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Effects of varieties and seasons on cost efficiency in rice farming: A stochastic metafrontier approach

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ABSTRACT
Rice production costs vary substantially across rice varieties and cropping seasons; however, the effects of rice varieties and cropping seasons on the cost efficiency of rice farming have not been given much attention by researchers. In this paper, we attempt to examine these effects on the cost efficiency of rice production in Vietnam. We use a stochastic metafrontier approach to compare the cost efficiency of rice production between two rice variety groups (a high-quality rice variety and a conventional rice variety group) and three cropping seasons (Winter-Spring, Summer-Autumn, and Autumn-Winter). The data consist of 918 observations collected from rice farmers in the Mekong River Delta, the main rice-cultivation region of Vietnam. The results show that there is statistical evidence for the effects of rice varieties and cropping seasons on cost efficiency. High-quality rice variety adopters performed less efficiently (0.837) than non-adopters (0.864). Rice farmers exhibited a lower mean cost efficiency in the Winter-Spring season (0.883) than in the Summer-Autumn (0.907) and Autumn-Winter (0.905) seasons. This research suggests that policies should support inefficient rice farmers to reduce their inefficiency in the Winter-Spring season as well as support high-quality rice variety adopters to catch up with the cost-efficiency level of conventional rice variety farmers.

Contribution/Originality: This is the first paper to employ a stochastic metafrontier approach to examine the effects of varieties and seasons on cost efficiency in rice farming in Vietnam. The findings concerning the variety and season effects provide useful information for policymakers to design policies to help rice farmers minimize production costs.

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1. INTRODUCTION
Rice farming plays an important role in national food security and households' livelihoods. However, the overuse of inputs such as chemical fertilizers, pesticides, and herbicides is increasing production costs, environmental issues (e.g., increasing greenhouse gas emissions (CH_4 and N_2O), water pollution, and soil quality degradation), and health

problems and leading to low-quality outputs. Therefore, the efficient use of inputs would be a feasible approach to mitigate these issues.

Many studies on the efficiency of rice farming have been conducted in Vietnam (Huy, 2009; Khai & Yabe, 2011; Linh, 2012; Truong, Nanseki, & Chomei, 2015; Tung, 2013); however, researchers have overwhelmingly focused on technical efficiency measurement and ignored the importance of input prices, which substantially affect farmers' decisions regarding the use of inputs. Moreover, the impacts of rice varieties and seasons have not been given much attention. Some studies related to cost efficiency (CE) measurement in rice farming can be found in the literature (Siagian & Soetjipto, 2020; Thanh, Hoang, & Seo, 2012; Tu & Trang, 2016). However, these studies did not consider the impacts of rice varieties and cropping season on cost efficiency. Only Gweyi-Onyango et al. (2021) have studied the effects of rice varieties and seasons on nitrogen use efficiency and management among rice farmers in Kenya.

To fill this gap, we adopted a stochastic metafrontier approach, introduced by Huang, Huang, and Liu (2014), to examine the impacts of rice varieties and seasons on cost efficiency among Vietnamese rice farmers in the Mekong River Delta. This paper makes the following contributions to the literature: (1) it is the first paper employing the stochastic metafrontier approach, which allows the researcher to control for the technology gap due to the differences in rice variety groups and seasons and thus assess the impacts of varieties and seasons on rice farming CE in Vietnam. (2) The findings regarding the variety and season effects on CE provide useful information for policymakers to build policies to help rice farmers minimize production costs.

The rest of the paper is structured as follows: Section 2 reviews the literature related to efficiency measurement methods and empirical applications. Section 3 outlines the materials and methods, including the stochastic cost metafrontier approach, empirical model, and data used in this paper. The results are reported and discussed in Section 4. Section 5 summarizes the conclusions and policy implications.

2. LITERATURE REVIEW

Cost efficiency is measured as the ratio of the minimum cost to the observed cost (Kumbhakar & Lovell, 2003). Two common methods have been used to measure CE, namely stochastic frontier analysis (SFA) (Aigner, Lovell, & Schmidt, 1977; Battese & Corra, 1977) and data envelopment analysis (DEA) (Charnes, Cooper, & Rhodes, 1978). While the SFA method is able to separate classical noise from inefficiency, the DEA approach cannot.

The concept of metafrontier was introduced by Hayami (1969), Hayami and Ruttan (1970), and Hayami and Ruttan (1971), who defined the meta-production function as "the envelope of commonly conceived neoclassical production functions" (Hayami & Ruttan, 1971). According to Binswanger, Ruttan, Hayami, Wade, and Weber (1978), the meta production is "the envelope of the production points of the most efficient countries," with the assumption that all firms in different groups, such as countries and regions, can access and produce using the same technology. There are two approaches to measuring the metafrontier. Battese, Rao, and O'Donnell (2004) and O'Donnell, Rao, and Battese (2008) used non-parametric approaches to measure the metafrontier. However, the main limitation of these approaches is that in the second step of the estimation procedure, they use mathematical programming techniques instead of regression techniques to calculate the metafrontier function. Thus, the metafrontier estimates in the second step of the estimation procedure do not have statistical properties (Huang et al., 2014). Huang et al. (2014) proposed an alternative method to solve this shortcoming by employing stochastic frontier regression to estimate the metafrontier in the second step of the estimation procedure.

In this paper, therefore, we employ the stochastic metafrontier method proposed by Huang et al. (2014). The stochastic metafrontier method has been commonly used in empirical studies related to efficiency measurement (Alem, Lien, Hardaker, & Guttormsen, 2019; Chaffai & Hassan, 2019; Dong, Mu, & Abler, 2019; Fontin & Lin, 2019; Issahaku & Abdulai, 2020; Lawin & Tamini, 2019; Le, Vu, & Nghiem, 2018; Melo-Becerra & Orozco-Gallo, 2017; Nguyen, Nghiem, Roca, & Sharma, 2016).

3. MATERIALS AND METHODS

3.1. Stochastic Metafrontier Approach

Following the approach of Huang et al. (2014), the stochastic cost frontier function of the ith farm in the jth group is written in Equation 1 as:

$$C_{ji} = f^j(Q_{ji}; W_{ji}; \beta_j)\, e^{\varepsilon_{ji}} \qquad (1)$$

Where C denotes the variable production cost, Q represents the quantity of output, W denotes a vector of input prices, β represents a vector of unknown parameters that need to be estimated, and ε is a composed error ($\varepsilon_{ji} = v_{ji} + u_{ji}$). Here v_{ji} captures a classical noise, assumed to be independently and identically distributed as $N(0, \sigma_v^{j2})$, and u_{ji} is a positive random variable to capture cost inefficiency and is assumed to be distributed as $N^+(\mu^j, \sigma_u^{j2})$.

The CE of the ith farmer with respect to the jth group's frontier is defined in Equation 2 as the ratio of the minimum cost to the observed cost:

$$CE_i^j = \frac{f^j(Q_{ji}; W_{ji}; \beta_j)\, e^{v_{ji}}}{f^j(Q_{ji}; W_{ji}; \beta_j)\, e^{v_{ji}+u_{ji}}} = e^{-u_{ji}} \qquad (2)$$

The common cost metafrontier function enveloping all group cost frontiers is defined as $f^m(Q_{ji}; W_{ji}; \beta_j)$, and its relationship with the individual group cost frontier $f^j(Q_{ji}; W_{ji}; \beta_j)$ is expressed in Equation 3 as:

$$f^j(Q_{ji}; W_{ji}; \beta_j) = f^m(Q_{ji}; W_{ji}; \beta_j)\, e^{-u_{ji}^m}, \qquad \forall\, j, i \qquad (3)$$

Where $u_{ji}^m \geq 0$. Hence, $f^m(.) \geq f^j(.)$, and the gap between the jth group's cost frontier to the cost metafrontier is the technology gap ratio (TGR), defined in Equation 4 as:

$$TGR_i^j = \frac{f^j(Q_{ji}; W_{ji}; \beta_j)}{f^m(Q_{ji}; W_{ji}; \beta_j)} = e^{-u_{ji}^m} \leq 1 \quad (4)$$

The meta cost efficiency (MCE) of the ith farm in the jth group is defined in Equation 5 as the performance of the farm with respect to the cost metafrontier, expressed as:

$$MCE_i^j = \frac{f^m(Q_{ji}; W_{ji}; \beta_j)\, e^{v_{ji}}}{f^j(Q_{ji}; W_{ji}; \beta_j)\, e^{v_{ji}+u_{ji}}} = TGR_i^j \times CE_i^j \quad (5)$$

The estimation procedure of the stochastic cost metafrontier comprises two steps. In step 1, we estimate each group-specific frontier in Equation 6 using the standard maximum likelihood estimation method.

$$\ln C_{ji} = \ln f^j(Q_{ji}; W_{ji}; \beta_j) + \varepsilon_{ji} \quad (6)$$

The CE of the ith farm against the jth group frontier is measured using the Jondrow, Lovell, Materov, and Schmidt (1982) estimator as the conditional expectation, written in Equation 7.

$$\widehat{CE}_i^j = \hat{E}\left(e^{-u_{ji}} \middle| \hat{\varepsilon}_{ji}\right) \quad (7)$$

Where $\hat{\varepsilon}_{ji} = \ln C_{ji} - \ln\hat{f}^j(Q_{ji}; W_{ji}; \beta_j)$ are the estimated composed errors, and $\ln\hat{f}^j(.)$ is the cost frontier estimate of the jth group's frontier.

In step 2, we predict the dependent values of each group frontier, $ln\hat{f}^j(Q_{ji}; W_{ji}; \beta_j)$, in Equation 6 and pool them as the new dependent variable for the metafrontier function in Equation 8 to estimate the TGR.

$$\ln\hat{f}^j(Q_{ji}; W_{ji}; \beta_j) = ln f^m(Q_{ji}; W_{ji}; \beta_j) + \varepsilon_{ji}^m \quad (8)$$

Where $\varepsilon_{ji}^m = v_{ji}^m + u_{ji}^m$ and $\hat{\varepsilon}_{ji}^m = \ln\hat{f}^j(Q_{ji}; W_{ji}; \beta_j) - ln\hat{f}^m(Q_{ji}; W_{ji}; \beta_j)$ are the estimated composed errors. The TGR is obtained following Jondrow's estimator (Jondrow et al., 1982) using Equation 9.

$$\widehat{TGR}_i^j = \hat{E}\left(e^{-u_{ji}^m} \middle| \varepsilon_{ji}^m\right) \quad (9)$$

The MCE is calculated using Equation 10, as the product of group frontier CE and TGR.

$$\widehat{MCE}_i^j = \widehat{TGR}_i^j \times \widehat{CE}_i^j \quad (10)$$

3.2. Empirical Model

To ensure the stochastic cost frontier function satisfies the homogeneity of degree +1 condition, we divide the variable cost and input prices by the labor price. We then demeaned these normalized variables. Thus, the estimates of first-order parameters of input prices and output quantity are interpreted as the partial cost elasticities with respect to output quantity and input prices at the mean values. The general form of the normalized stochastic translog variable cost frontier function for the ith rice farm is written in Equation 11 as:

$$\begin{aligned}\ln C_i = {} & \beta_0 + \beta_s \ln Ws_i + \beta_f \ln Wf_i + \beta_q \ln Q_i + \frac{1}{2}\beta_{ss}\ln Ws_i^2 + \beta_{sf}\ln Ws_i \ln Wf_i + \beta_{sq}\ln Ws_i \ln Q_i + \frac{1}{2}\beta_{ff}\ln Wf_i^2 \\ & + \beta_{fq}\ln Wf_i \ln Q_i + \frac{1}{2}\beta_{qq}\ln Q_i^2 + \beta_{HQRV} HQRV_i + \beta_{SA} SA_i + \beta_{AW} AW_i + v_i \\ & + u_i \end{aligned} \quad (11)$$

Where C_i is the variable cost (USD) of the ith rice farm that is equal to the total expenditure on seed, fertilizer, and labor inputs normalized by labor price (*Wl* in USD/man-day); *Ws* and *Wf* are seed and fertilizer prices (USD/kg), normalized by labor price; *Q* is output quantity (kg); *HQRV* (high-quality rice variety) is a dummy variable to measure the effect of rice varieties (*HQRV* is equal to 1 if farmers used high-quality rice varieties, 0 otherwise); *SA* and *AW* are two dummy variables to capture the impacts of cropping seasons (*SA* and *AW* take a value of 1 if rice is grown in the Summer-Autumn and Autumn-Winter seasons, respectively, 0 otherwise), and v_i, u_i, and β were defined earlier. The cost inefficiency term is expressed in Equation 12 as a function of farm and farmer characteristic factors.

$$\log \sigma_{u_i}^2 = \alpha_0 + \sum_{n=1}^{8} \alpha_n Z_{ni} \quad (12)$$

Where Z is a vector of explanatory factors of the cost inefficiency term. These variables included household heads' experience (*Experience* is measured as years of rice farming), education (*Education* is measured as years of schooling), rice area (*Fsize* is measured in hectares), family size (*Famsize* is the number of household members), extension (*Extension* is measured as the attendance of rice production training), rice land ownership (*Lownership* is measured as the percentage of rice land that is owned by farmers), natural disasters (*Ndisaster* is measured as the percentage of rice loss due to natural disasters such as typhoons, flooding, and drought), and rice diseases (*Rdisease* is measured as the percentage of rice loss due to rice diseases). α are unknown coefficients that need to be estimated.

3.3. Data

This study used data surveyed from 350 rice farmers in Can Tho, An Giang, and Bac Lieu provinces in the Mekong River Delta, Southern Vietnam, using a stratified random sampling technique (refer to Ho (2021)) pages 5 and 124 for details of the sampling procedure). The final data set consisted of 918 observations (rice farmers in the Mekong River Delta can grow rice for up to three seasons per year). The statistical description of the data set is presented in Table 1.

Table 1. Descriptive summary of data used in cost frontier and inefficiency models.

Variable (unit)	Pooled		Rice varieties				Seasons					
			HQRV adopter (n=384)		Non-adopter (n=534)		Winter-spring (n=339)		Summer-autumn (n=329)		Autumn-winter (n=250)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Variables of cost frontier function												
C (USD[a])	859.01	735.48	769.13	709.18	923.64	747.83	846.09	736.89	854.65	753.53	882.26	711.53
Ws (USD/Kg)	0.43	0.13	0.50	0.14	0.38	0.10	0.46	0.14	0.42	0.13	0.40	0.11
Wf (USD/Kg)	0.40	0.06	0.42	0.05	0.38	0.05	0.41	0.06	0.40	0.06	0.39	0.05
Wl (USD/Man-day)	5.77	1.58	5.83	1.16	5.73	1.82	5.80	1.53	5.76	1.55	5.74	1.69
Q (Kg)	15,305.3	14,144.2	12,781.9	12,097.6	17,119.8	15,203.4	16,973.9	15,475.5	14,297.7	13,972.3	14,368.4	12,185.9
HQRV	0.42	0.49	–	–	–	–	0.54	0.50	0.40	0.49	0.27	0.44
WS	0.37	0.48	0.48	0.50	0.29	0.45	–	–	–	–	–	–
SA	0.36	0.48	0.35	0.48	0.37	0.48	–	–	–	–	–	–
AW	0.27	0.45	0.17	0.38	0.34	0.48	–	–	–	–	–	–
Explanatory variables of inefficiency												
Education (Year)	6.17	3.27	6.17	3.42	6.17	3.17	6.22	3.36	6.12	3.23	6.18	3.22
Experience (Year)	26.95	12.08	27.63	12.57	26.46	11.71	27.10	12.21	27.07	12.14	26.60	11.87
Famsize (Person)	3.75	1.49	3.84	1.55	3.68	1.44	3.77	1.52	3.76	1.49	3.71	1.45
Fsize (Hectare)	2.38	2.09	2.08	1.86	2.59	2.22	2.32	2.03	2.40	2.19	2.43	2.05
Lownership (%)	75.11	37.41	79.48	35.57	71.97	38.40	76.29	36.76	75.38	37.35	73.15	38.40
Extension (Number)	2.45	4.88	2.34	4.63	2.52	5.06	2.34	4.78	2.39	4.81	2.67	5.12
Rdisease (%)	2.86	5.45	2.07	5.04	3.43	5.66	2.47	5.26	3.18	5.69	2.97	5.36
Ndisaster (%)	11.00	12.98	12.13	14.72	10.19	11.52	6.78	11.81	11.62	10.96	15.90	14.98

Note: [a]Exchange rate: 1 USD = 23,500 Vietnamese Dong (VND). SD is standard deviation. *n* is the number of observations.

The first part of Table 1 reports the variables that are used in the stochastic cost frontier functions, including variable cost (C), input prices (*Ws*, *Wf*, and *Wl*), output quantity (*Q*), and three dummy variables to measure the impacts of rice varieties (*HQRV*) and seasons (*WS*, *SA*, and *AW*). The mean cost of rice production is approximately $859.01 per farm (or approximately $384.41 per hectare) and varies significantly across rice variety groups and seasons. The mean seed price is $0.43 per kilogram and varies considerably across rice variety groups and seasons. The average fertilizer price[1] is $0.4 per kilogram. The average labor price is $5.77 per man-day. The average output quantity is 15,305.26 kg per farm (or a rice yield of 6,355.95 kg/hectare) and varies substantially across rice variety groups and seasons.

In Vietnam's Mekong River Delta, rice can be grown in up to three seasons per production year, namely in the Winter-Spring season (*WS*), Summer-Autumn season (*SA*), and Autumn-Winter season (*AW*). Rice farmers adopt different rice varieties across regions and seasons. The rice varieties in this study were grouped into the traditional rice variety group (e.g., OM4218 and IR50404) and the high-quality rice variety group (HQRV) (e.g., OM7347, Jasmine, and OM5451). Table 1 shows that Winter-Spring and Summer-Autumn are the main growing seasons, with 37% and 36% of observations, respectively, while Autumn-Winter is the third cropping season, with only 27% of observations. HQRVs have been promoted to help rice farmers increase their income; however, the adoption rate is only 42%.

The second part of Table 1 reports the details of the explanatory variables, which are assumed to affect farmers' cost inefficiency. The average educational level of rice farmers is quite low, 6.17 years; however, they have considerable rice farming experience, with 26.95 years. Rice farmers, on average, attended rice farming extension sessions 2.45 times. Each rice household has approximately 4 members on average. Rice land ownership, on average, accounts for 75.11% of the cultivated rice land. Rice diseases and natural disasters (e.g., typhoons, storms, and droughts) adversely affect rice production in the Mekong River Delta; the surveyed rice farmers estimated average paddy losses of 11% and 2.86% due to natural disasters and rice diseases, respectively.

4. RESULT AND DISCUSSION

4.1. Stochastic Cost Frontier Estimates

The estimates of stochastic cost frontiers for all models (step 1) are presented in Table 2, and the estimates of stochastic metafrontiers (step 2) are presented in Table A1 (Appendix). To check whether the use of stochastic metafrontiers was necessary, we used the generalized likelihood ratio (LR) test to examine whether rice production technology differed between the two rice variety groups (HQRV adopter and non-adopter groups) and three seasons (Winter-Spring, Summer-Autumn, and Autumn-Winter). In doing so, we estimated a pooled model that included binary variables (*HQRV*, *SA*, and *AW*) to capture the potential technology gap between rice variety groups and seasons. We then estimated a separate group frontier for each group. The generalized LR test was used to test the null hypothesis that there was no technology gap across the two rice variety groups and three seasons. The LR values to test the technology difference across rice variety groups and seasons were 95.67[2] and 52.12,[3] respectively, greater than the critical value $\chi^2_{(0.99)}(1) = 5.412$ (Kodde & Palm, 1986), which confirmed that there was different technology across rice variety groups and seasons at a statistically significant level of 1% and that the use of stochastic metafrontiers, in this case, was necessary to obtain unbiased estimates.

The estimates of input prices and output quantity for all models were, as expected, positive and statistically significant, implying that the results satisfied the properties of the cost frontier function. The normalized data were demeaned, so the first estimated coefficients, in this study, could be interpreted as the partially variable cost elasticity with respect to output quantity and input prices at the sample mean. Regarding variety groups, the variable cost elasticities of the HQRV group with respect to input prices and output quantity differed from the non-adopter group. The variable cost elasticities of the HQRV group with respect to output quantity, price of fertilizer, and price of seed, at the sample mean, were 0.954, 0.553, and 0.153, respectively, while the variable cost elasticities of the non-adopter group with respect to output quantity and price of fertilizer, at the sample mean, were lower than those of the HQRV adopter group, 0.890 and 0.495, respectively. However, the variable cost elasticity of non-adopters with respect to the price of seed, at the sample mean, was higher than that of the HQRV adopter group, at 0.351.

Regarding seasons, the partial elasticities of the variable production cost with respect to input prices and the quantity of output varied across cropping seasons. Particularly, the partial elasticity of the variable production cost with respect to the quantity of output, at the sample mean, was highest in the Autumn-Winter season, with 0.927, followed by the Winter-Spring and Summer-Autumn seasons, with 0.923 and 0.900, respectively. Similarly, the partial elasticity of the variable production cost with respect to the price of fertilizer, at the sample mean, was highest in the Autumn-Winter season, with 0.628, followed by the Summer-Autumn and Winter-Spring seasons, with 0.597 and 0.486, respectively. In contrast, the Summer-Autumn season had the highest partial elasticity of the variable production cost with respect to the price of seed, with 0.267 at the sample mean, followed by the Autumn-Winter season, with 0.25, and the Winter-Spring season with the lowest value of 0.230.

[1] Fertilizer price is the average price of all fertilizers farmers used ($\overline{\mathrm{P}} = \sum P_i Q_i / \sum Q_i$).

[2] $\mathrm{LR} = -2 * (\ln L_{\mathrm{Pooled}} - (\ln L_{\mathrm{HQRV\ Adopter}} + \ln L_{\mathrm{Non-adopter}}))$.

[3] $\mathrm{LR} = -2 * (\ln L_{\mathrm{Pooled}} - (\ln L_{\mathrm{Winter-Spring}} + \ln L_{\mathrm{Summer-Autumn}} + \ln L_{\mathrm{Autumn-Winter}}))$.

Table 2. Estimates of stochastic cost frontiers and inefficiency determinants for pooled and group frontier models.

Variable	Pooled		Rice varieties				Seasons					
			HQRV adopter		Non-adopter		Winter-spring		Summer-autumn		Autumn-winter	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Constant	−0.301***	0.023	−0.387***	0.035	−0.251***	0.026	−0.276***	0.040	−0.102***	0.034	−0.101***	0.031
lnW*s*	0.252***	0.035	0.153***	0.055	0.351***	0.046	0.230***	0.052	0.267***	0.060	0.250***	0.076
lnW*f*	0.585***	0.043	0.553***	0.082	0.495***	0.051	0.486***	0.063	0.597***	0.075	0.628***	0.088
lnQ	0.913***	0.013	0.954***	0.026	0.890***	0.014	0.923***	0.020	0.900***	0.023	0.927***	0.026
$0.5(\ln W_s)^2$	0.166	0.107	0.103	0.195	0.343***	0.129	−0.005	0.164	0.194	0.183	0.390*	0.211
lnW*s*_W*f*	−0.110	0.134	0.283	0.256	−0.301**	0.152	0.019	0.191	−0.118	0.237	−0.333	0.281
lnW*s*_Q	0.005	0.027	−0.080	0.050	0.045	0.033	0.008	0.044	−0.008	0.044	−0.008	0.055
$0.5(\ln W_f)^2$	0.401	0.273	0.290	0.572	0.436	0.284	0.130	0.417	0.314	0.471	0.818	0.539
lnW*f*_Q	0.099**	0.040	0.057	0.078	0.125***	0.048	0.140**	0.064	0.093	0.064	0.069	0.084
$0.5(\ln Q)^2$	0.091***	0.015	0.128***	0.026	0.033	0.020	0.071***	0.026	0.072***	0.025	0.144***	0.034
HQRV	−0.047***	0.017	–	–	–	–	−0.119***	0.027	−0.039	0.027	0.047	0.034
SA	0.184***	0.017	0.233***	0.028	0.138***	0.020	–	–	–	–	–	–
AW	0.205***	0.019	0.288***	0.039	0.153***	0.020	–	–	–	–	–	–
Inefficiency determinants												
Constant	−4.152***	0.459	−3.882***	0.661	−4.287***	0.536	−3.071***	0.845	−4.529***	0.806	−5.903***	1.116
Education	−0.104	0.121	−0.262	0.176	−0.017	0.148	−0.141	0.152	−0.094	0.211	−0.028	0.318
Experience	0.013	0.121	0.220	0.172	−0.163	0.160	0.069	0.171	0.086	0.231	−0.176	0.267
Famsize	−0.221*	0.113	−0.162	0.161	−0.236	0.150	−0.468**	0.212	−0.074	0.182	−0.157	0.270
Fsize	0.246**	0.116	0.173	0.195	0.434***	0.140	0.167	0.173	0.324	0.234	0.240	0.251
Lownership	−0.160	0.110	−0.305*	0.175	−0.052	0.138	−0.060	0.155	−0.251	0.204	−0.353	0.298
Extension	−0.087	0.110	−0.415**	0.189	0.224*	0.126	−0.080	0.173	0.018	0.172	−0.131	0.337
Rdisease	0.268***	0.102	0.470***	0.156	0.063	0.117	0.273**	0.138	−0.110	0.258	0.534*	0.320
Ndisaster	1.136***	0.158	1.074***	0.208	1.136***	0.209	0.855***	0.233	1.383***	0.362	1.512***	0.375
Model properties												
$E(\sigma_u)$	0.160	–	0.192	–	0.145	–	0.214	–	0.135	–	0.116	–
σ_v	0.193***	0.006	0.215***	0.011	0.159***	0.007	0.182***	0.013	0.188***	0.010	0.193***	0.010
Log*L*	128.06	–	7.57	–	168.32	–	52.43	–	60.02	–	41.71	–
n	918	–	384	–	534	–	339	–	329	–	250	–

Note: ***, **, and * denote statistically significant levels at 1%, 5%, and 10%, respectively. log*L* is the log-likelihood value. *n* is the number of observations. Coef. is coefficient. SE is standard error.

The results of the inefficiency models show that rice land ownership and extension (rice field training) have a negative effect on the cost inefficiency of the HQRV adopter group, while rice diseases and natural disasters have a positive effect. On the other hand, extension has a positive effect on the cost inefficiency of the non-adopter group. A positive effect of farm size and natural disasters on cost inefficiency is also found in the non-adopter group. Regarding the growing seasons, rice diseases and natural disasters are the key factors affecting cost inefficiency. Natural disasters have a strong positive effect on cost inefficiency across all seasons, whereas rice disease only has a positive effect on cost inefficiency in the Winter-Spring and Autumn-Winter seasons.

4.2. Effects of Varieties and Seasons on Cost Efficiency

Table 3 presents the summary of CE for all frontier models and the results of the one-sample T-test and analysis of variance (ANOVA) test to examine the difference in mean CE across rice variety groups and seasons, respectively. The results show that there are differences in mean CE between rice variety groups (HQRV adopter group and non-adopter group) and seasons (Winter-Spring, Summer-Autumn, and Autumn-Winter seasons) (Table 3 and Figure 1). The mean meta CE scores, in a varied range of 0.837-0.907, are close to the findings of Tu and Trang (2016) (0.9 with a varied range of 0.72–0.97) among rice farmers in An Giang province and Siagian and Soetjipto's (2020) findings (0.86) for Indonesian rice farmers. The mean meta CE of the HQRV adopter group is 0.837, lower than that of the non-adopter group, 0.864. These results are lower than those estimated by the pooled (mean CE_{Pooled} for HQRV adopter and non-adopter groups are 0.895 and 0.912, respectively) and separate group frontiers (mean CE_{Group} for HQRV adopter and non-adopter groups are 0.890 and 0.910, respectively) due to the technology gap between the two rice variety groups (mean TGRs for HQRV adopter and non-adopter groups are 0.940 and 0.950, respectively).

Table 3. Summary of cost efficiency for all models by rice variety and season.

Variable		Rice varieties		Difference	Seasons			F
		HQRV adopter (n=384)	Non-adopter (n=534)		Winter-spring (n=339)	Summer-autumn (n=329)	Autumn-winter (n=250)	
CE_{Pooled}	Mean	0.895	0.912	0.017***	0.922	0.908	0.877	17.7***
	SD	0.114	0.074		0.089	0.071	0.115	
CE_{Group}	Mean	0.890	0.910	0.020***	0.892	0.916	0.923	10.21***
	SD	0.115	0.079		0.098	0.074	0.101	
TGR	Mean	0.940	0.950	0.009***	0.990	0.989	0.980	30.8***
	SD	0.056	0.048		0.009	0.005	0.030	
Meta CE	Mean	0.837	0.864	0.026***	0.883	0.907	0.905	6.46***
	SD	0.124	0.081		0.100	0.075	0.111	

Note: Meta CE = CE_{Group} x TGR. Difference = mean (CE of Non-adopter) - mean(CE of Adopter). *** denotes statistical significance at 1%. F is the F value of the ANOVA test. *n* is the number of observations.

The mean meta CE of the Winter-Spring season is 0.883, lower than those of the Summer-Autumn (0.907) and Autumn-Winter (0.905) seasons. This result differs from those estimated by the pooled (CE_{Pooled}: 0.922, 0.908, and 0.877, respectively) and separate group frontier (CE_{Group}: 0.892, 0.916, and 0.923, respectively) models. This difference is due to the technology gap between seasons (TGR: 0.990, 0.989, and 0.980, respectively). The technology gap, in this case, is due to the different production conditions across seasons, such as rainfall, sunshine time, and temperature.

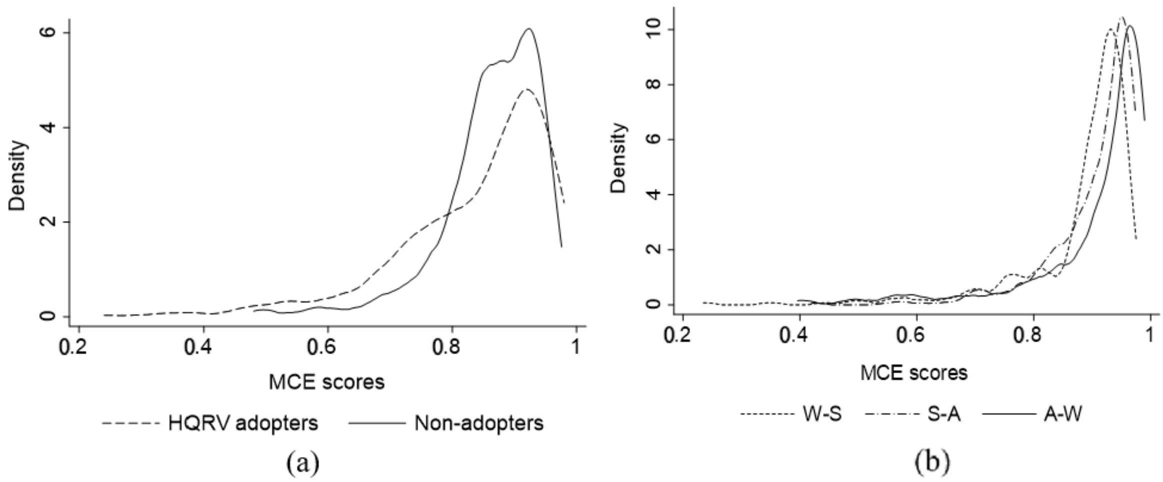

Figure 1. Distributions of meta cost efficiency (MCE) by variety (a) and season (b).

5. CONCLUSION AND POLICY IMPLICATIONS

This paper has examined the effects of rice varieties and seasons on cost efficiency (CE) in rice production in the Mekong River Delta, Vietnam. We used a stochastic metafrontier approach (Huang et al., 2014) to control the potential differences in rice variety technology and production technology across seasons, determined by production conditions such as temperature, sunshine time, rainfall, and irrigation. The data consisted of 918 observations collected from 350 rice farmers in three provinces in the Mekong River Delta, namely the An Giang, Can Tho, and Bac Lieu provinces. We estimated the pooled and group frontier models and then used a generalized likelihood ratio test to examine the potential differences in technology between rice variety groups and seasons. This research used a translog function, with an assumption of the truncated-normal distribution of the inefficiency term.

The results show that there is statistical evidence for the existence of a technology gap among the two rice variety groups (HQRV adopter and non-adopter groups) and three seasons (Winter-Spring, Summer-Autumn, and Autumn-Winter seasons). Thus, the use of the stochastic metafrontier approach is appropriate to control the technology gap and evaluate the impacts of rice varieties and seasons on CE. We find that mean meta CE varies across rice variety groups and seasons. The mean meta CE of the HQRV adopter group is 0.837, lower than that of the non-adopter group, 0.864. The mean (meta) CE of rice farmers in the Winter-Spring season is 0.883, lower than those in the Summer-Autumn (0.907) and Autumn-Winter (0.905) seasons.

The findings suggest that policies should support inefficient rice farmers to reduce their cost inefficiency in the Winter-Spring season. In addition, efforts should be made to support HQRV adopters to help them catch up with the CE level of non-adopters. The analysis of inefficiency models indicates that rice field extension and production skill training to deal with natural disasters and rice diseases would help farmers reduce their inefficiency. A further recommendation for researchers is that the technology gap between rice variety groups and seasons should be taken into account when conducting a comparison study of efficiency across rice variety groups and/or seasons.

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APPENDIX

Table A1. Estimates of stochastic metafrontiers

Variable	Rice varieties			Seasons		
	Coef.		SE	Coef.		SE
Cost metafrontier model						
Constant	−0.363	***	6.13E-07	−0.326	***	0.004
lnWs	0.242	***	7.68E-07	0.243	***	0.006
lnW*f*	0.620	***	1.43E-06	0.572	***	0.007
lnQ	0.890	***	4.69E-07	0.926	***	0.002
0.5(lnW*s*)^2	−0.021	***	1.37E-06	0.139	***	0.019
lnWs_Wf	0.140	***	7.16E-07	−0.060	**	0.024
lnW*s*_Q	0.038	***	1.09E-06	0.009	*	0.005
0.5(lnWf)^2	−0.098	***	2.94E-06	0.161	***	0.051
lnW*f*_Q	0.128	***	1.56E-06	0.088	***	0.007
0.5(lnQ)^2	0.037	***	3.40E-07	0.094	***	0.003
HQRV	−0.049	***	6.74E-07	−0.050	***	0.003
SA	0.232	***	5.27E-07	0.225	***	0.003
AW	0.248	***	5.00E-07	0.280	***	0.004
Technology gap determinants						
Constant	−1.899		1.644	−4.730	***	0.325
Education	−0.001		0.036	0.113		0.091
Experience	−0.022		0.035	0.177	**	0.080
Famsize	−0.029		0.034	−0.009		0.078

Variable	Rice varieties			Seasons		
	Coef.		SE	Coef.		SE
Fsize	0.052		0.032	−0.344	*	0.185
Lownership	−0.064	*	0.037	0.041		0.098
Extension	−0.064	*	0.033	−0.203		0.145
Rdisease	0.010		0.034	0.171	**	0.072
Ndisaster	−0.067	**	0.032	0.514	***	0.093
Model properties						
$E(\sigma_u)$	0.388			0.100		
σ_v	1.70E-10		1.92E-08	0.035	***	0.002
$\log L$	1,714.68			1,588.61		
n	918			918		

Note: ***, **, and * represent the statistically significant levels at 1%, 5%, and 10%. $\log L$ is the log-likelihood value, and n is the number of observations.