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Estimating profit, input demand and output supply elasticities in rice production: Evidence from Vietnam

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Abstract

Understanding rice farmers' responses to market prices is essential for policy makers to design effective policies to better manage input demand and rice supply. This paper applies duality theory to derive the elasticities of input demand and output supply for Vietnamese rice production using a translog profit function approach. We simultaneously estimate the translog profit function and its profit share equations using the seemingly unrelated regression method. This research uses primary farm-level data consisting of 918 observations surveyed in Vietnam's Mekong River Delta. The results indicate that rice farmers' production decisions and profits are more responsive to changes in paddy price than to input prices, with a supply elasticity of 0.33, indicating that a 1% increase in paddy price raises output by 0.33%. A higher paddy price also increases demand for inputs, with elasticities of 0.34 for seed, 0.67 for fertiliser and 0.94 for labour. In addition, variable profit rises by 1.77% for a 1% increase in paddy price, but declines by 0.16%, 0.35% and 0.26% in response to higher seed, fertiliser and labour prices, respectively. A comparison of variable input demand and rice supply elasticities between two rice variety groups shows that adopters of the high-quality rice variety are more responsive to market prices than non-adopters. This research suggests that policies designed on the basis of output price would affect rice farmers' behaviour and variable profits more than those based on input prices. In addition, policy makers should be aware that the same intervention in market prices will result in a different effect on farmers' variable profit, input demand and rice supply between rice variety groups.

Key words: elasticities, factor demand, output supply, translog profit function, SUR method

1. Introduction

The application of duality theory to derive the estimates of input demand and output supply elasticities, which are important for agricultural development policies, has received attention since the 1970s (Lau & Yotopoulos 1971, 1972; Yotopoulos & Lau 1973; Yotopoulos *et al*. 1976; Sidhu & Baanante 1979, 1981). In addition, the development of flexible production functional forms, which were proposed by Diewert (1971, 1973, 1974), Christensen *et al*. (1973) and Lau (1976), allows the application of duality theory for a more disaggregated analysis of the production structure than the traditional approaches (Sidhu & Baanante 1981).

Rice production contributes significantly to economic development and food security worldwide, especially in underdeveloped and developing agricultural countries (Ho *et al*. 2022). Rice is one of three main food sources (rice, wheat and corn) for the worldwide population (Reeves *et al*. 2016). However, the rapidly growing population increases the demand for food, while urbanisation, climate change and production inefficiencies constrain rice supply. This has led to a widening food shortage gap worldwide.

Vietnam is one of the world's leading rice producers and exporters, contributing significantly to the world's food security. Particularly, the Vietnamese rice sector produces approximately 44 million tons of paddy, ensuring domestic food security for approximately 100 million Vietnamese people, and exports about six million tons of milled rice (corresponding to 10% of international rice trading volume) (GSO 2023b). However, previous studies show that rice farming in Vietnam is inefficient. Many studies have been done on the efficiency measurement of rice farming; however, rice farmers' responses to market changes have not been paid much attention. Understanding rice farmers' input demand and rice supply responses to market price changes will provide useful information for policy makers in designing support policies to better manage the input demand and output supply, promoting the development of Vietnam's rice sector. This will make significant contributions to eliminating hunger worldwide.

A review of the literature shows that there have not been many empirical studies on rice farmers' input demand and output supply responses to the changes in market prices, especially in recent years. Several studies have applied the duality theory to derive the elasticities of input demand and output supply in rice farming worldwide. For instance, Shumway (1983) derived output supply and input demand functions for six commodities including rice in Texas. Abedin (1985) studied the elasticities of output supply and input demand for Bangladeshi rice farmers. Adesina and Djato (1996) applied the duality theory to study the economic efficiency of rice farms in Côte d'Ivoire. Chaudhary *et al*. (1998) used duality theory to estimate the elasticities of input demand and output supply of rice, cotton and mixed cropping belts in the Indian Punjab. However, these studies (conducted during the 1980s and 1990s) may now be outdated due to technological advancements in rice farming, climate change impacts, market structure evolution, and various production conditions across countries. Consequently, the conclusions and policy implications drawn from these earlier studies may no longer be directly applicable to Vietnam's contemporary rice sector. In addition, previous studies neglect potential differences in input demand and output supply responses across rice varieties. To fill this gap, we use this paper to derive the elasticities of input demand and rice supply for Vietnamese rice farmers by estimating the translog profit functions and their profit share equations using the seemingly unrelated regression (SUR) method. We also analyse these elasticities by rice variety groups, traditional rice varieties (CRVs) and high-quality rice varieties (HQRVs) to understand whether there are differences in rice farmers' responses between rice variety groups. The paper uses farm-level data surveyed in the Mekong River Delta, the major rice-cultivation region of Vietnam for export purposes.

The main contribution of this paper to the literature is empirical knowledge on rice farmers' responses to market prices, which are useful for policy makers to design proper policies to better manage the input demand and rice supply, thereby promoting the development of Vietnam's rice sector. The findings of this paper would also be a good reference for other rice-farming countries that have similar production conditions. This is the most recent study to employ duality theory in deriving input demand and output supply elasticities for rice farming in Vietnam since the work of Dũng (2010). This is the first study to disaggregate elasticities by HQRVs and CRVs in Vietnam, offering variety-specific policy insights. The dual system approach allows us to obtain robust estimates based on farmers' profit maximisation behaviour, instead of estimating the input demand and rice supply functions separately.

2. Methodology

Hotelling's lemma (Hotelling 1932) is useful since it allows us to derive the functional forms for input demand and output supply functions consistent with profit maximisation simply by selecting a functional form for the profit function and then taking the derivatives with respect to input and output prices (Diewert 1973; Diewert 1974). McFadden (1966) was the original author who appreciated the usefulness of duality theory in deriving the systems of input demand functions in the context of production theory (Diewert 1974).

The application of duality theory to obtain the input demand and output supply functions in agriculture has received attention since the 1980s. For instance, Sidhu and Baanante (1979, 1981) applied the duality theory to estimate input demand and wheat supply elasticities in the Indian Punjab. McKay *et al*. (1983) studied input demand and output supply functions for agricultural multiproduct firms in Australia. Shumway *et al*. (1988) estimated multiproduct supply and input demand in the US agriculture sector, while Roberts and Schlenker (2013) identified supply and demand elasticities of US agricultural commodities. Rahman *et al*. (2016) studied competitiveness, profitability, input demand and output supply of maize production in Bangladesh, and Ejimakor *et al*. (2017) studied agricultural factor use and substitution in the south-eastern United States. Furthermore, several studies have applied the duality theory to derive the elasticities of input demand and output supply in rice farming worldwide (Shumway 1983; Abedin 1985; Adesina & Djato 1996; Chaudhary *et al*. 1998).

2.1 Profit function and duality theory

For the given fixed inputs and technology, the profit function of a maximised-profit firm is written as a function of variable input prices, output price and fixed inputs. The assumptions of the profit function are: (i) firms are profit-maximising, (ii) firms are price takers in both output and variable inputs markets, and (iii) the production function is concave in the variable inputs (Lau & Yotopoulos 1972).

The profit function of a profit-maximised firm with a single output and M inputs is expressed as:

$$\pi = P_y F\left(X_j, Z_k\right) - \sum_{j=1}^{M} W_j X_j, \tag{1}$$

where π denotes variable profit, P_y is the price of output, W_j represents a vector of variable input prices, and $F(X_j, Z_k)$ is the production (output supply) function. X_j and Z_k denote a vector of variable inputs and quasi-fixed inputs, respectively.

To make sure that there is a duality with a corresponding production possibility set or transformation function it is sufficient for the variable profit function (π) to satisfy its regularity conditions (the properties of a profit function) (McFadden 1971; Diewert 1973), as regularity conditions play an important role in the estimation of the profit function (Sickles & Zelenyuk 2019; Kutlu *et al*. 2020).

The properties of a profit function are
(a) π is a non-negative;
(b) π is non-increasing in the variable input prices (W);
(c) π is non-decreasing in the output price (P);
(d) π is a proper convex function in W and P;
(e) π is continuous and homogeneous of degree one in W and P.

A standard way to impose a linear homogeneity restriction is to normalise variable profit (π) and the prices of inputs in Equation (1) by the price of output. We then get the normalised profit function as

$$\frac{\pi}{P_y} = \frac{P_y}{P_y} F\left(X_j, Z_k\right) - \sum_{j=1}^{M} \frac{W_j}{P_y} X_j \tag{1'}$$

or

$$\pi^* = F\left(X_j, Z_k\right) - \sum_{j=1}^{M} P_j X_j, \tag{1''}$$

where π^* is the normalised variable profit and P_j represents a vector of the normalised prices of variable inputs. Other variables were early defined.

Applying Hotelling's lemma (Hotelling 1932; Lau & Yotopoulos 1972), the optimal variable input demand function is a function of input and output prices, and is derived from Equation $(1'')$ by taking the derivatives of the normalised variable profit (π^*) with respect to the normalised prices of variable inputs (P_j).

$$X_j^* = -\frac{\partial \pi^*}{\partial P_j} \tag{2}$$

After multiplying both sides of equation (2) with $\frac{P_j}{\pi^*}$, we have

$$\frac{X_j^* P_j}{\pi^*} = -\frac{\partial \pi^*}{\partial P_j}\frac{P_j}{\pi^*} = -\frac{\partial \ln \pi^*}{\partial \ln P_j} \tag{2'}$$

or

$$X_j^* P_j = \pi^* \left(-\frac{\partial \ln \pi^*}{\partial \ln P_j}\right). \tag{2''}$$

Substituting Equation $(2'')$ into Equation $(1'')$, we have the optimal output supply function as a function of normalised input prices and quasi-fixed inputs, as

$$\pi^* = F^*\left(P_j, Z_k\right) - \sum_{j=1}^{M} \pi^* \left(-\frac{\partial \ln \pi^*}{\partial \ln P_j}\right) \tag{3}$$

or

$$\pi^* = F^*\left(P_j, Z_k\right) + \sum_{j=1}^{M} \pi^* \frac{\partial \ln \pi^*}{\partial \ln P_j} \quad (3')$$

or

$$Y^*_{(P_j, Z_k)} = F^*\left(P_j, Z_k\right) = \pi^* - \sum_{j=1}^{M} \pi^* \frac{\partial \ln \pi^*}{\partial \ln P_j} = \pi^* \left(1 - \sum_{j=1}^{M} \frac{\partial \ln \pi^*}{\partial \ln P_j}\right). \quad (3'')$$

2.2 Translog profit function

The general form of the normalised restricted translog profit function, proposed by Christensen *et al*. (1973) and Diewert (1974), is written as:

$$\ln \pi^* = \alpha_0 + \sum_{j=1}^{M} \alpha_j \ln P_j + \frac{1}{2} \sum_{j=1}^{M} \sum_{h=1}^{M} \gamma_{jh} \ln P_j \ln P_h + \sum_{j=1}^{M} \sum_{k=1}^{K} \delta_{jk} \ln P_j \ln Z_k + \sum_{k=1}^{K} \beta_k \ln Z_k + \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \emptyset_{kl} \ln Z_k \ln Z_l + \varepsilon, \quad (4)$$

where π^*, P_j and Z_k were defined earlier; $\alpha, \beta, \gamma, \delta$ and $\emptyset$ are unknown parameters to be estimated; and ε is an error term, assumed to be normally distributed.

Sidhu and Baanante (1981) and Kumbhakar and Lovell (2003) defined $S_j = \frac{P_j X_j}{\pi^*}$ as the ratio of variable expenditures for the jth input relative to normalised profit (the actual variable profit share equations).

From Equation $(2')$, we have $\frac{X_j^* P_j}{\pi^*} = -\frac{\partial \ln \pi^*}{\partial \ln P_j}$, with the definition of S_j combining with equations $(2')$ and (4). From this, we have the variable profit share equation for the jth input as

$$-S_j = -\frac{X_j^* P_j}{\pi^*} = \frac{\partial \ln \pi^*}{\partial \ln P_j} = \alpha_j + \sum_{h=1}^{M} \gamma_{jh} \ln P_h + \sum_{k=1}^{K} \delta_{jk} \ln Z_k + v_j, \quad (5)$$

where v_j is the error term representing the divergence between the expected and realised price of the jth variable input.

From the estimates of system equations (4) and (5), we apply Hotelling's lemma to obtain the elasticities of variable input demand and output supply.

2.3 Deriving input demand and output supply elasticities

We derive the elasticities of input demand and output supply from the normalised translog profit function by applying Hotelling's lemma as follows:

2.3.1 Variable input demand elasticities

From equations (2), $(2')$ and (5), the demand function for the jth variable input can be expressed as

$$X_j^* = \frac{\pi^*}{P_j}\left(-\frac{\partial \ln \pi^*}{\partial \ln P_j}\right). \quad (6)$$

We take the logarithm on both sides of Equation (6), and we have

$$\ln X_j^* = \ln\pi^* - \ln P_j + \ln\left(-\frac{\partial \ln\pi^*}{\partial \ln P_j}\right). \tag{7}$$

From Equation (7), we can obtain the own-price elasticity of demand (η_{jj}) for the jth input with respect to its own price, P_j, by

$$\eta_{jj} = \frac{\partial \ln X_j^*}{\partial \ln P_j} = \frac{\partial \ln\pi^*}{\partial \ln P_j} - \frac{\partial \ln P_j}{\partial \ln P_j} + \frac{\partial \ln}{\partial \ln P_j}\left(-\frac{\partial \ln\pi^*}{\partial \ln P_j}\right), \tag{8}$$

$$\eta_{jj} = -S_j^* - 1 + \left(-\frac{\partial^2 \ln\pi^*}{\partial^2 \ln P_j}\Big/ -\frac{\partial \ln\pi^*}{\partial \ln P_j}\right), \tag{8'}$$

and from Equation (5), we have $\frac{\partial \ln\pi^*}{\partial \ln P_j} = -S_j$, hence

$$\eta_{jj} = -S_j^* - 1 - \frac{\gamma_{jj}}{S_j^*}, \tag{8''}$$

where S_j^* is the average value of S_j.

Similarly, from Equation (7), we can obtain the cross-price elasticity of demand (η_{jh}) for the jth input with respect to the price of the hth input, P_h, by

$$\eta_{jh} = \frac{\partial \ln X_j^*}{\partial \ln P_h} = \frac{\partial \ln\pi^*}{\partial \ln P_h} + \frac{\partial \ln}{\partial \ln P_h}\left(-\frac{\partial \ln\pi^*}{\partial \ln P_j}\right), \tag{9}$$

$$\eta_{jh} = -S_h^* + \left(-\frac{\partial^2 \ln\pi^*}{\partial \ln P_j\, \partial \ln P_h}\Big/ -\frac{\partial \ln\pi^*}{\partial \ln P_j}\right), \tag{9'}$$

$$\eta_{jh} = -S_h^* - \frac{\gamma_{jh}}{S_j^*}\ , \tag{9''}$$

where $j \neq h$.

From equation (7), we can derive the elasticity of input demand (η_{jy}) for the jth input with respect to the price of output, P_y, by

$$\eta_{jy} = \frac{\partial \ln X_j^*}{\partial \ln P_y} = \frac{\partial \ln\pi^*}{\partial \ln P_y} - \frac{\partial \ln P_j}{\partial \ln P_y} + \frac{\partial \ln}{\partial \ln P_y}\left(-\frac{\partial \ln\pi^*}{\partial \ln P_j}\right), \tag{10}$$

$$\eta_{jy} = \sum_{j=1}^{M} \frac{\partial \ln\pi^*}{\partial \ln P_j}\frac{\partial \ln P_j}{\partial \ln P_y} - \frac{\partial \ln P_j}{\partial \ln P_y} + \sum_{h=1}^{M}\left(-\frac{\partial^2 \ln\pi^*}{\partial \ln P_j\, \partial \ln P_h}\frac{\partial \ln P_h}{\partial \ln P_y}\Big/\left(-\frac{\partial \ln\pi^*}{\partial \ln P_j}\right)\right), \tag{10'}$$

$$\eta_{jy} = \sum_{j=1}^{M} -S_j^*\,(-1) - (-1) + \sum_{h=1}^{M} \frac{-\gamma_{jh}(-1)}{S_j^*}, \tag{10''}$$

$$\eta_{jy} = \sum_{j=1}^{M} S_j^* + 1 + \sum_{h=1}^{M} \frac{\gamma_{jh}}{S_j^*}\ , \tag{10'''}$$

where $j = h = 1, \ldots, M$.

From Equation (7), we can derive the elasticity of input demand $\left(\eta_{jk}\right)$ for the jth input with respect to the kth fixed input, Z_k, by

$$\eta_{jk} = \frac{\partial \ln X_j^*}{\partial \ln Z_k} = \frac{\partial \ln \pi^*}{\partial \ln Z_k} + \frac{\partial \ln}{\partial \ln Z_k}\left(-\frac{\partial \ln \pi^*}{\partial \ln P_j}\right), \tag{11}$$

$$\eta_{jk} = \frac{\partial \ln \pi^*}{\partial \ln Z_k} + \left(-\frac{\partial^2 \ln \pi^*}{\partial \ln P_j\, \partial \ln Z_k} \Big/ -\frac{\partial \ln \pi^*}{\partial \ln P_j}\right), \tag{11'}$$

$$\eta_{jk} = \sum_{j=1}^{M} \delta_{jk} \ln P_j + \beta_k + \sum_{l=1}^{K} \emptyset_{kl} \ln Z_l \; - \frac{\delta_{jk}}{S_j^*}, \tag{11''}$$

where $j = 1, \ldots, M$ and $k = l = 1, \ldots, K$.

2.3.2 Output supply elasticities

Recalling Equation $(3'')$, we have the optimal output supply function as

$$Y^*_{(P_j, Z_k)} = \pi^* \left(1 - \sum_{j=1}^{M} \frac{\partial \ln \pi^*}{\partial \ln P_j}\right).$$

Taking the logarithm on both sides of Equation $(3'')$, we have

$$\ln Y^* = \ln \pi^* + \ln\left(1 - \sum_{j=1}^{M} \frac{\partial \ln \pi^*}{\partial \ln P_j}\right). \tag{12}$$

From Equation (12), we can obtain the elasticity of output supply (ϵ_{yj}) with respect to the price of the jth variable input by

$$\epsilon_{yj} = \frac{\partial \ln Y^*}{\partial \ln P_j} = \frac{\partial \ln \pi^*}{\partial \ln P_j} + \frac{\partial ln}{\partial \ln P_j}\left(1 - \sum_{j=1}^{M} \frac{\partial \ln \pi^*}{\partial \ln P_j}\right), \tag{13}$$

$$\epsilon_{yj} = \frac{\partial \ln \pi^*}{\partial \ln P_j} + \sum_{h=1}^{M} -\frac{\partial^2 \ln \pi^*}{\partial \ln P_j\, \partial \ln P_h} \Big/ \left(1 - \sum_{h=1}^{M} \frac{\partial \ln \pi^*}{\partial \ln P_h}\right), \tag{13'}$$

$$\epsilon_{yj} = -S_j^* - \sum_{h=1}^{M} \gamma_{jh} / \left(1 + \sum_{h=1}^{M} S_h^*\right), \tag{13''}$$

where $j = h = 1, \ldots, M$.

From Equation (12), the own-price elasticity of output supply (ϵ_{yy}) is obtained by

$$\epsilon_{yy} = \frac{\partial \ln Y^*}{\partial \ln P_y} = \frac{\partial \ln \pi^*}{\partial \ln P_y} + \frac{\partial ln}{\partial \ln P_y}\left(1 - \sum_{j=1}^{M} \frac{\partial \ln \pi^*}{\partial \ln P_j}\right), \tag{14}$$

$$\epsilon_{yy} = \sum_{j=1}^{M} \frac{\partial \ln \pi^*}{\partial \ln P_j}\frac{\partial \ln P_j}{\partial \ln P_y} + \sum_{j=1}^{M}\sum_{h=1}^{M} -\frac{\partial^2 \ln \pi^*}{\partial \ln P_j \partial \ln P_h}\frac{\partial \ln P_h}{\partial \ln P_y} \Big/ \left(1 - \sum_{h=1}^{M} \frac{\partial \ln \pi^*}{\partial \ln P_h}\right), \tag{14'}$$

$$\epsilon_{yy} = \sum_{j=1}^{M} -S_j^*\,(-1) + \sum_{j=1}^{M}\sum_{h=1}^{M} -\gamma_{jh}(-1) / \left(1 - \sum_{j=1}^{M} -S_h^*\right), \tag{14''}$$

$$\epsilon_{yy} = \sum_{j=1}^{M} S_j^* + \sum_{j=1}^{M}\sum_{h=1}^{M}\gamma_{jh}/\left(1+\sum_{j=1}^{M} S_h^*\right), \tag{14'''}$$

where $j = h = 1, \dots, M$.

Finally, from Equation (12), the elasticity of output supply (ϵ_{yk}) with respect to the kth quasi-fixed input, Z_k, can be obtained by

$$\epsilon_{yk} = \frac{\partial \ln Y^*}{\partial \ln Z_k} = \frac{\partial \ln \pi^*}{\partial \ln Z_k} + \frac{\partial ln}{\partial \ln Z_k}\left(1-\sum_{j=1}^{M}\frac{\partial \ln \pi^*}{\partial \ln P_j}\right), \tag{15}$$

$$\epsilon_{yk} = \frac{\partial \ln \pi^*}{\partial \ln Z_k} + \sum_{j=1}^{M} - \frac{\partial^2 \ln \pi^*}{\partial \ln P_j\, \partial \ln Z_k}\Bigg/\left(1-\sum_{j=1}^{M}\frac{\partial \ln \pi^*}{\partial \ln P_j}\right), \tag{15'}$$

$$\epsilon_{yk} = \sum_{j=1}^{M}\delta_{jk}\ln P_j + \beta_k + \sum_{l=1}^{K}\emptyset_{kl}\ln Z_l - \sum_{j=1}^{M}\delta_{jk}/\left(1+\sum_{j=1}^{M} S_j^*\right). \tag{15''}$$

2.4 Estimation procedure

We simultaneously estimated system equations (4) and (5) using the iterative seemingly unrelated regressions (ITSUR) method (Zellner 1962). There are common parameters in the translog profit function and its share equation (equations (4) and (5)). Therefore, parameter constraints, which ensure these parameters are equal, were imposed. The estimated parameters were then used to derive the elasticities of input demand and rice supply using equations (7) to (15”). We estimated the full (pooled) and disaggregated (HQRVs and CRVs) models to gain insight into farmers’ input demand and rice supply responses to market prices by rice variety groups. The models were implemented using STATA 17 software.

2.5 Data and variables

This study uses primary farm-level data consisting of 918 observations, collected from 350 rice farmers in the Mekong River Delta (MRD), Vietnam. The MRD region was selected to evaluate rice farmers’ input demand and output supply responses to market prices because it is the largest rice-cultivated region in Vietnam, accounting for 53.49% of the total national rice-cultivated areas (3.80 million hectares), and contributes more than 90% of the country’s rice export volume (GSO 2023a). This indicates that rice production in this region is primarily trade-oriented, with an open and dynamic market, making it suitable for applying the profit function approach. In the MRD, rice is cultivated across 13 provinces, where production conditions – such as soil quality, land resources and freshwater availability – vary significantly. To ensure a representative sample of the cultivated areas, a three-stage stratified random sampling method was employed to select the samples. In the first stage, the 13 provinces were categorised into three groups based on the size of their rice-cultivated area (two groups of four provinces and one group of five provinces). One province was randomly selected from each group, followed by the random selection of two districts from each chosen province. In the second stage, two communes were randomly selected from each district, and subsequently, two villages were chosen from each commune. In the final stage, 33 and 34 rice farmers were randomly selected from the two villages and surveyed through face-to-face interviews. This sampling process yielded 406 respondents. After excluding incomplete responses, the final dataset used in this study includes 350 farmer responses, with 918 observations. The definition and statistical summary of the variables used are presented in Table 1. The variables used in the profit function include the variable profit (π), the input prices of seed (Ws), fertiliser (Wf) and labour (Wl), the price of paddy (Py), fixed input (*Land*), and the dummy variables to capture the effects of rice varieties (*D_HQRVs*) and cropping seasons (*D_SA* and *D_AW*) on farmers' variable profits.

3. Results and discussion

3.1 Data description

The statistical result shows that, on average, the variable profit of rice farming is approximately \$2 456.06 per farm (or \$975.61 per hectare). Rice farmers sold their fresh paddy at an average price of \$0.21 per kilogram. The survey indicates that the main variable inputs of rice production in the Mekong River Delta are seed, fertiliser and labour inputs. The prices of seed and fertiliser, which farmers purchase, are \$0.43 and \$0.40 per kilogram on average. The average labour price, which farmers pay to rent labour, is \$5.77 per man-day. Table 1 also shows that the adoption rate of HQRVs is quite low, at around 42%, while the adoption rate of CRVs is 58%. This affects the quality of exported rice. The Vietnamese government therefore has to make more efforts to promote the adoption of HQRVs to address this issue and enhance rice farmers' income.

Table 1: Definition and descriptive statistics of variables used

Variable	Definition (unit)	Pooled (*n* = 918)		HQRVs (*n* = 384)		CRVs (*n* = 534)	
		Mean	SD	Mean	SD	Mean	SD
Π	Variable profit (USD)	2 456.06	2 560.09	2 151.87	2 279.39	2 674.80	2 725.90
Py	Paddy price (USD/kg)	0.21	0.03	0.22	0.02	0.20	0.02
Ws	Seed price (USD/kg)	0.43	0.13	0.50	0.14	0.38	0.10
Wf	Fertiliser price (USD/kg)	0.40	0.06	0.42	0.05	0.38	0.05
Wl	Labour price (USD/man-day)	5.77	1.58	5.83	1.16	5.73	1.82
Land	The rice-cultivated area (ha)	2.38	2.09	2.08	1.86	2.59	2.22
D_HQRVs	Equal to 1 for high-quality rice varieties, 0 otherwise	0.42	0.49	–	–	–	–
D_SA	Equal to 1 for the Summer-Autumn season, 0 otherwise	0.36	0.48	0.35	0.48	0.37	0.48
D_AW	Equal to 1 for the Autumn-Winter season, 0 otherwise	0.27	0.45	0.17	0.38	0.34	0.48

Notes: Exchange rate: approximately 1 USD = 23 500.0 Vietnamese dong (VND) in 2022

Regarding the cropping seasons, rice farmers in the Mekong River Delta region can grow rice in up to three seasons per year. The statistical summary shows that the main cropping seasons are Winter-Spring (treated as the baseline) and Summer-Autumn, accounting for 37% and 36% of observations, respectively. The third cropping season is Autumn-Winter, which accounts for only 27% of observations.

3.2 Estimates of translog profit function

The parameter estimates of the normalised translog profit function and the profit share equations for the pooled, HQRV and CRV models are presented in Table 2. These estimates were used to derive the elasticity estimates of rice supply and variable input demand (for seed, fertiliser and labour), which are presented in Table 3. The first-order coefficient estimates of seed, fertiliser and labour prices in all models are consistent with the economic theory, and negative and statistically significant at a 1% level, implying that the variable profit has a strong negative relationship with input prices. It is consistent with the findings of Khounthikoumane *et al*. (2021) and Wijetunga (2023). In addition, the first-order coefficient of land is positive and statistically significant at the 1% level for all models, as expected.

The results show that rice variety groups and cropping seasons have a significant effect on the variable profit of rice farmers. The estimate of HQRVs is -0.139 and it is statistically significant at the 1% level, meaning that the variable profit of HQRVs is lower than that of CRVs. This can explain why the adoption rate of HQRVs is still low, at 42% (Table 1). The estimates of *D_SA* and *D_AW* are -0.275 and -0.313, respectively, implying that the variable profits of rice farming in the Summer-Autumn (*D_SA*) and Autumn-Winter (*D_AW*) are lower than in the Winter-Spring.

Table 2: Estimates of translog profit function and its share equations

Variables	Parameter	Pooled (n = 918)		HQRVs (n = 384)		CRVs (n = 534)	
		Coef.	SE	Coef.	SE	Coef.	SE
Translog profit function							
Constant	α_0	0.103***	0.025	-0.034	0.036	0.073***	0.025
lnWs	α_1	-0.168***	0.013	-0.199***	0.026	-0.153***	0.012
lnWf	α_2	-0.360***	0.026	-0.447***	0.049	-0.317***	0.025
lnWl	α_3	-0.246***	0.019	-0.281***	0.032	-0.237***	0.021
lnLand	β_1	1.018***	0.021	1.034***	0.043	1.007***	0.020
0.5lnWs_sq	γ_{11}	-0.123***	0.018	-0.123***	0.034	-0.119***	0.013
lnWs_Wf	γ_{12}	-0.057**	0.026	-0.032	0.047	-0.052**	0.025
lnWs_Wl	γ_{13}	-0.025	0.018	-0.029	0.032	-0.027	0.021
lnWs_Land	δ_{11}	-0.007	0.013	-0.019	0.026	-0.008	0.012
0.5lnWf_sq	γ_{22}	-0.297***	0.051	-0.226**	0.089	-0.324***	0.051
lnWf_Wl	γ_{23}	-0.018	0.034	0.011	0.055	-0.044	0.041
lnWf_Land	δ_{21}	-0.005	0.024	-0.039	0.048	-0.014	0.023
0.5lnWl_sq	γ_{33}	-0.142***	0.026	-0.064	0.041	-0.178***	0.036
lnWl_Land	δ_{31}	0.067***	0.018	0.043	0.031	0.050**	0.020
0.5lnLand_sq	β_{11}	-0.049**	0.023	-0.020	0.039	-0.062**	0.025
D_HQRVs	ρ_1	-0.139***	0.021	–	–	–	–
D_SA	ρ_2	-0.275***	0.023	-0.361***	0.040	-0.188***	0.025
D_AW	ρ_3	-0.313***	0.026	-0.441***	0.050	-0.225***	0.025
Profit share to seed							
Constant	α_1	-0.168***	0.013	-0.199***	0.026	-0.153***	0.012
lnWs	γ_{11}	-0.123***	0.018	-0.123***	0.034	-0.119***	0.013
lnWf	γ_{12}	-0.057**	0.026	-0.032	0.047	-0.052**	0.025
lnWl	γ_{13}	-0.025	0.018	-0.029	0.032	-0.027	0.021
lnLand	δ_{11}	-0.007	0.013	-0.019	0.026	-0.008	0.012
Profit share to fertiliser							
Constant	α_2	-0.360***	0.026	-0.447***	0.049	-0.317***	0.025
lnWf	γ_{22}	-0.297***	0.051	-0.226**	0.089	-0.324***	0.051
lnWs	γ_{12}	-0.057**	0.026	-0.032	0.047	-0.052**	0.025
lnWl	γ_{23}	-0.018	0.034	0.011	0.055	-0.044	0.041
lnLand	δ_{21}	-0.005	0.024	-0.039	0.048	-0.014	0.023
Profit share to labour							
Constant	α_3	-0.246***	0.019	-0.281***	0.032	-0.237***	0.021
lnWl	γ_{33}	-0.142***	0.026	-0.064	0.041	-0.178***	0.036
lnWs	γ_{13}	-0.025	0.018	-0.029	0.032	-0.027	0.021
lnWf	γ_{23}	-0.018	0.034	0.011	0.055	-0.044	0.041
lnLand	δ_{31}	0.067***	0.018	0.043	0.031	0.050**	0.020

Notes: * = $P < 0.10$, ** = $P < 0.05$ and *** = $P < 0.01$. n is the number of observations.

Table 3: Derived elasticity estimates for rice supply and variable input demand

Output and inputs	Values	Paddy price	Seed price	Fertiliser price	Labour price	Land
Pooled						
Rice supply	Mean	0.33	-0.04	-0.14	-0.15	1.00
	SD	*0.19*	*0.05*	*0.08*	*0.10*	*0.06*
Seed demand	Mean	0.34	-0.30	0.05	-0.09	1.08
	SD	*0.64*	*0.37*	*0.19*	*0.12*	*0.06*
Fertiliser demand	Mean	0.67	0.01	-0.47	-0.20	1.05
	SD	*0.35*	*0.07*	*0.23*	*0.09*	*0.05*
Labour demand	Mean	0.94	-0.05	-0.27	-0.62	0.73
	SD	*0.51*	*0.07*	*0.09*	*0.37*	*0.19*
HQRVs						
Rice supply	Mean	0.65	-0.10	-0.30	-0.25	1.05
	SD	*0.11*	*0.05*	*0.05*	*0.04*	*0.02*
Seed demand	Mean	0.89	-0.51	-0.25	-0.13	1.14
	SD	*0.45*	*0.29*	*0.10*	*0.08*	*0.05*
Fertiliser demand	Mean	1.34	-0.12	-0.90	-0.32	1.13
	SD	*0.15*	*0.05*	*0.11*	*0.04*	*0.03*
Labour demand	Mean	1.64	-0.10	-0.47	-1.08	0.89
	SD	*0.12*	*0.05*	*0.05*	*0.07*	*0.04*
CRVs						
Rice supply	Mean	0.15	-0.02	-0.05	-0.09	1.01
	SD	*0.22*	*0.04*	*0.09*	*0.12*	*0.07*
Seed demand	Mean	0.08	-0.17	0.12	-0.02	1.09
	SD	*0.65*	*0.37*	*0.19*	*0.13*	*0.07*
Fertiliser demand	Mean	0.19	0.05	-0.15	-0.08	1.07
	SD	*0.54*	*0.07*	*0.36*	*0.13*	*0.06*
Labour demand	Mean	0.37	0.01	-0.07	-0.31	0.76
	SD	*0.85*	*0.09*	*0.17*	*0.60*	*0.20*
Difference *t*-statistics						
Rice supply		40.74***	-26.48***	-49.75***	-26.54***	11.23***
Seed demand		21.10***	-14.64***	-35.27***	-14.96***	13.54***
Fertiliser demand		40.81***	-38.24***	-39.23***	-34.49***	16.49***
Labour demand		29.01***	-19.55***	-44.05***	-25.05***	12.62***

Notes: The *t*-statistic values from the t-test with the null hypothesis show that there is no difference in mean values between the HQRV and CRV groups. * = $P < 0.10$, ** = $P < 0.05$, *** = $P < 0.01$.

The signs of all own-price coefficients in profit-share equations (or the squared term coefficients of the profit function) are consistent with economic theory (McFadden 1971; Diewert 1973). They are negative and statistically significant at the 1% level. In the profit-share equation for seed, the coefficients for seed price (-0.123) and fertiliser price (-0.057) are both statistically significant, with the former at the 1% level and the latter at the 5% level. In contrast, labour price and land show no significant effects. Similarly, in the fertiliser equation, fertiliser price (-0.297) and seed price (-0.057) remain significant at the 1% level and 5% level, respectively, while labour price and land remain insignificant. Finally, in the labour equation, only labour price (-0.142) and land (0.067) have statistically significant effects at the 1% level, whereas seed price and fertiliser price show no significant effects.

Table 4 shows the summary of the partial variable profit elasticities with respect to prices and land for all models. The estimates are consistent with the economic theory that variable profit has a positive relationship with output price and fixed input, while it has a negative relationship with input prices. In general, the variable profit of rice is elastic with output price and rice area, but inelastic with input prices. Particularly, the partial variable profit elasticities with respect to seed, fertiliser and labour prices, on average, are -0.16, -0.35, and -0.26, respectively, as indicated by the pooled model. This implies that, if the prices of seed, fertiliser and labour inputs increase by 10%, the variable profit will decrease by 1.6%, 3.5%, and 2.6%, respectively, all other factors remaining unchanged. This result is consistent with the findings of Wijetunga (2023). The partial variable profit elasticity with respect to paddy price is 1.77, indicating that a 10% increase in the price of paddy would result in a 17.7% increase in the variable profit of rice, assuming all other factors remain constant. Similarly, the partial variable profit elasticity with respect to rice land is 1.03, suggesting that a 10% increase in rice land would lead to a 10.3% increase in the variable profit, holding other factors constant.

Table 4: Partial profit elasticities with respect to prices and fixed inputs

Variable	Pooled (*n* = 918)		HQRVs (*n* = 384)		CRVs (*n* = 534)		Difference *t*-statistics
	Mean	SD	Mean	SD	Mean	SD	
Paddy price	1.77	0.15	1.92	0.09	1.67	0.17	25.66***
Seed price	-0.16	0.04	-0.19	0.05	-0.14	0.04	-21.77***
Fertiliser price	-0.35	0.06	-0.43	0.05	-0.30	0.07	-33.20***
Labour price	-0.26	0.09	-0.30	0.04	-0.24	0.10	-10.16***
Land	1.03	0.05	1.04	0.02	1.02	0.06	4.16***

Notes: The *t*-statistic values from the t-test with the null hypothesis show that there is no difference in mean values between the HQRV and CRV groups. * = $P < 0.10$, ** = $P < 0.05$, *** $P = < 0.01$.

A comparison of the partial variable profit elasticities with respect to market prices between rice variety groups shows that the variable profit of the HQRV group is more elastic than that of the CRV group. Specifically, the partial profit elasticity with respect to paddy price for the HQRV group is 1.92, higher than for the CRV group (1.67). Similarly, the elasticities of variable profit with respect to seed price (-0.19 vs. -0.14), fertiliser price (-0.43 vs. -0.30), and labour price (-0.30 vs. -0.24) are consistently higher (in absolute value) for the HQRV group than for the CRV group.

3.3 Variable input demand and rice supply elasticities

Table 3 shows the derived elasticity estimates for variable input (seed, fertiliser and labour) demand and rice supply for all models. In general, the signs of the variable input demand and rice supply elasticities with respect to their own price align with expectations, showing positive for rice supply and negative for variable input demand. The variable input demand and rice supply also have positive elasticities with respect to quasi-fixed input (land) in all models, as expected.

3.3.1 Pooled elasticities of variable input demand

The demand elasticities of key inputs in rice production provide insight into how farmers respond to changes in input prices. As input prices rise, the corresponding demand decreases, with varying degrees of responsiveness depending on the inputs. Specifically, the seed demand elasticity with respect to its own price (seed price) is -0.30, indicating that an increase of 10% in seed price will result in a decrease in seed demand by 3%. The fertiliser demand elasticity with respect to its price is -0.47, implying that, if the fertiliser price increases by 10%, the fertiliser demand will decrease by 4.7%. The labour demand elasticity with respect to its own price is inelastic, at -0.62, showing that, if the labour price increases by 10%, the labour demand for rice farming will decrease by 6.2%. This is consistent with the findings of Chaudhary *et al*. (1998) and Wijetunga (2023).

The derived elasticity of input demand with respect to output price demonstrates that an increase in output price leads to higher demand for inputs. The derived elasticity of seed demand with respect to output price is 0.34, implying that, if the paddy price increases by 10%, the seed demand will increase by 3.4%. The value of fertiliser demand elasticity with respect to paddy price is 0.67, suggesting that if the paddy price increases by 10%, the fertiliser demand will increase by 6.7%. The elasticity of labour demand with respect to paddy price is 0.94, indicating that the labour demand will increase by

9.4% if the output price increases by 10%. This finding is in line with empirical evidence from Chaudhary *et al*. (1998) and Wijetunga (2023).

In terms of the cross-price elasticities of inputs, the results indicate that seed and fertiliser function as substitute inputs. However, seed and labour, as well as fertiliser and labour, are complementary inputs. This result aligns with those of previous studies (Yotopoulos *et al*. 1976; Chaudhary *et al*. 1998; Wijetunga 2023). In particular, the cross-price elasticities of seed demand with respect to fertiliser and labour prices are 0.05 and -0.09. This is interpreted as that, if the fertiliser price increases by 10%, farmers will use more seed by 0.5%, whereas if the price of labour increases by 10%, the seed demand will decrease by 0.9%. The cross-price elasticities of fertiliser demand with respect to seed and labour prices are 0.01 and -0.20. This suggests that, if the seed price increases by 10%, fertiliser demand will increase by 1%, while an increase in labour price of 10% will result in a reduction of 2% in fertiliser demand. In addition, the labour demand with respect to seed price is -0.05, suggesting that the seed price has a minor effect on labour demand. The labour demand elasticity with respect to fertiliser price is -0.27, showing that an increase of 10% in fertiliser price will result in a decrease of 2.7% in labour demand. This is consistent with the results of Chaudhary *et al*. (1998).

Regarding the relationship between inputs and land, the derived elasticity of seed demand with respect to land is 1.08, implying that an increase in rice area of 10% will lead to an increase in seed demand by 10.8%. The fertiliser demand elasticity with respect to land is 1.05, indicating that an increase of 10% in land will lead to an increase of 10.5% in fertiliser demand. The elasticity of labour demand with respect to land is inelastic, at 0.73, implying that, if the rice area increases by 10%, the labour demand will increase by only 7.3%. In fact, an expansion in area of rice cultivation increases input demand, as larger areas require more inputs to maintain appropriate planting density. Thus, the demand for inputs rises in line with the increase in cultivated land. This is consistent with the results of Chaudhary *et al*. (1998).

3.3.2 Variable input demand elasticities for different variety groups

A comparison of the HQRV and CRV groups reveals notable differences in the own price elasticity of demand for inputs among different rice variety groups. In particular, the elasticity of seed demand with respect to its own price for HQRVs is -0.51, greater than that for CRVs, at only -0.17, implying that, if the price of seed increases by 10%, the seed demand for HQRVs will increase by 5.1%, while the seed demand for CRVs will increase by only 1.7%. The elasticity of fertiliser demand with respect to its price for HQRVs is -0.90, much greater than that for CRV, at only -0.15, leading to a 9% versus 1.5% reduction in fertiliser demand for a 10% increase in price. The labour demand is elastic with respect to its own price for HQRVs, at -1.08, but inelastic for CRVs, at -0.31.

Regarding the input demand elasticities to paddy price, the result shows that seed demand for HQRVs is more elastic with respect to paddy price than for CRVs, at 0.89 and 0.08, respectively. This indicates that a 10% rise in paddy prices would increase seed demand by 8.9% for HQRVs, but only by 0.8% for CRVs. The fertiliser demand with respect to paddy price is elastic for HQRVs, at 1.34, but inelastic for CRVs, at 0.19,. This indicates that, if the paddy price increases by 10%, the HQRV adopters will increase fertiliser quantity by 13.4%, while the CRV adopters will only increase this by 1.9%. Labour demand is also more elastic for HQRVs (1.64) compared to CRVs (0.37), meaning a 10% increase in rice price would increase the labour demand for HQRVs by 16.4%, while there is a less responsive rise of just 3.7% for CRVs in response to the same increase in rice price.

For the input demand elasticities to fertiliser price, a comparison between the HQRV and CRV groups shows that seed demand with respect to fertiliser price is more responsive for HQRVs than CRVs, at

-0.25 and 0.12, respectively. A 10% rise in fertiliser prices would reduce seed demand by 2.5% for HQRVs, but increase seed demand by about 1.2% for CRVs. Similarly, for HQRVs, the elasticity of labour demand is -0.47, higher than the -0.07 for CRVs, indicating that a 10% increase in fertiliser prices would reduce labour demand by 4.7% for HQRVs and 0.7% for CRVs.

In the case of the input demand elasticities with respect to land, the elasticity of seed demand for HQRVs is estimated at 1.14, slightly higher than the 1.09 observed for CRVs. This implies that a 10% increase in land would lead to a 11.4% rise in seed demand for the HQRV group, while the CRV group would experience only a 10.9% increase. Fertiliser demand is similarly more sensitive for the HQRV group (1.13) than the CRV group (1.07), with labour demand also more elastic for the HQRV group (0.89 versus 0.76). If land increases by 10%, the fertiliser demand will increase by 11.3% for the HQRV group and 10.7% for the CRV group. In addition, for a 10% increase in land, the labour demand will increase by 8.9% for HQRVs and 7.6% for CRVs.

The fertiliser demand elasticities with respect to seed price furthermore show that fertiliser and seed are complementary inputs for HQRVs (-0.12), but substitute inputs for CRVs (0.05). The elasticities of fertiliser demand with respect to labour price are -0.32 for the HQRV group and -0.08 for the CRV group, implying that an increase of 10% in labour price will result in a decrease of 3.2% and 0.8% in fertiliser demand for the HQRV and CRV groups, respectively. However, the elasticities of labour demand with respect to seed price are minor, at -0.10 for HQRVs and 0.01 for CRVs. This suggests that labour and seed are complementary inputs for HQRVs, but substitute inputs for CRVs.

Overall, the comparison of input demand elasticities between the HQRV and CRV groups reveals significant differences in farmer responsiveness to changes in market prices and cultivation area. HQRVs exhibit higher elasticity for seeds, fertilisers, labour and land, indicating that farmers are more responsive to input price, output price and land fluctuations when cultivating higher-quality rice varieties. This indicates that an intervention by the government will be more effective in the case of the HQRV group than the CRV group. These findings underscore the importance of considering input prices, output price and land sensitivity when formulating policies aimed at supporting rice farmers, particularly in the context of promoting sustainable practices and enhancing rice quality.

3.3.3 Rice supply elasticities

The elasticities of rice supply with respect to input prices, output price and land, obtained from equations $(13'')$, $(14''')$ and $(15'')$, respectively, are consistent with economic theory. The rice supply elasticity with respect to paddy price is 0.33, implying that if the paddy price increases by 10%, the paddy supply will increase by 3.3%. The rice supply elasticity with respect to seed, fertiliser and labour prices are -0.04, -0.14 and -0.15, respectively, suggesting that input prices have little effect on rice supply. If the prices of seed, fertiliser and labour increase by 10%, the rice supply will decrease by 0.4%, 1.4% and 1.5%, respectively. This result aligns with the findings of Wijetunga (2023). The rice supply elasticity with respect to the rice area is constantly elastic, at 1.0, implying that, if the rice area increases by 10%, the rice supply will increase by 10%. This is consistent with the findings of Yotopoulos *et al*. (1976) and Wijetunga (2023).

In a comparison between the two rice variety groups, the rice supply elasticities with respect to input prices, paddy price and land for the HQRV group are more elastic than those of the CRV group. Specifically, the rice supply elasticities with respect to paddy price, seed price, fertiliser price, labour prices and land for the HQRV group are 0.65, -0.10, -0.30, -0.25 and 1.05, respectively. The rice supply elasticities with respect to paddy price, seed price, fertiliser price, labour prices and land for the CRV group are much lower, at 0.15, -0.02, -0.05, -0.09 and 1.01, respectively. This pattern aligns with the earlier comparison of input demand elasticities between HQRVs and CRVs, confirming that the input demand and rice supply elasticities of the HQRV group is consistently more sensitive to market prices than those of the CRV group. These findings highlight the critical need for policymakers to consider these differential responsiveness patterns when designing rice supply management policies, particularly those utilising price-based instruments.

4. Conclusion and policy implications

This study aimed to analyse how rice farmers in Vietnam's Mekong River Delta respond to changes in output and input prices. By applying duality theory and employing a translog profit function approach, the research derived input demand and output supply elasticities to understand how farmers adjust their production decisions in response to price fluctuations. The findings are critical for policymakers to design effective policies that enhance input demand management, stabilise rice supply, and improve the economic performance of the rice sector. This study uses primary farm-level data consisting of 918 observations collected from rice farmers in the MRD, Vietnam's primary rice-producing region for export.

The results reveal that rice farmers' input demand and paddy supply are more responsive to changes in paddy price than to input prices. Furthermore, farmers adopting high-quality rice varieties (HQRVs) exhibit significantly higher sensitivity in both input demand and output supply to market price fluctuations compared to the adopters of conventional rice varieties (CRVs), suggesting the need for tailored policy interventions. The analysis also indicates that the variable profit of rice production is elastic with respect to paddy price, but inelastic to input prices. These findings collectively emphasise the critical role of output price mechanisms in shaping farmers' production choices and economic returns. Policy formulation should prioritise output price stabilisation strategies as the primary lever for influencing both rice supply and farm profitability. Policies should account for the different responsiveness of HQRV and CRV adopters, with targeted support for HQRV farmers to enhance the impact of interventions. Input price policies, while important, should be designed cautiously, as their effects on rice supply and input demand are relatively limited compared to paddy price policies.

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