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Economic Impacts of Hybrid Rice Varieties in Vietnam: An Instrumental Analysis

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ABSTRACT

Adoption of agricultural technology is important for improving rice yield and household income in developing countries. Using fixed effects, random effects, and Instrumental Variable/Two-Stage Least-Squares (IV/2SLS) methods, this study examined the economic impacts of agricultural technology adoption by focusing on the case of hybrid rice varieties in rural Vietnam. The empirical results revealed that hybrid varieties adoption significantly increased productivity but induced higher intermediate costs. Meanwhile, there was no significant impact of adoption on value added. In addition, poor adopters had higher productivity and incur more intermediate costs than non-poor adopters. The findings suggest that the Vietnamese government should enact relevant policies to enhance the farmers' access to better inputs and the effectiveness of rice farming activities.

Keywords: High-yielding varieties, Instrumental variable, Modern agricultural inputs, Productivity.

INTRODUCTION

Agriculture plays a crucial role in the economy of every country, especially in developing countries. Agriculture contributes to ensuring food security and generates income for economic development. Moreover, in less-developed countries, agriculture is a major income source for rural households derived from domestic sales and exports. Therefore, improvement in the quantity and quality of agricultural outputs is a focal point of governments in developing countries (Bonnin and Turner, 2012).

The literature documents that the adoption of new agricultural technologies has played a key role in increasing agricultural productivity, enhancing food security, and stimulating agricultural growth in developing countries (Faltermeier and Abdulai, 2009). Agricultural technologies also improve rural households' welfare directly by enhancing their income and indirectly via creating jobs, increasing wages of landless households, and lowering prices of agricultural products. Meanwhile, low adoption of improved agricultural technologies limited the impact of agricultural research on poverty reduction (Esmaeeli and Sadighi, 2017). Agricultural technologies can be measured by different criteria such as improved agricultural inputs (varieties, fertilizers) or new farming practices (Mendola, 2007; Shiferaw *et al.*, 2008; Faltermeier and Abdulai, 2009; Kassie *et al.*, 2011; Ricker-Gilbert *et al.*, 2011; Yorobe *et al.*, 2016). This study analyzes the adoption of agricultural technology by focusing on the case of hybrid rice varieties.

Rice has played a significant role at both the household and national levels in the

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developing world, in general, and Vietnam, in particular. In the past decades, Vietnam has made tremendous efforts in rice land expansion. Moreover, in some regions, especially in Southern Vietnam, rice can be grown under a high crop rotation intensity annually. Furthermore, urbanization has been very rapid, which has resulted in fewer land resources for agricultural production. Accordingly, it is indicated that the expansion of production scale via land reclamation and increases in crop intensity is no longer appropriate in Vietnam (Duong and Thanh, 2019). Therefore, the most probable solution to enhance production output is to adopt new high-yielding agricultural technology, including improved varieties (e.g., locally improved and hybrid varieties) (Hung and Duong, 2018; Thanh and Duong, 2020).

A review of world literature has revealed the positive effects of improved or modern rice varieties on farm households. The adoption of improved or modern rice varieties, including hybrid varieties, is an effective way to enhance productivity and other economic outcomes due to their attributes of short duration, high yield, and tolerance of severe climatic events (Sall *et al.*, 2000; Yorobe *et al.*, 2016; Khandker and Thakurata, 2018). Improved rice varieties can enhance productivity, ensure food security, improve crop income, alleviate poverty and reduce income inequality (Ragasa and Chapoto, 2017; Arouna *et al.*, 2017; Alia *et al.*, 2018; Duong and Thanh, 2019; Ghimire and Huang, 2016; Shen *et al.*, 2021). Regarding hybrid rice, literature also documented that farm households benefit from the adoption of hybrid varieties. In particular, the adoption of hybrid rice significantly increased yield and profitability, thereby contributing to food security and income (Li *et al.*, 2009; Yuan *et al.*, 2017; Anwar *et al.*, 2021).

Hybrid rice was introduced to Vietnam in the early 2000s and has been widely accepted and adopted by Vietnamese farmers (Thanh and Duong, 2020). However, there has been, to date, a lack of empirical studies quantifying the yield and economic effects of hybrid rice in Vietnam. Therefore, a critical question is whether the hybrid rice varieties truly benefit adopters in Vietnam. This paper aims to fill these gaps. Using panel data from the Vietnam Access to Resources Household Surveys (VARHS) in 2012 and 2014, we examine the impacts of the adoption of hybrid rice varieties (from Vietnam or China) on such outcomes as productivity (yield), intermediate costs (e.g., varieties, fertilizers, pesticides, herbicides, and rental of machinery or equipment), and value added (equal total production value less total intermediary cost) per hectare. The results are estimated using a Random-Effect Model (REM) and a Fixed-Effect Model (FEM). However, an important issue is potential endogeneity in which there may exist unobservable factors that affect both adoption and economic outcomes. To deal with this potential endogeneity, we apply an Instrumental Variable/Two-Stage Least-Squares (IV/2SLS) approach with distance from home to input sellers as an instrument. In addition, since hybrid varieties adoption may have different impacts on adopting households with different socio-economic statuses, we also assess the heterogeneous impacts of adoption by poverty status.

This paper makes several contributions to the extant literature. First, we provide empirical evidence on the yield and economic impacts of hybrid rice varieties on adopting farm households in Southeast Asia. Second, we apply the IV/2SLS method to control for selection bias stemming from unobserved heterogeneity, thereby yielding more precise causal effects of adoption on yield and economic outcomes. Third, since the effects of the adoption of hybrid rice varieties may be different across different socio-economic statuses, we divide our sample into poor and non-poor groups to capture which group benefit or benefit more from adoption. The findings from these analyses allow us to draw relevant policy implications to enhance farmers' access to better inputs and the effectiveness of the adoption of hybrid rice varieties. Our paper

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also contributes to agriculture-led poverty reduction theory and practice by focusing on the adoption of agricultural technologies (i.e., hybrid rice varieties).

This study aimed to examine the economic impacts of agricultural technology adoption by focusing on the case of hybrid rice varieties in rural Vietnam and to fill the information gaps by quantifying the impacts of adoption of hybrid rice varieties on productivity, intermediate cost and value added (or income).

MATERIALS AND METHODS

Research Hypotheses

Theoretically, agriculture-led poverty reduction theory asserted that there may exist a link between agricultural productivity and poverty alleviation (Dzanku *et al.*, 2015). Increasing productivity could increase income of farm households, especially the poor (Minten and Barrett, 2008). Adoption of agricultural technologies (e.g., high-yielding varieties, modern fertilizers, new farming practices) is an important factor that contributes to higher productivity.

Literature has documented the effects of improved or modern varieties on farm household. Empirical studies from African countries revealed that the adoption of improved rice varieties enhances yield, food security and crop income, and contributes to reduction of poverty and income inequality (Alia *et al.*, 2018; Ragasa and Chapoto, 2017; Kassie *et al.*, 2011; Sall *et al.*, 2000). A review of existing literature on improved rice varieties from 16 sub-Saharan African countries also found that the adoption of improved rice varieties had positive impacts on productivity, production, income, expenditures, poverty reduction, and food security (Arouna *et al.,* 2017). Similarly, empirical evidences in Asian countries also confirmed the role of modern rice varieties in improving productivity, food security, income and expenditure, and reducing poverty (Bannor *et al.*, 2020; Ghimire and Huang, 2016; Wang *et al.*, 2020; Yorobe *et al.*, 2016; Saito *et al.*, 2007).

A review of literature on hybrid rice varieties also documented the positive impacts of adoption of hybrid rice on yield and economic outcomes. In particular, adoption of hybrid rice varieties significantly increased yield and total rice production, thereby contributing to food security (Li *et al.*, 2009). Similarly, hybrid rice was found to have higher yield and profitability than even old high-yielding, inbred or conventional rice varieties (Anwar *et al.*, 2021; Yuan *et al.*, 2017). However, adopters of modern rice varieties, including hybrid rice, may incur higher input costs such as fertilizers, pesticides, herbicides, hired-in labors or irrigation fees (Duong and Thanh, 2019).

To the best of our knowledge, neither of empirical studies in Vietnam has evaluated the yield and economic impacts of hybrid rice varieties, except for Duong and Thanh, 2019. However, the study by Thanh and Duong (2019) only examined the impacts of modern rice varieties, including hybrid rice, but not hybrid rice separately. In addition, Thanh and Duong (2019) did not examine the impacts of adoption of modern varieties on intermediate cost. Therefore, we aim to fill these gaps by quantifying the impacts of adoption of hybrid rice varieties on productivity, intermediate cost and value added (or income). Based on literature review, we proposed the following hypotheses:

H1: Adoption of hybrid rice varieties significantly improves productivity,

H2: Adoption of hybrid rice varieties leads to significantly higher intermediate cost.

H3: Adoption of hybrid rice varieties significantly enhances value added (or income).

Empirical Model

In this study, we use various strategies to quantify the economic effects of hybrid rice

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varieties adoption. We started with a Pooled OLS specification as follows:

$$Y_{i,t} = \beta_0 + \beta_1 A_{i,t} + \beta_2 X_{i,t} + \beta_3 Z_i + u_i + e_{i,t} \quad (1)$$

Where, *i* and *t* denote household and time, respectively. *Y* is the economic outcome of interest (e.g., productivity, value added, or cost). $A_{i,t}$ is the adoption variable. $X_{i,t}$ is a set of time-variant factors (e.g., age of household head, household size, loan). Z_i is a vector of time-invariant factors (e.g., ethnicity). $e_{i,t}$ and u_i are error terms that account for the time-variant and time-invariant unobservable heterogeneities, respectively. Because this study examined the impact of hybrid varieties adoption on household economic outcomes, we were highly interested in the β_1 coefficient and expected that β_1 would be positive.

The estimates using Equation (1) may be biased due to two sources of unobserved heterogeneity. With panel data, it is possible to resolve the potential endogeneity by using a household-level Fixed Effects Model (FEM) or Random-Effects Model (REM). As described in Section 3.2, Hausman tests strongly reject the null hypothesis that household REM provides consistent estimates. Therefore, we adopt the household FEM as our main specification. The estimation using FEM is written as follows:

$$Y_{i,t} = \beta_i + \beta_1 A_{i,t} + \beta_2 X_{i,t} + e_{i,t} \quad (2)$$

Where, β_i is a dummy variable, which takes the value 1 for household *i* and 0 otherwise. The FEM captures the household time-invariant characteristic and thus reduces a bias resulting from unobservable factors that affect both the adoption decision and economic outcome. As compared to Equation (1), the time-invariant observable (Z_i) and unobservable (u_i) factors are canceled out in Equation (2). Therefore, the biases associated with time-invariant heterogeneity that may be correlated with both the adoption and outcomes are removed, and thus Equation (2) may yield a less biased estimate of the impact of hybrid varieties adoption.

FEM can reduce estimation bias as it sweeps out the time-invariant heterogeneity; however, the bias may persist due to time-variant heterogeneity, affecting both the adoption and outcome variables. Therefore, Instrumental Variable/Two-Stage Least-Squares (IV/2SLS) method is applied to tackle the potential endogeneity bias of hybrid varieties adoption.

Variables Used for Analysis

Four sets of variables are used for empirical analysis, including:

Hybrid varieties adoption: The adoption variable is defined as whether rice farmers adopt hybrid rice varieties made in Vietnam or China. This variable is a dummy and assigned to be 1 if farmers adopt any of these hybrid varieties, and 0 if farmers adopt improved local varieties, traditional local varieties or other varieties.

Outcomes: Literature documents that there are many indicators to measure outcomes from adoption of modern varieties, including hybrid rice, such as productivity (measured by yield per hectare, yield per labor), income, net benefit, poverty gap, or severity (Alene and Coulibaly, 2009; Amare *et al.*, 2012; Manda *et al.*, 2018; Mason and Smale, 2013; Takam-Fongang *et al.*, 2019; Wang *et al.*, 2020; Wu *et al.*, 2010). This study used productivity, intermediate costs, and value added per hectare to measure yield and economic outcomes from the adoption of hybrid rice varieties. Productivity is the yield produced per unit area of land (measured by tons per hectare). Productivity is considered a good indicator of food security as higher yield indicates higher food availability and food stability, and food access, thereby ensuring food security (Arouna *et al.*, 2017; Garibaldi *et al.*, 2018; Okello *et al.*, 2017; Schmidhuber and Tubiello, 2007; Wang *et al.*, 2020). Intermediate cost, measured by million VND per hectare, includes such production cost as varieties, chemical and organic fertilizers (self-produced and

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purchased), pesticides, herbicides, rental of cattle for ploughing, and rental of asset, machinery, equipment and means of transport. Value added, measured by million VND per hectare, equals total production value minus total intermediate cost. Value added from rice farming is a proxy for welfare, with higher value added, indicating better income and poverty reduction (Arouna *et al.*, 2017).

Control variables: Based on literature (Amare *et al.*, 2012; Duong and Thanh, 2019; Kassie *et al.*, 2011; Khonje *et al.*, 2015; Yorobe *et al.*, 2016), relevant variables are selected to be incorporated in the model. These control variables include the characteristics of the household head (e.g., education, age, gender and ethnicity), household (e.g., household size, credit, land and poverty status) and commune (e.g., availability of market within commune). In addition, provincial dummies are included in the model to capture the different agro-ecological and macroeconomic conditions (Ali and Rahut, 2018; Makate *et al.*, 2017).

Instrumental variable: Based on the literature (Ragasa and Chapoto, 2017), this study used a continuous variable indicating the distance from the farmers' home to the agricultural input sellers (in kilometers) as a potential instrument.

All the variables used for analyses, their definitions, and descriptive statistics are presented in Table 2. To ensure that the calculations are comparable over time, we use all variables measured in monetary value at the constant price: the base year is 2012.

Data Source

This study used large-scale panel data from the Vietnam Access to Resources Household Surveys (VARHS) in 2012 and 2014. VARHS is conducted under the cooperation between the Central Institute for Economic Management (CIEM), the Institute of Labor Science and Social Affairs (ILSSA), the Institute of Policy and Strategy for Agriculture and Rural Development (IPSARD), Vietnam; and the University of Copenhagen, Denmark. VARHS collects data biannually from approximately 2,600 rural households in 12 provinces representing six socio-economic regions in Vietnam.

The survey instrument included: (i) A commune module and (ii) A household module. The commune questionnaire provides information on the general characteristics of the commune (population, average income per capita), infrastructure, income-activities, development programs, community problems, and access to services. The household questionnaire provides detailed and rich information on the demographic and socio-economic characteristics of the households and household members, such as education, ethnicity, labor, land, access to agricultural input and output markets, economic activities, income sources, food expenditures, credit, savings, and social capital. This survey also contains information on the adoption of rice varieties and outcomes derived from rice cultivation. This information is used to construct the variable of interest in this paper.

RESULTS AND DISCUSSIONS

Descriptive Statistics

Table 1 reports some of the descriptive statistics of hybrid rice varieties adoption using pooled data from both surveys. Totally, 2,680 farmers were found to have adopted at least one type of hybrid rice varieties, while the number of non-adopters was only 1,248, which indicates a high proportion of adopters (68.2%) from both surveys. In addition, the ratio of adopters tends to increase across time, from 65.6% in 2012 to 70.8% in 2014.

Further investigation of both surveys shows that 49.4 and 18.8% of farmers adopt hybrid varieties from Vietnam and China, respectively. The statistics indicate that most farmers adopt hybrid varieties from

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Table 1. Hybrid rice varieties adoption. [a]

Type(s)	Both surveys		Survey 2012		Survey 2014	
	N	%	*N*	%	*N*	%
Adopter	*2,680*	*68.2%*	*1,289*	*65.6%*	*1,391*	*70.8%*
Hybrid varieties from Vietnam	1,942	49.4%	871	44.3%	1,071	54.5%
Hybrid varieties from China	738	18.8%	418	21.3%	320	16.3%
Non-adopter	*1,248*	*31.8%*	*675*	*34.4%*	*573*	*29.2%*
Improved local varieties	465	11.8%	238	12.1%	227	11.6%
Traditional local varieties	716	18.2%	401	20.4%	315	16.0%
Other varieties	67	1.7%	36	1.8%	31	1.6%
Total	3,928	100.0%	1,964	100.0%	1,964	100.0%

[a] Source: Own calculation.

Vietnam, and the ratio of these adopters tends to increase across time, from 44.3% in 2012 and up to 54.5% in 2014. Meanwhile, the number of farmers adopting hybrid varieties from China is quite low and experiences a decreasing tendency across time, from 21.8% in 2012 down to 16.3% in 2014.

Table 2 presents the definition and summary statistics of the variables used for analysis. As shown in the table, the adopters and non-adopters have group mean differences along most of the observed characteristics, except for marital status, gender of the household head, and value of the production assets. Household heads of the adopting group are better educated and slightly older than the household heads of the non-adopting group. The ethnicity of adopters is significantly more Kinh-dominated than that of non-adopters. The adopters had larger production loans, savings, and transfers, but possessed less cultivation land than the non-adopters. Also, adopters were located in areas closer to an all-weather road. In terms of poverty status and location, compared to non-adopters, a significantly larger proportion of adopters were non-poor and resided in a Table 2 also reports statistically significant differences in the outcomes between adopters and non-adopters of hybrid varieties. In particular, adopters have significantly higher productivity and intermediary cost, but lower value added than non-adopters.

Estimation using REM and FEM

Table 3 presents the estimates using both REM and FEM. The Hausman test shows that FEM is more favorable than REM. In addition, the F-test reveals that FEM is more appropriate than the Pooled OLS model (see Appendix A7). Therefore, the discussion and the interpretation in this section will be presented using the estimations from FEM.

Table 3 shows the impact of hybrid rice varieties adoption on productivity, intermediary costs, and value added from rice farming. Overall, the adoption of hybrid varieties has significant and positive impacts on productivity, intermediary cost, and value added. In particular, productivity for hybrid varieties adoption significantly increases by around 0.191 tons per hectare. Similarly, hybrid varieties adoption significantly raises the total output value and intermediary costs by around 0.758 and 0.675 million VND per hectare, respectively. However, there is no sufficient evidence to conclude the effect of hybrid varieties adoption on value added.

Addressing Endogeneity: An IV/2SLS Approach

The FEM estimates reveal that the adoption of hybrid varieties has no significant effect on value added. Although adoption significantly enhances

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Table 2. Descriptive statistics of sample households by adoption status. [a]

Variable(s)	Definition/Measurement	Mean			Difference in mean between adopters and non-adopters	
		Whole	Adopters	Non-adopters	Diff	*P*-value
Control variables						
Education	Grade completed by household head	6.03	6.48	5.04	1.441***	0.00
Age	Age of household head	49.61	50.07	48.62	1.442***	0.00
Marital status	1 if married household head, 0 otherwise	0.85	0.86	0.84	0.015	0.21
Gender	1 if male-headed household, 0 otherwise	0.85	0.85	0.84	0.016	0.20
Ethnicity	1 if Kinh ethnic majority households, 0 otherwise	0.55	0.62	0.40	0.218***	0.00
Production credit	Loan amount borrowed for production in the last 12 months preceding the survey (Million VND)	6.55	7.11	5.36	1.747*	0.08
Saving	Saving amount possessed in the last 12 months preceding the survey (Million VND)	16.30	17.94	12.79	5.142***	0.00
Production asset	Value of production assets possessed in the last 12 months preceding the survey (Million VND)	3.75	3.80	3.62	0.179	0.89
Transfer	Value of private transfer (remittance) and public transfer (e.g., pension, social insurance, regular social assistance, benefit for national program) received in the last 12 months preceding the survey (Million VND)	10.08	10.69	8.76	1.930**	0.03
Poverty status	1 if classified as poor household in the last 12 months preceding the survey, 0 otherwise	0.25	0.23	0.31	-0.088***	0.00
Agricultural labor	Number of labors actively involved in agriculture in the last 12 months preceding the survey	3.04	2.96	3.21	-0.255***	0.00
Extension services	1 if visited by agricultural extension agent in the last 12 months preceding the survey	0.17	0.19	0.13	0.053***	0.00
Cultivation land	Total area of all cultivated land possessed or managed in the last 12 months preceding the survey (hectare)	0.64	0.52	0.91	-0.383***	0.00
Distance	Distance from home to all-weather road (Kilometers)	1.78	1.68	1.99	-0.314***	0.00
Market	1 if availability of any markets in the commune, 0 otherwise	0.58	0.64	0.44	0.202***	0.00
Ha Tay	1 if located in Ha Tay, 0 otherwise	0.18	0.21	0.12	0.094***	0.00
Lao Cai	1 if located in Lao Cai, 0 otherwise	0.13	0.16	0.06	0.096***	0.00
Phu Tho	1 if located in Phu Tho, 0 otherwise	0.12	0.17	0.02	0.148***	0.00
Lai Chau	1 if located in Lai Chau, 0 otherwise	0.12	0.10	0.16	-0.058***	0.00
Dien Bien	1 if located in Dien Bien, 0 otherwise	0.12	0.04	0.31	-0.270***	0.00
Nghe An	1 if located in Nghe An, 0 otherwise	0.07	0.09	0.02	0.074***	0.00
Quang Nam	1 if located in Quang Nam, 0 otherwise	0.10	0.11	0.08	0.030***	0.00
Khanh Hoa	1 if located in Khanh Hoa, 0 otherwise	0.02	0.02	0.01	0.002	0.56
Dak Lak	1 if located in Dak Lak, 0 otherwise	0.06	0.05	0.09	-0.038***	0.00
Dak Nong	1 if located in Dak Nong, 0 otherwise	0.03	0.02	0.04	-0.020***	0.00
Lam Dong	1 if located in Lam Dong, 0 otherwise	0.01	0.01	0.00	0.002	0.51
Long An	1 if located in Long An, 0 otherwise	0.05	0.03	0.09	-0.059***	0.00
Outcome variables						
Productivity	Yield per hectare in the last 12 months preceding the survey (Ton)	4.46	4.60	4.15	0.451***	0.00
Intermediary cost	Intermediary cost per hectare in the last 12 months preceding the survey (Million VND)	13.48	14.67	10.93	3.736***	0.00
Value added	Value added per hectare in the last 12 months preceding the survey (Million VND)	12.67	12.46	13.14	-0.685***	0.00
Instrumental variables						
Distance to input sellers	Distance from home to agricultural input (e.g., varieties, fertilizers) sellers (Kilometers)	2.85	3.28	1.93	1.35	0.00
	Observation	3,928	2,680	1,248		

[a] Source: Own calculation.* Significant at 10%, ** Significant at 5%, and *** Significant at 1%.

Table 3. Economic impacts of hybrid varieties adoption: FEM and REM approaches. *a*

Variable(s)	Productivity		Intermediary cost		Value added	
	FEM	REM	FEM	REM	FEM	REM
Hybrid varieties adoption	0.124**	0.205***	0.675***	0.589***	0.083	0.505*
	(0.022)	(0.000)	(0.009)	(0.001)	(0.824)	(0.055)
Education	0.001	0.017***	0.045	0.052**	-0.099	0.061*
	(0.940)	(0.003)	(0.554)	(0.039)	(0.366)	(0.090)
Age	-0.004	-0.001	0.104***	0.005	-0.203***	-0.007
	(0.571)	(0.511)	(0.001)	(0.455)	(0.000)	(0.434)
Marital status	0.099	0.062	0.173	0.170	-0.635	-0.179
	(0.539)	(0.427)	(0.821)	(0.619)	(0.567)	(0.713)
Gender	-0.096	-0.012	0.001	-0.196	0.323	0.316
	(0.623)	(0.876)	(0.999)	(0.554)	(0.810)	(0.501)
Ethnicity		0.531***		1.632***		1.246***
		(0.000)		(0.000)		(0.003)
Production credit	0.001	0.000	-0.003	0.002	0.012**	-0.003
	(0.424)	(0.779)	(0.526)	(0.399)	(0.040)	(0.479)
Saving	-0.000	0.001***	0.006*	0.007***	-0.009*	0.002
	(0.996)	(0.002)	(0.059)	(0.001)	(0.055)	(0.507)
Production assets	0.000	0.001	0.004	0.003	-0.002	0.001
	(0.499)	(0.246)	(0.174)	(0.211)	(0.701)	(0.791)
Transfer	-0.000	-0.001	0.013***	0.008**	-0.015**	-0.011**
	(0.668)	(0.296)	(0.005)	(0.010)	(0.033)	(0.015)
Poverty status	-0.106	-0.239***	-0.449	-0.783***	-0.071	-0.675**
	(0.111)	(0.000)	(0.158)	(0.000)	(0.878)	(0.014)
Agricultural labor	0.047**	0.002	0.063	-0.186***	0.209	0.130
	(0.049)	(0.917)	(0.576)	(0.004)	(0.204)	(0.156)
Extension services	0.146**	0.135***	0.616**	0.457**	-0.023	0.085
	(0.014)	(0.003)	(0.028)	(0.027)	(0.956)	(0.773)
Cultivation land	-0.004	-0.021*	-0.075	-0.108**	0.095	-0.109
	(0.774)	(0.057)	(0.311)	(0.030)	(0.377)	(0.126)
Distance	0.011	-0.005	-0.076	-0.023	0.100	-0.105*
	(0.478)	(0.589)	(0.292)	(0.567)	(0.338)	(0.064)
Market	0.035	0.009	1.293***	0.096	-2.011***	-0.455*
	(0.682)	(0.832)	(0.002)	(0.599)	(0.001)	(0.078)
Constant	4.377***	4.022***	6.483***	12.416***	24.062***	12.899***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
Province fixed effect	YES	YES	YES	YES	YES	YES
rho	0.561	0.168	0.557	0.0610	0.463	0.0290
Hausman test	32.50		40.93		81.11	
(Prob> Chi^2)	(0.005)		(0.000)		(0.000)	
F-test that all u_i= 0	2.01		2.06		1.270	
(Prob> F)	(0.000)		(0.000)		(0.000)	
No of observation	3,928		3,928		3,928	

a REM: Random-Effect Model; FEM: Fixed-Effect Model ; *P*-value in parentheses. * Significant at 10%; ** Significant at 5%, *** Significant at 1%.
Source: Own calculation.

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productivity, the increasing magnitude is quite small.

This study examines the relationship between hybrid varieties adoption and economic outcomes while controlling for some characteristics of farmers and their farms. In addition, FEM is applied to remove the effects of time-invariant heterogeneity. However, there may exist some time-varying unobservable factors that may affect both the adoption and outcome variables. Therefore, the FEM estimates may be biased. To deal with this potential endogeneity problem, we employed the Instrumental Variable/Two-Stage Least-Squares (IV/2SLS) method. Distance from home to agricultural input sellers was used as the instrumental variable for hybrid varieties adoption. To be a valid instrument, this distance variable must satisfy two conditions: (1) It is highly related to hybrid varieties adoption and (2) It is not correlated with the outcomes.

To test the first condition, we ran a regression of adoption on this distance and other farmer- and farm-specific characteristics. The first stage results from Table 4 show that distance is significantly related to hybrid varieties adoption. The test for week instruments shows that the null hypothesis of week instrument is rejected, meaning that distance is a valid instrument for hybrid varieties adoption. As for the second condition, this distance variable, by nature, is unlikely, or less likely, to affect economic outcomes derived from rice farming.

In the second stage of the IV/2SLS regression method, the endogeneity tests revealed that hybrid varieties adoption was not endogenous in the model with value added as the outcome variable, and thus the OLS regression was more suitable. However, estimates for value added were similar in both the OLS and IV/2SLS regressions.

Meanwhile, hybrid varieties adoption was endogenous in the model, with productivity and intermediary cost as the outcome variables. Therefore, IV/2SLS estimators were more appropriate. As compared to the estimates from FEM in Table 3, the IV/2SLS estimators are nearly the same in terms of statistical significance, but much different regarding the impact magnitude. The IV/2SLS estimators are much higher than FEM. In particular, the estimates reveal that hybrid varieties adoption significantly increases productivity by 1.124 tons per hectare and intermediary costs by 3.52 million VND per hectare. To our understanding, the IV/2SLS estimators seem to be more reasonable and in accordance with reality.

In terms of productivity and intermediate cost, our findings are in line with previous studies that found the higher yield and intermediate cost from the adoption of hybrid rice varieties (Anwar *et al.*, 2021; Duong and Thanh, 2019; Yuan *et al.*, 2017; Li *et al.*, 2009). Meanwhile, our findings on valued added are similar to the results of Duong and Thanh (2019), who found insignificant impacts of modern varieties on value added, but contrary to the previous studies that found positive effects of improved varieties (including hybrid rice) on crop income (Anwar *et al.*, 2021; Wang *et al.*, 2020, 2010)

Heterogeneity Analysis

To check the robustness of the full-sample results, the sample was divided into poor and non-poor households. Tables 5 and 6 show the results obtained for these two sub-samples using the FEM, REM, and IV/2SLS approaches. In both sample groups, the relevant tests reveal that the IV/2SLS estimators are better, except for the model using value added as the outcome.

These estimates for both the poor and non-poor groups experience the same pattern as the whole sample. The adoption of hybrid varieties significantly increases productivity and intermediate costs, but the effects on value added remain statistically insignificant for both the poor and the non-poor groups. It is noteworthy that the poor adopters had

Table 4. Economic impacts of hybrid varieties adoption: IV/2SLS approach.[a]

Variable(s)	First stage	Second stage		
	Hybrid adoption	Productivity	Intermediate cost	Value added
Distance to input sellers	0.056***			
	(0.000)			
Hybrid varieties adoption		1.124***	3.520***	0.720
		(0.000)	(0.001)	(0.609)
Education	0.013*	0.013**	0.033	0.070**
	(0.085)	(0.030)	(0.204)	(0.048)
Age	0.003	-0.002	0.000	-0.003
	(0.221)	(0.275)	(0.966)	(0.718)
Marital status	-0.089	0.079	0.232	-0.152
	(0.388)	(0.318)	(0.501)	(0.750)
Gender	0.187*	-0.053	-0.277	0.179
	(0.061)	(0.496)	(0.409)	(0.698)
Ethnicity	0.072	0.507***	1.711***	1.001**
	(0.445)	(0.000)	(0.000)	(0.015)
Production credit	0.000	-0.000	0.003	-0.005
	(0.753)	(0.981)	(0.255)	(0.217)
Saving	0.001	0.001***	0.005**	0.004
	(0.327)	(0.003)	(0.015)	(0.133)
Production assets	0.000	0.001	0.002	0.002
	(0.910)	(0.263)	(0.329)	(0.581)
Transfer	-0.001	-0.000	0.007**	-0.008*
	(0.165)	(0.516)	(0.023)	(0.077)
Poverty status	-0.118**	-0.210***	-0.528***	-0.909***
	(0.048)	(0.000)	(0.008)	(0.001)
Agricultural labor	0.005	-0.009	-0.231***	0.161*
	(0.786)	(0.560)	(0.000)	(0.073)
Extension services	-0.015	0.139***	0.551***	-0.068
	(0.816)	(0.004)	(0.009)	(0.814)
Cultivation land	-0.019	-0.018	-0.077	-0.137*
	(0.277)	(0.132)	(0.131)	(0.051)
Distance	-0.015	-0.005	-0.015	-0.111**
	(0.203)	(0.587)	(0.701)	(0.043)
Market	-0.060	0.025	-0.076	-0.059
	(0.279)	(0.560)	(0.682)	(0.818)
Constant	0.336*	3.407***	10.042***	13.504***
	(0.065)	(0.000)	(0.000)	(0.000)
Time fixed effect	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES
Weak identification test	75.02			
(Prob> chi^2)	(0.000)			
Endogeneity test		17.321	9.839	0.001
(P-value)		(0.000)	(0.002)	(0.980)
No of observation	3,928	3,928	3,928	3,928

[a] *P*-value in parentheses; * Significant at 10%; ** Significant at 5%, *** Significant at 1%. Refer to Appendix 4 for more details on the province fixed effect. Source: Own calculation.

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Table 5. Economic impacts of hybrid varieties adoption by poor and non-poor samples: FEM and REM approaches.[a]

Variable(s)	Poor sample						Non-poor sample					
	Productivity		Intermediary cost		Value added		Productivity		Intermediary cost		Value added	
	FEM	REM	FEM	REM	FEM	REM	FEM	REM	FEM	REM	FEM	REM
Hybrid varieties	0.151	0.202**	0.854	1.027**	-0.225	-0.270	0.121**	0.195***	0.668**	0.459**	0.121	0.685**
	(0.225)	(0.028)	(0.155)	(0.017)	(0.786)	(0.634)	(0.044)	(0.000)	(0.019)	(0.024)	(0.774)	(0.022)
Education	-0.032	-0.002	0.100	-0.019	-0.395*	0.073	0.014	0.024***	0.035	0.071**	-0.002	0.067
	(0.300)	(0.882)	(0.509)	(0.737)	(0.059)	(0.322)	(0.431)	(0.000)	(0.683)	(0.012)	(0.987)	(0.104)
Age	0.031*	-0.002	0.290***	0.003	-0.200	-0.015	-0.007	-0.001	0.075**	0.005	-0.191***	-0.008
	(0.091)	(0.508)	(0.001)	(0.839)	(0.102)	(0.449)	(0.348)	(0.636)	(0.028)	(0.470)	(0.000)	(0.484)
Marital status	0.478	0.071	3.560*	0.940	-2.534	-1.298	0.039	0.039	-0.501	0.027	-0.151	-0.055
	(0.224)	(0.692)	(0.061)	(0.251)	(0.333)	(0.216)	(0.828)	(0.657)	(0.551)	(0.943)	(0.903)	(0.921)
Gender	-0.743*	0.019	-4.263**	-0.641	2.686	1.585	0.104	0.019	1.250	-0.036	-0.433	0.143
	(0.080)	(0.916)	(0.037)	(0.440)	(0.341)	(0.135)	(0.643)	(0.821)	(0.240)	(0.921)	(0.783)	(0.787)
Ethnicity		0.541***		2.249***		0.384		0.496***		1.279***		1.427***
		(0.001)		(0.003)		(0.689)		(0.000)		(0.000)		(0.003)
Production credit	0.019***	0.012**	0.089***	0.070***	0.031	0.002	0.000	0.000	-0.004	0.002	0.011*	-0.002
	(0.007)	(0.023)	(0.009)	(0.005)	(0.506)	(0.953)	(0.625)	(0.937)	(0.360)	(0.499)	(0.058)	(0.571)
Saving	-0.001	0.001	0.013	0.024	-0.054	-0.051	0.000	0.002***	0.006**	0.008***	-0.009**	0.003
	(0.866)	(0.889)	(0.737)	(0.375)	(0.326)	(0.160)	(0.981)	(0.001)	(0.040)	(0.000)	(0.049)	(0.393)
Production assets	-0.004	0.001	0.087*	0.105***	-0.111*	-0.106**	0.000	0.001	0.004	0.003	-0.001	0.001
	(0.695)	(0.861)	(0.067)	(0.002)	(0.093)	(0.018)	(0.478)	(0.204)	(0.208)	(0.218)	(0.850)	(0.667)
Transfer	0.001	-0.003	0.046***	0.030**	-0.043*	-0.059***	-0.001	-0.000	0.009*	0.006*	-0.011	-0.006
	(0.669)	(0.254)	(0.004)	(0.014)	(0.052)	(0.000)	(0.508)	(0.504)	(0.066)	(0.077)	(0.141)	(0.183)
Agricultural labor	-0.021	-0.031	-0.067	-0.250*	0.181	0.070	0.059**	0.013	0.054	-0.147**	0.220	0.164
	(0.667)	(0.275)	(0.769)	(0.057)	(0.569)	(0.680)	(0.033)	(0.450)	(0.681)	(0.048)	(0.255)	(0.133)
Extension services	0.249*	0.209*	1.684**	1.245**	-0.329	-0.252	0.124*	0.129***	0.369	0.346	0.076	0.161
	(0.075)	(0.057)	(0.013)	(0.016)	(0.723)	(0.714)	(0.056)	(0.010)	(0.230)	(0.120)	(0.868)	(0.623)
Cultivation land	0.003	-0.008	-0.041	-0.034	0.075	-0.045	-0.114*	-0.070***	-0.761**	-0.416***	0.638	-0.304*
	(0.844)	(0.507)	(0.606)	(0.567)	(0.497)	(0.563)	(0.089)	(0.006)	(0.016)	(0.000)	(0.172)	(0.056)
Distance	-0.052*	-0.034**	-0.347**	-0.117	0.109	-0.078	0.031*	0.010	-0.022	0.009	0.140	-0.084
	(0.069)	(0.048)	(0.013)	(0.146)	(0.568)	(0.458)	(0.085)	(0.359)	(0.798)	(0.853)	(0.264)	(0.211)
Market	-0.056	0.109	1.054	0.916**	-2.672**	-0.460	0.074	-0.006	1.352***	-0.139	-1.697**	-0.344
	(0.755)	(0.246)	(0.222)	(0.034)	(0.025)	(0.409)	(0.448)	(0.906)	(0.003)	(0.486)	(0.013)	(0.239)
Constant	2.792***	4.222***	-3.034	11.081***	23.518***	15.752***	4.441***	3.938***	8.207***	12.749***	22.924***	12.194***
	(0.002)	(0.000)	(0.492)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Province fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
rho	0.570	0.166	0.650	0.103	0.486	0.0139	0.551	0.168	0.539	0.0482	0.448	0.0267
Hausman test	27.01		28.44		25.21		23.02		31.34		60.32	
(Prob> Chi²)	(0.019)		(0.012)		(0.032)		(0.060)		(0.005)		(0.000)	
F-test that all u_i=0	1.85		2.18		1.25		2.030		1.98		1.26	
(Prob> F)	(0.000)		(0.000)		(0.011)		(0.000)		0.000		0.000	
No of observation	838		838		838		3,090		3,090		3,090	

[a] *P*-value in parentheses. [*] Significant at 10%; [**] Significant at 5%, [***] Significant at 1%. Refer to Appendix 5 for more details on the province fixed effect. Source: Own calculation.

Table 6. Economic impacts of hybrid varieties adoption by poor and non-poor samples: IV/2SLS approach.[a]

Variable(s)	Poor sample				Non-poor sample			
	First stage	Second stage			First stage	Second stage		
	Hybrid adoption	Productivity	Intermediate cost	Value added	Hybrid adoption	Productivity	Intermediate cost	Value added
Distance to input sellers	0.045***				0.058***			
	(0.000)				(0.000)			
Hybrid varieties adoption		1.353**	6.380**	2.000		1.026***	4.197***	-0.751
		(0.015)	(0.012)	(0.515)		(0.000)	(0.001)	(0.675)
Education	0.030*	-0.010	-0.068	0.052	0.012	0.020***	0.047	0.089**
	(0.065)	(0.462)	(0.279)	(0.492)	(0.184)	(0.003)	(0.112)	(0.030)
Age	-0.002	-0.001	0.005	-0.012	0.005*	-0.002	-0.002	-0.001
	(0.587)	(0.698)	(0.758)	(0.543)	(0.053)	(0.259)	(0.765)	(0.935)
Marital status	0.115	0.021	0.632	-1.185	-0.096	0.054	0.097	-0.046
	(0.617)	(0.910)	(0.448)	(0.240)	(0.414)	(0.544)	(0.804)	(0.932)
Gender	-0.229	0.119	-0.027	1.362	0.294***	-0.042	-0.295	0.176
	(0.328)	(0.524)	(0.975)	(0.185)	(0.009)	(0.625)	(0.443)	(0.742)
Ethnicity	0.682***	0.323	1.445	-0.342	-0.104	0.514***	1.455***	1.231***
	(0.002)	(0.105)	(0.111)	(0.755)	(0.341)	(0.000)	(0.000)	(0.008)
Production credit	-0.003	0.011**	0.086***	-0.019	0.000	-0.000	0.002	-0.004
	(0.703)	(0.049)	(0.001)	(0.561)	(0.869)	(0.934)	(0.389)	(0.362)
Saving	0.003	-0.001	0.005	-0.033	0.001	0.002***	0.006***	0.005*
	(0.714)	(0.922)	(0.860)	(0.346)	(0.311)	(0.001)	(0.005)	(0.086)
Production assets	-0.000	0.003	0.114***	-0.108**	0.000	0.001	0.002	0.002
	(0.990)	(0.672)	(0.001)	(0.013)	(0.926)	(0.223)	(0.331)	(0.493)
Transfer	-0.013***	0.000	0.033*	-0.024	-0.000	-0.000	0.005	-0.005
	(0.000)	(0.946)	(0.069)	(0.266)	(0.784)	(0.565)	(0.116)	(0.277)
Agricultural labor	0.050	-0.054*	-0.422***	0.112	-0.007	0.006	-0.172**	0.193*
	(0.189)	(0.080)	(0.003)	(0.513)	(0.761)	(0.744)	(0.026)	(0.073)
Extension services	-0.051	0.228*	1.203**	-0.057	0.014	0.131**	0.438*	-0.022
	(0.747)	(0.059)	(0.029)	(0.931)	(0.853)	(0.013)	(0.061)	(0.947)
Cultivation land	-0.022	-0.001	0.033	-0.066	-0.002	-0.073***	-0.418***	-0.335**
	(0.466)	(0.927)	(0.609)	(0.398)	(0.962)	(0.004)	(0.000)	(0.032)
Distance	-0.034	-0.022	-0.019	-0.104	-0.006	0.005	-0.001	-0.085
	(0.147)	(0.253)	(0.823)	(0.319)	(0.660)	(0.617)	(0.991)	(0.200)
Market	-0.039	0.129	0.536	0.162	-0.059	0.001	-0.238	-0.068
	(0.755)	(0.194)	(0.236)	(0.767)	(0.352)	(0.983)	(0.258)	(0.818)
Constant	0.069	3.469***	6.977***	15.514***	0.305	3.398***	10.096***	13.549***
	(0.863)	(0.000)	(0.001)	(0.000)	(0.137)	(0.000)	(0.000)	(0.000)
Time fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
Weak identification test	13.54				55.89			
(Prob> chi^2)	(0.000)				(0.000)			
Endogeneity test		5.304	6.310	0.407		9.040	10.201	0.83
(*P*-value)		(0.021)	(0.012)	(0.524)		(0.003)	(0.001)	(0.362)
No. of observation	838	838	838	838	3,090	3,090	3,090	3,090

[a] *P*-value in parentheses. [*] Significant at 10%; [**] Significant at 5%, [***] Significant at 1%. Refer to Appendix 6 for more details on the province fixed effect. Source: Own calculation.

slightly greater productivity, but experienced much higher intermediary costs than the non-poor adopters. Therefore, relevant policies should be applied to support poor households with better accessibility to the adoption of new varieties and cost-reducing techniques. As poor farmers are typically smallholders and non-poor farmers are typically medium or large landholders, our findings are contrary to the results of Duong and Thanh (2019), who revealed that only large landholders significantly improved their productivity by adopting modern varieties.

The estimates find that the adoption of hybrid varieties leads to significant increases in productivity for all cases, including the whole sample, and the poor and non-poor household sample groups. However, the results for the 'value added' outcomes are statistically insignificant in all cases. There are two plausible reasons for this outcome. First, hybrid varieties adoption requires more intermediary costs, including fertilizers, pesticides, herbicides, and laborers, which is confirmed by our estimated results. Second, hybrid rice is normally of lower quality, less tasty, and less preferred by consumers if they have other choices. As such, the price of hybrid rice is normally the lowest in the market. Three important policy implications can be drawn from these results. First, agronomists should continue to research to improve the quality of hybrid rice to increase its market price. Second, cost-saving techniques are also preferred to reduce the intermediary costs to increase the value added. Third, the adoption of modern varieties may only optimize the outcomes when being applied as a package of technologies (Karanja *et al.*, 2003; Nakano and Kajeisa, 2012). That is, modern farming techniques and practices, and other new agricultural inputs should be introduced to the adopters together with the hybrid varieties. It is noteworthy that the estimates using the whole sample reveal the significant and negative effects of poverty status on productivity and total output value, indicating that the poor have fewer advantages in rice farming than the non-poor. However, the estimates for the sub-samples categorized by poverty status reveals that, in terms of productivity, poor adopters of hybrid varieties benefit more than the non-poor adopters. Therefore, relevant policies should be applied to support poor households with better accessibility to the adoption of new varieties.

It is also worth mentioning that agricultural extension services have significant and positive effects on productivity, and that these services benefit the poor more than non-poor households in terms of productivity. These results indicate an important role of extension services in improving the effectiveness of rice farming. Agricultural extension services may support farmers in providing information, knowledge, and training activities; thenceforth, the farmers can optimize their returns from hybrid varieties cultivation. However, extension visits had no significant effects on value added, but had significant and positive effects on intermediary costs. Agricultural extension services also lead to higher costs incurred by poor households. These findings imply that the operation of agricultural extension centers has not been truly effective. To better support rice farmers, especially the poor, the efficiency of agricultural extension services should be promoted. Thenceforth, the farmers can be equipped and provided with better information and knowledge regarding modern inputs, agronomic techniques, and practices.

CONCLUSIONS

Rice is a very important and indispensable food crop in Asia, Africa, and developing countries. Due to decreases in land availability for expanding growing areas, increases in population and urbanization, and climate change, proposing land area expansion to enhance rice outputs is no longer appropriate. Therefore, a feasible

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solution to ensure rice outputs is to adopt new agricultural technologies, including modern rice varieties. This study examined the adoption of hybrid rice varieties in rural Vietnam. Such econometric techniques as FEM, REM, and IV/2SLS were employed to quantify the impacts of hybrid varieties adoption on productivity, value added, and intermediary costs.

The findings reveal that hybrid varieties adoption significantly increases productivity but has no effect on valued added. Meanwhile, hybrid varieties adoption also increased a farmer's intermediate costs. The results are similar for the poor and non-poor samples. However, the poor adopters experience higher productivity and intermediate costs than the non-poor adopters. Our findings contribute to agriculture-led poverty reduction theory and practice by emphasizing the role of the adoption of hybrid rice varieties.

The above findings carry important policy implications. First, investments in Research and Development (R&D) activities should focus on improving the quality of hybrid rice varieties and lowering other costs related to the adoption of these varieties. In addition, since hybrid varieties adoption may require a large amount of capital, rural credit markets should also be improved to enhance the farmers' accessibility to formal and sufficient loans.

The adoption of hybrid rice varieties should be introduced together with new farming techniques and other modern inputs (e.g., fertilizers) as a package to optimize the outcomes (Karanja *et al.*, 2003; Nakano and Kajeisa, 2012). Henceforth, the role of agricultural extension centers and farmer unions should be improved to provide famers with relevant and updated knowledge, information, and training activities. The role of cooperatives should also be promoted to help farmers have access to input and output markets, thus allowing farmers to reduce intermediary costs and increase the output value derived from rice farming.

Our study has some limitations. First, due to data limitation, we could not include in the model information about the attributes of rice varieties such as seed quality, price, yield stability, and adaptability to local soils/weather. Second, value added derived from rice farming, a proxy for welfare (poverty reduction), may have limitations. Future research should focus on the impact of adoption of hybrid varieties on poverty indices such as poverty rate, poverty gap, and poverty severity.

Supplementary Files

Appendices A3 – A7 related to Tables 4–6 in this paper may be found online.

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اثرات اقتصادی واریته های هیبرید برنج در ویتنام: تحلیلی ابزاری

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چکیده

در کشورهای در حال توسعه، کاربرد فناوری کشاورزی برای بهبود عملکرد برنج و درآمد خانوار از اهمیت برخوردار است. در این پژوهش، با استفاده از "اثرات ثابت"، اثرات تصادفی، و روشها ی متغیر ابزاری/ حداقل مربعات دو مرحله ای (IV/2SLS)، اثرات اقتصادی کاربرد فناوری کشاورزی با تاکید

بر کشت واریته های هیبرید برنج در روستاهای ویتنام بررسی شد. نتایج تجربی اشکار ساخت که کشت واریته های هیبرید به گونه ای معنادار بهره وری را افزایش داد ولی منجر به افزایش هزینه های میانی و متوسط (intermediate costs) شد. در عین حال، کاربرد این فناوری هیچ اثر معناداری روی ارزش افزوده نداشت. همچنین، کاربران تهیدست این فناوری، بهرهوری بیشتر و هزینه های متوسط بیشتری از گروه غیر-تهیدست داشتند. این یافته ها چنین اشاره دارد که دولت ویتنام باید سیاستهایی را وضع کند که منجر به ارتقا وسهولت دسترسی کشاورزان به نهاده های بهتر وموثرتر در عملیات مربوط به زراعت برنج شود.