, thus, farmers who manage somewhat larger farms may allocate more time and labor to obtain higher rice yield and income. Irrigation condition has a significant positive effect on the adoption of RR. This is due to the fact that more water will be allocated into the ratooning stage compared to other crops and fallow. Mechanical service was the most important technical limit factor for RR production in the past, and the availability can significantly increase the possibility of adoption. A negative effect is found in land fragmentation, suggesting that labor constraint may hinder RR farmers to benefit more in the management of numerous paddy fields because of the longer duration of RR. Moreover, information provided by the government and farmers increase the probability of RR adoption.

Let us turn to the yield effect of adoption of RR, which is the main objective of this study. The results for the two regime equations in ERS model are reported in the third and the fourth columns of Table 2. At farm input level, fertilizer quantity has the greatest positive elasticity: A 1% increase in fertilizer quantity would lead to about 29 and 5% yield increase in RR and SR production, respectively. This indicates that the resource efficiency of fertilizer by RR is

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Table 2. Parameter estimates with endogenous switching regression of rice yield. [a]

Variables	Criterion	Regime function	
		SR	RR
Seed quantity (kg ha^{-1}), log	0.15	0.03**	0.06***
	(0.13)	(0.02)	(0.02)
Fertilizer quantity (kg ha^{-1}), log	1.62***	0.06**	0.29***
	(0.17)	(0.03)	(0.03)
Pesticide quantity (kg ha^{-1}), log	0.13	-0.00	0.02
	(0.09)	(0.01)	(0.02)
Total labor(h ha^{-1}), log	0.27***	-0.02**	0.01
	(0.06)	(0.01)	(0.01)
Gender of household head	0.17	-0.03	0.04
	(0.18)	(0.02)	(0.03)
Age of household head	0.00	0.00*	0.00
	(0.01)	(0.00)	(0.00)
Education level	0.016	0.01***	-0.00
	(0.02)	(0.00)	(0.00)
Decisionmaker in rice production	0.10	-0.02	0.03
	(0.19)	(0.03)	(0.03)
Farming labor in family	-0.02	-0.01	0.01
	(0.05)	(0.01)	(0.01)
Member in cooperative	0.40***	0.01	0.02
	(0.12)	(0.02)	(0.02)
Total rice area cultivated	0.12**	-0.00	0.01
	(0.05)	(0.01)	(0.01)
Land fragmentation	-0.00**	-0.00	-0.00
	(0.00)	(0.00)	(0.00)
Irrigation condition	0.30***	0.02	0.04***
	(0.10)	(0.01)	(0.02)
Mechanical services	1.47***	0.01	0.11***
	(0.10)	(0.03)	(0.02)
Crop rotation	-0.29*	0.04**	-0.00
	(0.18)	(0.02)	(0.03)
Government extension	0.33***	/	/
	(0.10)		
Farmer to farmer extension	0.41***	/	/
	(0.09)		
Region dummy variables	Control	Control	Control
Constant	-13.40***	8.54***	7.13***
	(1.18)	(0.20)	(0.21)
$\ln\sigma_{RR}$, $\ln\sigma_{SR}$		-1.73***	-1.59***
		(0.03)	(0.04)
$\rho_{\varepsilon\psi_{RR}}$,$\rho_{\varepsilon\psi_{SR}}$		-0.05	0.88***
		(0.18)	(0.14)
F test of IV	F= 0.95 Prob>F= 0.39		
LR (Wald test) for independent equation χ^2	Chi2 (2)= 234.00 Prob> Chi2= 0.00		
Number of observations			1284

[a] *Note:* The dependent variable is the log of rice yield (kg ha^{-1}).* Significant at the 10% level; ** Significant at the 5% level, *** Significant at the 1% level.

greater than that of SR. Another important factor is seed quantity: A 1% increase in seed increases rice yield by about 6 and 3% in RR and SR production, respectively. The practice of sowing in both RR and SR production is once, but RR production will yield more rice due to the ratooning management. Additionally, total labor has negative effect on rice yield in SR production. Other differences between the two regimes are related to irrigation service, mechanical service, and crop rotation. Irrigation condition has a significant positive effect on yield in RR production, while it has no effect on SR production. This is due to the fact that RR consists of the main stage and ratooning stage, thus total water supply is required more to cover the longer duration. Similarly, having access to mechanical service increases yield by about 11% in RR production but no effect on SR production, therefore, mechanical service is a great technical problem and more important for RR cultivation. In contrast, crop rotation had no effect on RR production, while a significant positive effect was found in SR production. Rice-based rotation patterns are planting patterns of increasing yield and improving soil fertility, and are mostly practiced in SR cultivated regions (Chen *et al*., 2018).

We used Equations (6)-(11) to calculate the average treatment effect of RR adoption on rice yield. Table 3 presents the net impacts on rice yield accounting for selection bias from observed and unobserved factors. RR farmers would have a significant loss in rice yield if they had not adopted RR (ATT= 0.46). A 5.15% increase is observed in Table 3, which is higher than the increase in Table 1 {4.87%= [ln(12276.11)-ln(7926.33)]/ln(7926.33)}.The SR farmers, if they could have adopted, would have gained 1.89% of rice yield. The net yield effect of scale heterogeneity is also compared in Table 3. Large farms and small farms are differentiated by the area owned above and below 2 ha (World Bank, 2003). In particular, the expected increase in yield is 5.23% for large farms and 5.00% for small farms, respectively. The ATU for the two types of farms also indicates that SR farmers would benefit if they switched to RR, though it is relatively small. Hence, the decision of RR adoption seems to be rational for farmers.

Rice Income Effects

The results for rice income effect of RR adoption estimated by the ESR model are shown in Table 4. Rice yield effects were reported above, and we will further quantify to what extent yield productivity from RR adoption can translate into income. The coefficient of $\rho_{\varepsilon\psi_{RR}}$ is non-zero and significantly negative; $\rho_{\varepsilon\psi_{SR}}$ is non-zero and

Table 3. Average treatment effects of RR on rice yield. [a]

	Observation	With RR		Without RR		Treatment effect	In %
		Mean ln (Yield)	SD	Mean ln (Yield)	SD		
RR	616	9.45	0.11	8.99	0.08	ATT: 0.46***	5.12
SR	668	9.15	0.09	8.98	0.10	ATU: 0.17***	1.89
Large farm-RR	69	9.46	0.10	8.99	0.07	ATT: 0.47***	5.23
Large farm-SR	111	9.16	0.10	8.98	0.10	ATU: 0.18***	2.00
Small farm-RR	547	9.45	0.12	9.00	0.08	ATT: 0.45***	5.00
Small farm-SR	557	9.15	0.09	8.98	0.10	ATU: 0.17***	1.89

[a] Note: The yields shown are predictions based on the coefficients estimated with the ESR model. As the dependent variables in the model are logarithm of yields in kg per hectare, the predictions are also given in logarithm form. Converting the mean back to kg would lead to inaccuracies, due to the inequality of arithmetic and geometric means.
* Significant at the 10% level; ** Significant at the 5% level, *** Significant at the 1% level.

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significantly positive. This indicates that there is heterogeneity that could lead to biased estimates without corrections. Again, extension service serves as instrument in ESR model.

The parameters estimation in the selection equation is shown in column 2 of Table 4. Several factors at farm input level, such as prices of seed, fertilizer, and pesticide have significant and negative effects on RR adoption, while total labor shows a negative and significant effect on the adoption. Membership in a cooperative, irrigation condition, and mechanical service have significant positive effect on RR adoption. We also note that the two variables of government extension and farmer-to-farmer extension, used as instruments, are both positive and significant drivers of RR adoption.

Two regimes equations are shown in columns 3 and 4 of Table 4. Notable differences are found between the RR and SR in various factors. Pesticides price has negative elasticity in both regimes. Increase in pesticide price by 1% would decrease rice income by about 41% on RR farms and about 25% on SR farms. Total labor, on the other hand, has negative elasticity in RR production. A 1% increase in total labor decreases rice income in RR production by about 5%. As for other factors, irrigation condition and mechanical service have significant and positive effects on rice income in both regimes. A positive effect is also found in crop rotation for SR production.

The average treatment effects of RR adoption on rice income are presented in Table 5. The ATT is statistically significant, meaning that adopters benefit economically from RR adoption. RR farmers would experience 3.74% reduction in rice income if they had not adopted RR. A significant positive increase of 5.20% is observed in rice income if they could have adopted RR. When accounting for scale heterogeneity, the ATT shows that large farms benefit significantly more than small farms. A similar trend is also found in ATU when SR farmers switched to RR production. This is due to the higher degree of specialization of large farms, which means RR adoption is associated with higher importance of rice income in household income and lower opportunity costs in other economic activities.

Technical Efficiency (TE)

The average treatment effects of RR adoption on TE are presented in Table 6. TE is first calculated by EBM model. Then, the TE score as dependent variable and the adoption of RR as independent variable are included into ERS model to estimate the results. Again, extension service is selected as instrumental variable. The selection equation is shown in the second column. Several factors such as membership in cooperative, irrigation condition, mechanical service have significant effects on the adoption of RR. Government extension and farmer-to-farmer extension were also identified as major constraint for the adoption of RR.

The two regime equations are shown in the third and fourth columns of Table 6. In both regimes, land fragmentation has a significant positive effect on TE. This is because land fragmentation may discourage commercialization, resulting in inefficiency in agricultural production (Manjunatha *et al*., 2013). A large and positive effect is found in irrigation condition. Adequate irrigation water is conducive to improving the technical efficiency of rice production (Kea *et al*., 2016). For SR farmers, farm size has a significant positive effect on TE, and one hectare increase in farm size will increases technical efficiency scores about 0.01, which is consistent with the research results of Bojnec and Latruffe (2013).

Table 7 presents the estimates of the effect of the adoption of RR on TE. The average adoption effects are calculated by Equations (6)-(11) after controlling for observed and unobserved heterogeneity. Generally, the adoption of RR has an average positive impact on TE. Strikingly, RR

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Table 4. Parameter estimates with endogenous switching regression of rice income. [a]

Variables	Criterion	Regime function	
		SR	RR
Seed price (Yuan kg^{-1}), log	0.29***	-0.02	-0.01
	(0.10)	(0.02)	(0.02)
Fertilizer price (Yuan kg^{-1}), log	-0.65***	-0.07	-0.05
	(0.21)	(0.04)	(0.03)
Pesticide price (Yuan kg^{-1}), log	-1.05***	-0.25***	-0.41***
	(0.40)	(0.08)	(0.07)
Labor (h ha^{-1}), log	0.30***	-0.01	-0.05***
	(0.06)	(0.01)	(0.01)
Gender of household head	0.13	-0.07**	0.04
	(0.17)	(0.03)	(0.03)
Age of household head	0.00	0.00**	0.00*
	(0.01)	(0.00)	(0.00)
Household head year of schooling	0.01	0.01***	-0.00
	(0.02)	(0.00)	(0.00)
decision maker in rice production	-0.04	-0.02	0.01
	(0.19)	(0.03)	(0.03)
total labor force in family	-0.04	-0.01	0.01
	(0.05)	(0.01)	(0.01)
Member in cooperative	0.51***	0.03	0.02
	(0.12)	(0.03)	(0.02)
Total rice area cultivated	0.07	0.01	0.00
	(0.05)	(0.01)	(0.01)
Land fragmentation	-0.00	-0.00	0.00
	(0.00)	(0.00)	(0.00)
Irrigation condition	0.39***	0.05***	0.05***
	(0.10)	(0.02)	(0.02)
Mechanical services	1.53***	0.08**	0.06**
	(0.10)	(0.03)	(0.03)
Crop rotation	-0.13	0.07**	0.02
	(0.17)	(0.03)	(0.03)
Governmentextension	0.49***	/	/
	(0.10)		
Farmer to farmer extension	0.57***	/	/
	(0.09)		
Region	Control	Control	Control
Constant	1.158	11.000***	12.110***
	(1.414)	(0.269)	(0.264)
$\ln\sigma_{RR}$, $\ln\sigma_{SR}$		-1.51***	-1.59***
		(0.03)	(0.03)
$\rho_{\varepsilon\psi_{RR}}$,$\rho_{\varepsilon\psi_{SR}}$		0.37**	-0.38**
		(0.18)	(0.17)
F test of IV			F=0.59 Prob>F= 0.55
LR (Wald test) for independent equation χ^2			Chi2 (2)= 173.51 Prob> Chi2= 0.00
Number of observations			1284

[a] *Note*: The dependent variable is the log of rice income (Yuan ha^{-1}). * Significant at the 10% level; ** Significant at the 5% level, *** Significant at the 1% level.

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Table 5. Average treatment effects of RR on rice income.

	observation	With RR		Without RR		Treatment effect	In %
		Mean ln (Income)	SD	Mean ln (Income)	SD		
RR	616	10.26	0.12	9.89	0.08	ATT: 0.37***	3.74
SR	668	10.32	0.13	9.81	0.10	ATU: 0.51***	5.20
Large farm-RR	69	10.28	0.13	9.90	0.09	ATT: 0.38***	3.84
Large farm-SR	111	10.35	0.13	9.83	0.10	ATU: 0.52***	5.29
Small farm-RR	547	10.26	0.12	9.89	0.08	ATT: 0.37***	3.74
Small farm-SR	557	10.31	0.12	9.80	0.10	ATU: 0.51***	5.20

[a] Note: The income shown are predictions based on the coefficients estimated with the ESR model. As the dependent variables in the model are logarithm of income in yuan per hectare, the predictions are also given in logarithm form. Converting the mean back to yuan would lead to inaccuracies, due to the equality of arithmetic and geometric means. * Significant at the 10% level; ** Significant at the 5% level, *** Significant at the 1% level.

farmers would have significantly greater TE had they adopted SR, implying an ATT of 20.75%.

A positive and significant ATU is also found for SR farmers, suggesting that mean TE could be 44.00% higher if RR were adopted by them. With regard to scale heterogeneity, the percentage changes show a little difference. For instance, the ATT is statistically significant with 20.37% in magnitude for large farms, but it is relatively smaller than small farms. The difference between the two farms underlines heterogeneity in impacts due to various agro-ecological and socio-economic factors.

CONCLUSIONS

The economic assessment of RR production is important to promote effective adoption behavior, as farmers place an important weight on the perceived and actual economic returns when adopting a technology. We used a survey sample of paddy farms from Hubei Province to quantify the economic performances of RR production in terms of yield, income, and technical efficiency. Using ESR framework, we corrected selection bias and endogeneity from both observed and unobserved heterogeneity.

Controlling for selection bias, we find a positive and significant relationship between farmers' adoption decision of RR and impacts of rice yield, rice income, and TE. For RR farmers, the adoption of RR increases rice yield by 5.12%, rice income by 3.74%, and TE by 20.75%. Interestingly, the magnitude of ATU effects is similar to ATT. Predictions in this study show that SR farmers would get higher yield (1.89%), rice income(5.20%), and TE (44.00%) when they switch to RR. The estimates, differentiated by farm size, revealed that the yield and income gains brought by the adoption of RR for large farms were higher than that for small farms. This suggests that farmers with large farms will benefit more from the adoption of RR.

RR production may help to achieve three primary goals in rice production: to lower production costs, reduce environmental pollution, and to adapt successfully to climate variability. Economic performance is pivotal to make a persuasive argument of why RR might be a more viable option than SR, and to eventually increase the adoption of this technology. Our study provides a micro perspective on the impact of RR adoption (rice yield, rice income and technical efficiency), which will allows us to better understand the exact benefits if farmers decide to switch from SR to RR in rice production.

Policies aiming to promote RR should focus on technical training in pesticide management, irrigation, and mechanical service. Our study also shows that policies and strategies should target farmers with large farm in the early stage of RR promotion. This study has some limitations that should be addressed in future studies. First, the economic benefits of RR production depend on farmers' motivation and

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Table 6. Parameter estimates with endogenous switching regression of technical efficiency.

Variables	Criterion	Regime function SR	Regime function RR
Gender of household head	0.17	0.00	0.04**
	(0.16)	(0.02)	(0.02)
Age of household head	-0.00	0.00***	0.00
	(0.01)	(0.00)	(0.00)
Household head year of schooling	0.01	0.01***	0.00
	(0.02)	(0.00)	(0.00)
decision maker in rice production	-0.04	-0.03	0.02
	(0.18)	(0.02)	(0.02)
total labor force in family	0.01	-0.02***	-0.00
	(0.05)	(0.00)	(0.01)
Member in cooperative	0.52***	0.02	-0.01
	(0.12)	(0.02)	(0.01)
Total rice area cultivated	0.04	0.01*	0.00
	(0.05)	(0.01)	(0.01)
Land fragmentation	-0.00	-0.00*	-0.00**
	(0.00)	(0.00)	(0.00)
Irrigation condition	0.38***	0.04***	0.04***
	(0.10)	(0.01)	(0.01)
Mechanical services	1.59***	-0.03	-0.02
	(0.10)	(0.02)	(0.02)
Crop rotation	-0.17	0.02	0.03
	(0.17)	(0.02)	(0.02)
Governmentextension	0.42***	/	/
	(0.10)		
Farmer to farmer extension	0.45***	/	/
	(0.09)		
Region	Control	Control	Control
Constant	-1.39***	0.48***	0.63***
	(0.39)	(0.05)	(0.05)
$\ln\sigma_{RR}, \ln\sigma_{SR}$		-1.90***	-1.92***
		(0.03)	(0.03)
$\rho_{\varepsilon\psi_{RR,}} \rho_{\varepsilon\psi_{SR}}$		0.28	-0.27*
		(0.18)	(0.15)
F test of IV		F= 0.22 Prob> F= 0.80	
LR (Wald test) for independent equation χ^2		Chi2 (2)= 113.81 Prob> Chi2= 0.00	
Number of observations			1284

* Significant at the 10% level; ** Significant at the 5% level, *** Significant at the 1% level.

Table 7. Average treatment effects of ratoon tice on technical efficiency.

	observation	With RR		Without RR		Treatment effect	%
		Mean TE	SD	Mean TE	SD		
RR	616	0.64	0.06	0.53	0.06	ATT: 0.11***	20.75
SR	668	0.72	0.07	0.50	0.06	ATU: 0.22***	44.00
Large farm-RR	69	0.65	0.06	0.54	0.05	ATT: 0.11***	20.37
Large farm-SR	111	0.71	0.08	0.51	0.07	ATU: 0.20***	39.22
Small farm-RR	547	0.64	0.06	0.53	0.06	ATT: 0.11***	20.74
Small farm-SR	557	0.72	0.07	0.50	0.06	ATU: 0.22***	44..00

* Significant at the 10% level; ** Significant at the 5% level, *** Significant at the 1% level.

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ability to adapt local circumstances (Noltze *et al*., 2013). For RR farmers, the impact of adoption may change over time with growing experience, which could not be examined with the cross-section data. Panel data will be acquired for dynamic analysis of the impact in the future.

Second, the impact of the adoption of RR depends on the access to technical information and advice (Basu and Leeuwis, 2012). Identifying effective extension methods is important to promote the successful spread of new technology. Government extension and farmer-to-farmer extension were taken into account. However, interaction effects between these two typical types of extensions might provide unique insight into the adoption-decision making process.

Third, due to data limitations, our research focused on farmer's production behavior in Hubei Province, a typical and important region of central China. Thus, the generalizability of our results is limited to central China. Data from different regions (e.g. Guangdong in South China, Heilongjiang in North China) should be included to make the results more general.

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کمّی کردن عملکرد اقتصادی تولید برنج راتون در چین: تحلیل با رگرسیون تعویضی درون زا

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چکیده

به منظور رشد بهره وری و کاهش اثرات محیطی، برنج راتون (RR) به عنوان جایگزینی موثر برای سامانه کشت برنج پیشنهاد شده است، ولی در مورد RRداده های عملکرد اقتصادی برای کشاورزان محدود است. در این پژوهش، برای ارزیابی اثر کاشت RRدر منطقه Hubei در چین، یک بررسی پیمایشی در مزارع برنجکاری انجام شد. به این منظوراز رگرسیون تعویضی درون زا (Endogenous switching regression) برای توضیح ناهمگنی مشاهده شده و مشاهده نشده استفاده شد. در این رابطه، اثر عملکرد، درآمد، و کارآیی فنی کشت RR تجزیه تحلیل شد. نتایج نشان داد که کشت RRروی عملکرد، درآمد، و کارآیی فنی اثرات بزرگی میگذارد. در مورد شالیکارانی که RRکاشته بودند، افزایش عملکرد برنج به اندازه ۵٪ و درآمد در حد ۳/۷۴٪ به دست آمد. همچنین، در صورتی که برنجکاران به جای کشت یک نوبت برنج در سال (single rice) از برنج RR استفاده کنند، عملکرد، درآمد، و کارآیی فنی به طور معناداری افزایش می یابد. در مواردی که کشاورزان به جای کشت یک نوبت برنج در سال ، برنج RR کاشته بودند

کارآیی فنی اختلاف زیادی نشان داد. کاشت RR برای هر دو شالیکاران مزارع کوچک و مزارع بزرگ سود آور بود. مزارع بزرگ عملکرد و درآمدی بیشتر از مزارع کوچک به دست می آورند، در حالیکه در مزارع کوچک کارآیی فنی بیشتر از مزارع بزرگ است. داده های به دست آمده این پژوهش نتایج معقول و زمان بندی شده ای در زمینه برنامه ها و سیاستگزاری های ملی چین در آینده برای کاشت RR و با هدف ترویج بیشتر عملیات زراعی پایدار همراه با کاهش اثرات محیطی در کشاورزی فراهم آورده است.

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