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Economic efficiency versus social equity: the productivity challenge for rice production in a 'greying' rural Vietnam

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Abstract

Increasing productivity in agriculture is often deemed necessary to enhance rural income and ultimately narrow the urban-rural disparity in transitional economies. However, the objectives of social equity and economic efficiency can contradict each other, especially in the context of fierce competition for resources between agriculture and non-agricultural sectors and given the inherently redundant and unskilled aging rural population that often occurs during the economic transition to a market economy. We investigate the case of Vietnam during its high economic growth period (2000-2016), over which the country introduced policies to increase efficiency in rice production and income for farmers. Contrary to expectations, we find a steadily decreasing trend in the terms of trade for rice, indicating regression in farm income. At the same time, the Malmquist productivity index has been falling in most regions due to a decline in technical change, along with little improvement in technical efficiency. We further examine the causes of inefficiency using data from two household surveys in 2004 and 2014 (with plot-level information) along with semi-structured interviews with farmers in 2016-2017. The high ratio of aging farm workers who are unable to find alternative employment during the transition emerges as an essential impediment to rice productivity, in addition to previously documented land-use related issues. This demographic feature, along with government equity-targeting measures, hinders the farm amalgamation progress, further limiting efforts to enhance productivity. Thus, the goals of economic efficiency and social equity appear contradic-

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tory features of Vietnam's rice policies, posing a significant development challenge for the country's current and likely future development.
Keywords: greying agriculture, productivity, rice, Vietnam, Data Envelopment Analysis, the Malmquist productivity index, Stochastic Frontier Analysis
JEL: O12, O13, Q12, Q15

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1. Introduction

Since 1986, Vietnam has become a model of economic development, in which price-guided market principles and open trade have blended within the framework of democratic centralism, driving rapid economic growth and impressive poverty reduction. However, inequality in Vietnam has been on the rise (World Bank, 2012), contrary to prevailing socialist principles. One of the main forces at play is that the benefits of integration with the world economy have accrued disproportionally to the non-agricultural sector, resulting in a widening rural-urban income gap (World Bank, 2018). At the same time, labor remains concentrated in agriculture, a sector that has been shrinking substantially in its contribution to GDP (Nguyen et al., 2020; Tarp, 2017).

To address this income gap, Vietnamese policy has focused on agriculture, countryside and peasantry (the so-called 'three nongs' issue) after joining the World Trade Organization (WTO) in 2007. Specifically, it has highlighted the role of 'three nongs' as *"the basis and an important force for socio-economic development and maintaining political stability"* (Resolution 26-NQ/TW). In this light, various policy measures, ranging from changes in land use, irrigation and technology to market and price reform, have been implemented to enhance efficiency, productivity, and value-added in agricultural production, with a goal to eventually raise income for farmers. These measures are mainly aimed at the rice sector, which plays a vital political and socio-economic role in Vietnam (Nguyen et al., 2020).

In this context, the objective of this paper is twofold. We (a) examine whether there have been productivity increases in rice production and (b) investigate what factors have hindered any productivity increases. To do so, we first focus on regional income terms of trade (TOT) and the Malmquist productivity index (MPI) during 2000-2016. We find a steadily decreasing trend in TOT for rice producers, indicating regression in farm income.

There are at least two reasons for this. First, labor cost, which accounts for about 50% of the total cost, increases much faster than the output price, given the high economic growth of Vietnam, thus harming the TOT for farmers. Second, regional MPI suggests that productivity has been regressing, largely due to the decline in technical change, coupled with little improvement in technical efficiency in most regions. So what would explain this trend?

To identify impediments to productivity, we take advantage of the 2004 and 2014 Vietnam Household Living Standards Survey (VHLSS) data and our semi-structured interviews with farmers and various stakeholders in the rice sector in 2016-2017. The VHLSS data collected by the General Statistical Office (GSO) is the only nationally-representative surveys that contain questions on land use at the plot level. We find the high ratio of elderly farm members (55 years old or older) has emerged as an important impediment to rice productivity, in addition to previously-documented land-related constraints and institutions. Our interviews reveal a subsistence-production trap for most farmers, especially those who cannot find alternative employment due to their mature age and the lack of appropriate skills. The result suggests that rural Vietnam will be further left behind due to bearing a double-burden of an aging unskilled population and the smaller share in the gains from the country's export-led economic growth.

Our paper complements a related and now influential literature which tries to understand cross-country productivity differences in agriculture, such as Kuznets (1971) and Gollin et al. (2014), among many others. Two main and recently-proposed theories include distortions that misallocate resources across farms (Adamopoulos and Restuccia, 2014) and self-selection of relatively unproductive workers to work in agriculture in developing countries due to subsistence food requirements (Lagakos and Waugh, 2013). Our work differs in that it provides a detailed analysis of agricultural productivity in a rapidly-transforming country and transitional economy. In this sense, we contribute to the growing literature shedding light on country-specific determinants and the development of agricultural productivity in transitional economies [1]. Indeed, this literature has

[1] For example, Gong (2018) discusses the case of China; Foster and Rosenzweig (2004); Ghatak and Roy (2007) on India; Rahman and Salim (2013) on Bangladesh; Temoso et al. (2018) on Botswana; and Anik et al. (2017) on South Asia.

provided useful insights and important evidence to support economic theories that explain observed cross-country differences in agricultural productivity. A common feature of this literature, which differs from ours, is that their analysis is typically done at either the aggregate or household level, but not both.

Our work most closely relates to several studies that analyze productivity in Vietnam's rice sector. Previous assessments at the aggregate level were conducted for the periods until 2006, capturing the trend in the early stage of the reforms (Nghiem and Coelli, 2002; Kompas et al., 2012). Other studies, at the household level, focus on investigating factors that lead to rice farm inefficiency during a specific year, using either their own farm survey data or VHLSS data sets in the early 2000s (e.g. Huynh and Yabe, 2011; Linh, 2012; Kompas et al., 2012). Despite being more recent, the work by Diep (2013); Pedroso et al. (2018); Trong and Napasintuwong (2015), examine only one of the eight regions in Vietnam, and thus is not country-representative. The availability of new and high-quality regional data, along with established agricultural censuses, the unique plot-level data of 2004 and 2014 in the VHLSS, and the in-depth interviews with farmers, provides an excellent opportunity not only to update the knowledge gained through the previous studies but even more so to assess whether government measures since the late 2000s have been effective.

2. Background

Vietnam has been one of the most successful stories in world economic development. Since the launch of economic reforms in 1986, the country has experienced high economic growth and moved from being one of the world's poorest nations into a lower-middle-income state. The pro-poor nature is arguably the most prominent feature of Vietnam's growth pattern, with the poverty rate falling by 51 percentage points during 1992-2017 when Gross Domestic Product (GDP) per capita increased by nearly four-fold over the same period (Figure 1).

However, the driver behind this inclusive growth has changed over time. Earlier gains had been achieved thanks to the distribution of agricultural land to rural households and the incentives provided to them to increase their farm production (e.g. Che et al., 2001; Nghiem and Coelli, 2002; Kompas et al., 2012). But these gains had been reaped by the early 2000s. Since then, the driving forces behind poverty reduction in Vietnam are job creation by the substantial expansion in trade due to the signing of dozens of multi- and bi-lateral trade agreements (Figure 1), and the increased integration of agriculture to the market economy (World Bank, 2003, 2018).

The rapid export-led economic growth has shifted Vietnam's focus from poverty to inequality since the mid-2000s (VASS, 2011; World Bank, 2012, 2018). There are at least two reasons behind this shift. First, Vietnam is a socialist state in transition, and therefore, curbing inequality is vital for its political and social stability. Second, about 38 out of 50 million jobs in the economy are family farming, household businesses, or un-contracted labor (Cunningham and Pimhidzai, 2019). These jobs typically have low productivity, low profits, meager earnings, and little worker protection. Although administrative restrictions on migration, in the form of residence registration, have been considerably relaxed, thus allowing for considerable labor mobility across the country, other constraints such as age and a lack of human, physical, and financial capital remain substantial (Narciso, 2017). Hence, the poor are mostly rural dwellers and ethnic minorities who fail to benefit from the ongoing economic growth (World Bank, 2018). This phenomenon goes hand in hand with the rapid expansion of the middle class in the urban areas, and hence the rural-urban gap has been widening (World Bank, 2018).

In this context, a new wave of agricultural reforms was initiated in 2007, with an aim to boost economic efficiency and social equity. For economic efficiency, Vietnamese policy has attempted to *"restructure the agricultural sector to enhance its value-added and sustainable development to increase farmers' income"* (Resolution 26-NQ/TW issued in 2007). To do so, two important measures have been implemented. The first is the 2013 revised Land Law, which allows farmers to accumulate annual land, including rice land, from the previously-set limit of 6 hectares to now 30 hectares in the Mekong River delta, and from the limit of 4 hectares to now 20 hectares in other regions. As for perennial land, the limit has been increased from 20 hectares to now 100 hectares in the deltas and 50 hectares to 300 hectares in highlands/mountainous areas. In parallel, the land tax for allocated land was waved between 2003 and 2010, and reduced by half for accumulated land (2003 and 2010 (Revised) Land Law)[2]. As the second measure, Vietnam reduced irrigation service fees in 2003 and then removed them in 2008 (Degrees No.115/ND-CP and No.143/ND-CP). This second measure has benefited rice farmers mostly since rice land represents about 80 percent of Vietnam's irrigated land. It is worth noting that the spending on irrigation has accounted for 60-80 percent of the total public expenditure on agriculture, on average, since the early 2000s. In comparison, research and development have represented less than three percent (MARD, 2013, 2017).

Regarding social equity, rice policies have become instrumental. The reason is that about 80 percent of rural households remained involved in rice production by 2014, while rice contributed about half of the calorie intake of rural dwellers (Nguyen et al., 2020). In this context, rice policies have substantial pro-poor implications.

At the risk of oversimplification, we classify equity-targeting policies into two groups. The first one seeks to achieve long-term food security by protecting an area of rice land that is sufficient to produce rice for the nation by 2030 (Decree 63/ND-CP in 2009, Resolution 17/2011/QH13 in 2011)[3]. Accordingly, Vietnam is among the only two countries in the world in which farmers are not allowed to plant any crops other than rice in their rice-designated area (Markussen et al., 2011; Giesecke et al., 2013). Given this crop constraint, the profit of rice production is the lowest among all annual crops (World Bank, 2018). To address this disparity, cash transfers of about \$20 per hectare of wet rice land and \$10 per hectare of dry rice land were provided to farmers during 2012-2015 (Decree 35/2015/ND-CP).

The second group of policies aims to ensure that rice farmers have at least a 30 percent profit (Document 430/TTg-KTN, 2010). To achieve this, the government has built big temporary storage depots to store paddy purchased from farmers during the harvest time when the price is low (Decision 1518/QD-TTg, 2009). Loans with subsidized interest rates were also provided to implement this purchase for the first few years, after the

[2]Vietnam has been controlling farm size by setting limits on land allocation and accumulation. In particular, the former is the maximum amount of land granted by the state to a household; the latter is the maximum amount of land a household can accumulate via transactions on the land market.

[3]Chu et al. (2017) find that economic efficiency would be enhanced if 13% of the proposed protected cultivated rice land can be released into the pool of land for other crops. However, this release is pro-rich and thus implies a trade-off between economic efficiency and inequality in Vietnam.

depots were built. Rice has been listed among 11 essential commodities which have been under price regulation by the government since 2012 (Price Law, 2012). This regulation can be implemented strictly due to the government's full control over rice exports and long-distance trade (Nguyen et al., 2020).

Against this background, we aim to assess to what extent there were productivity increases in rice production during the second wave of agricultural reforms, and investigate what may have prevented these or any increases in Vietnam.

3. Methods

We use both quantitative and qualitative methods to achieve our research aim. Specifically, the time trends of regional productivity are estimated using MPI, alongside rice TOT. Meanwhile, factors that affect productivity are identified using Stochastic Frontier Analysis (SFA) of household data. Quantitative results are interpreted with the aid of semi-structured interviews with various stakeholders of the rice sector. This section explains each of the methods.

3.1. The terms of trade

TOT is the ratio of Tornqvist output and input price indices. Each index is a weighted geometric average of the price relatives where the weights are quantity averages across the two periods t and s (Tornqvist, 1936), in the form:

$$TOT_{ts} = \frac{\prod_{j=1}^{n} \frac{p_{jt}}{p_{js}}^{\frac{(w_{js}+w_{jt})}{2}}}{\prod_{k=1}^{m} \frac{p_{kt}}{p_{ks}}^{\frac{(v_{ks}+v_{kt})}{2}}} \tag{1}$$

where p denotes price; w and v are shares, being $w_j = p_j q_j / \sum_{j=1}^{n} p_j q_j$ and $v_k = p_k q_k / \sum_{k=1}^{m} p_k q_k$ for output j and input k. We subpress the time indices t and s in our explanation of the notations to ease presentation.

3.2. The Malmquist productivity index

The MPI is introduced by Malmquist (1953) to measure the Total Factor Productivity (TFP) growth of a Decision-Making Unit (DMU) over two periods of time. It is defined as the product of efficiency (EC) and technological change (TC) terms, reflecting changes in efficiency, along with those of the frontier technology over time. In particular, for DMU_0 with its sets of inputs x_0 and outputs y_0, its MPI_0 is calculated as follows:

$$MPI_0 = \underbrace{\frac{\sigma^{t_2}\left((x_0, y_0)^{t_2}\right)}{\sigma^{t_1}\left((x_0, y_0)^{t_1}\right)}}_{\text{Efficiency Change}} \times \underbrace{\left[\frac{\sigma^{t_1}\left((x_0, y_0)^{t_1}\right)}{\sigma^{t_2}\left((x_0, y_0)^{t_1}\right)} \times \frac{\sigma^{t_1}\left((x_0, y_0)^{t_2}\right)}{\sigma^{t_2}\left((x_0, y_0)^{t_2}\right)}\right]^{1/2}}_{\text{Technical Change}} \quad (2)$$

where $\sigma^i\left((x_0, y_0)^j\right)$ represents the efficiency score of the sets (x_0, y_0) in period j with respect to the frontier in period i.

We estimate MPI using the Data Envelopment Analysis (DEA), one of the two main efficiency analysis techniques. DEA allows a flexible and non-parametric production structure, but its results can be highly sensitive to the randomness in data because DEA is based on an implicit assumption that there is no noise in the data (Charnes et al., 1978; Bogetoft and Otto, 2010). Therefore, we choose DEA to find regional MPI time trends because we prefer not to make any assumptions about the production function of DMUs, which are aggregated, and the data used has little randomness due to aggregation.

Our Malmquist model to estimate MPI is non-radial and non-oriented to address the issue of super-efficiency, or the neglect of slacks (Andersen and Petersen, 1993), and to ensure a feasible solution (Tone, 2002). Thus, following Tone and Tsutsui (2017), we calculate the adjusted cumulative MPI (CMPI) over T periods in the form:

$$CMPI_0{}^{1\to t} = \Pi_{\tau=1}^{t} MPI_0^{\tau\to\tau+1} \quad (t = 1, \ldots, T-1) \quad (3)$$

where the value of the CMPI in period 1 is the efficiency score in the base period to capture the relative efficiency of the DMUs at the outset. In a similar manner, we calculate the cumulative EC and TC, but adjusting for the relative efficiency is not needed for easy presentation and interpretation.

3.3. The stochastic frontier analysis

As with DEA, the stochastic frontier analysis (SFA) is a popular efficiency analysis technique. SFA allows consideration of both random variations in output, for a given level of inputs, and factors other than inputs that influence efficiency (Aigner et al., 1977; Meeusen and van Den Broeck, 1977). As a parametric method, the downside of SFA is its lack of flexibility in model structure. Although DEA is superior to SFA in terms of flexibility, its results will not be valid if the data used are somewhat random. Therefore, the choice between DEA and SFA boils down to whether model flexibility or the precision in noise separation is more important in each application.

With this in mind, we choose SFA as the method to find constraints to farm productivity. The justification for this choice is twofold. First, for this analysis, we use household data, which likely contains noise. Second, production theory in economics is relatively well-established, allowing us to make some standard assumptions about the farm production function. In this light, we follow Battese and Coelli (1995) to specify the production function for firm i in the form:

$$Y_i = f(X_i, \beta)e^{v_i - u_i} \tag{4}$$

where Y_i is output, X_i is a $1 \times k$ vector of inputs and β is a $k \times 1$ vector of parameters to be estimated. The composite error term has two components, namely the usualy random noise $v_i \sim N(0, \sigma_v^2)$ and the non-negative random variable $u_i \sim N^+(z_i\delta, \sigma_u^2)$, capturing firm-specific technical inefficiency in production in the form:

$$u_i = z_i\delta + w_i \tag{5}$$

where z_i is a $1 \times m$ vector of explanatory variables, δ is a $m \times 1$ vector of unknown coefficients and w_i is a random variable

Parameters of both models (4) and (5) can be estimated simultaneously and consistently using the maximum likelihood estimator (Wang and Schmidt, 2002). The likelihood function is expressed in terms of the variance parameters, $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2/\sigma^2$ where $\gamma \in [0, 1]$. The SFA model specification is appropriate only when γ approaches to 1. This specification can be tested using a likelihood ratio test which follows a mixed chi-square distribution (Coelli and Battese, 1996). The technical efficiency for each DMU is defined as $TE = exp(-u_i) \in [0, 1]$ by construction to ensure that all observations lie on or under the stochastic production frontier (Battese and Coelli, 1995).

3.4. Semi-structured interviews

To aid the interpretation of quantitative results, we use information from semi-structured interviews with rice farmers in three key rice-producing provinces. These interviews are part of a comprehensive qualitative study of the rice sector in Vietnam described in Nguyen et al. (2020). Each of them contains two parts. The first part has structured questions to get an overview of farmers' production, sales, revenues, and profit, and whether their products were sold for domestic consumption or exports. The second part has open questions, asking about their production plan, the support they have received from the Government, and the challenges they have faced.

4. Data and model specification

This section describes the data sources, variables, and model specification to implement our methods. All values are in 2010 constant prices, and adjusted for differences among regions, using either the regional price index (RCPI) or the Spatial Cost of Living Index (SCOLI) if available. Detailed explanations on RCPI and SCOLI are contained in Appendix A.

4.1. Regional data for calculating the terms of trade and the Malmquist productivity index

TOT and MPI are calculated using input and output prices and quantities. The output is paddy, while the input includes land, labor, capital, and materials, which in turn consist of fertilizer, pesticide, and seeds. As the data to construct output and input time series come from various sources, adjustment and imputation sometimes need to be made when they are not available (details are in Appendix B).

4.2. Household data for the stochastic frontier analysis and model specification

SFA is carried out using data from VHLSS in 2004 and 2014. As with other VHLSS, these two surveys are nationally representative and collected by Vietnam's General Statistical Office with technical support from the World Bank. However, being different from other VHLSS, they have an extended module on agriculture, which provides us with essential information to determine factors that restrict farm productivity. As our analysis focuses on rice production, following Kompas et al. (2012), we limit our sample to households, whose rice revenues account for about three-quarters of the total crop revenues.

To this end, the pool data set used for this paper has about 5900 farms-households in total.

We start with a general model, in the form of translog, to provide the local second-order approximation to any production frontier (Christensen et al., 1973). Furthermore, to accommodate the technical change from 2004 to 2014, we follow Kumbhakar et al. (2015) to add a time dummy for the year 2014 and its interactions with all input variables. Finally, to control for regional fixed effects, our model also includes regional dummies. Hence the specification is in the form:

$$\ln y = \underbrace{\beta_0 + \sum_g \beta_g lnx_g + \frac{1}{2}\sum_g \sum_h \beta_{gh} lnx_g lnx_h}_{\text{Translog}} + \underbrace{\beta_t d14 + \sum_g \beta_{gt} lnx_g d14}_{\text{Technical change}} + \underbrace{\sum_k \beta_{rk} Reg_k}_{\text{Regional Fixed Effects}} + v - u \quad (6)$$

where $\beta_{gh} = \beta_{hg}$ and $u = \delta_0 + \sum_m \delta_m z_m + w$ (as described in equation 5).

Table 1 present the summary statistics of variables for both production and technical inefficiency models. We show not only their sample averages but also their quartiles since the distribution of some variables is quite skewed.

The model outcome is the farm's annual rice output, measured in either quantity or value. Output quantities are often used in SFA to avoid complications caused by intertemporal and spatial price effects (Aigner et al., 1977). However, in this paper, we also consider output values, alongside output quantities, to account for differences in rice quality due to region-specific topographical conditions and rice varieties (Department of Crop Production, 2015; Bui et al., 2010). On average, a farm produced about 5 tonnes of rice in 2014, and earned approximately 20 million VND (or 1,000 USD) per year, increasing by a quarter in both quantity and value compared with those a decade ago (Table 1, columns 1-2).

Our stochastic frontier has six inputs, all of which matter to rice production. Land (LAN) is the total area of annual cropland, measured in hectares. Labor is split into two variables, namely household labor ($FLAB$), measured in hours, and hired labor ($HLAB$), measured in money – a unit of measurement applied to the remaining inputs.

Capital (CAP) covers both rentals if farmers rent in capital goods, primarily machines and equipment, for production, and depreciation if they own them. Finally, fertilizer (FER) and pesticide (PES) are the costs of these materials, respectively.

As seen in Table 1 (columns 1-2), all inputs have increased over time, except for household labor. Indeed, household labor has reduced by about a quarter over a decade, being offset by hired labor. Of those inputs that have increased, farmland has increased the least, by about 6 percent. By 2014, the average farm size was approximately 0.54 ha, suggesting the persistent nature of subsistent rice production in Vietnam, even decades after the launch of economic reforms in 1986. Nonetheless, rice production has been mechanized considerably, with expenses on capital more than doubling between the two periods. The same is true with the use of pesticides, which, unfortunately, has raised serious concerns over health and environmental damage in rural Vietnam (e.g. Toan et al., 2013; Lamers et al., 2011). Finally, fertilizer has also increased, but to a lesser extent, by 60 percent.

The inefficiency model has eight explanatory variables, which can be classified into two groups. The first group relates to land, while the second one captures household demographics. For the land group, land quality is captured by two variables. One variable is the ratio of the land area, which has favorable conditions for rice production, to the total land area (TYP), while the other is the ratio of irrigated land to the total land area (IRR). Land ownership is measured by the ratio of the land area, which has been granted land-use certificates, to the total land area (LUC). Last, but not least, land fragmentation (SI) is quantified using the Simpson index, which takes into account both the number of plots and the size of each plot (Simpson, 1949), in the form:

$$SI = 1 - \frac{\sum_{n=1}^{N} a_n^2}{(\sum_{n=1}^{N} a_n)^2} \tag{7}$$

where N is the number of plots, and a_n is the area of plot n. SI, by construction, is bounded by zero and one where zero indicates that a farm has only one plot or not fragmented at all, while one implies that a farm has an infinite number of plots.

As seen in Table 1 (columns 1-2), land quality and ownership variables have worsened between the two periods. In particular, they have fallen by approximately ten percentage points. From a statistical point of view, part of these reductions can be explained by the sampling variation since sample estimates using two different cross-sectional surveys, carried out at different points in time, are expected to be different. However, at a deeper level, the reductions likely stem from the relative contraction of quality paddy land compared with nation-wide total paddy land. Indeed, rapid urbanization has converted a large area of paddy land, much of which is in good condition and with land-use certificates, into other use purposes (e.g. Huu et al., 2015). The conversion is more visible in main rice-producing regions, which are also economic hubs with high economic growth (e.g. the two deltas and North and South Central Coasts (NCC and SCC)), as seen in Appendix C. In terms of land fragmentation, the evidence in Table 1 indicates some progress made in addressing this issue in rural Vietnam.

The group of household demographics has four variables. The first three relate to the household head's gender (GEN), age (AGE), and educational level (EDU). The last one, (MAT), is the ratio of household members, who are 55 years or older, to the total number of household members, who are involved in rice production. As seen in Table 1, there is little change in the characteristics of the household head. However, the ratio of older household labor has increased considerably, by 10 percentage points, from 2004 to 2014. This result is plausible since young and skilled rural labor can move out of agriculture to find alternative employment, leaving only old and unskilled labor behind to do farm work. This situation is more pronounced in delta regions because it is easier to migrate and find social and employment connections here (Phuong et al., 2008).

4.3. Semi-structured interviews

During December 2016 - January 2017, 15 semi-structured interviews were carried out with farmers in three key rice-producing provinces. The provinces include Can Tho and An Giang in the Mekong River Delta and Nam Dinh in the Red River Delta. Farmers were selected from large-, medium- and small-sized groups to provide as diverse as possible perspectives.

5. Results

In this section, we first discuss regional trends of TOT and MPI. We then focus our attention on the factors that constrain technical efficiency at the household level. Semi-structured interviews provide additional insights.

5.1. Regional trends in the terms of trade and the adjusted cumulative Malmquist productivity index

Figure 2 shows the TOT in rice production since 2000 – the base year. TOT has been deteriorating, save for some marginal improvement during 2002-2005. Even the price spikes in 2008 and 2011 could only bring TOT to the same level as the base year. The underlying reason for this deterioration is two-fold. The first is the steady increase in input prices, mostly driven by rising labor costs since 2003. High economic growth and rapidly expanding non-agricultural sectors have moved substantial rural labor out of agriculture and increased the labor cost since the early 2000s. The second reason is the collapse in output prices since 2012. Under these circumstances, TOT, and thus the income of rice farmers, has worsened.

Figure 3 shows the adjusted cumulative Malmquist productivity index and its decomposition into cumulative EC and TC by region. The indices are calculated using the package DJL in R (Lim, 2020). The cumulative EC is on the top panel. As can be seen, there were no changes in the cumulative EC in the two main rice-producing deltas (RRD and MRD) and the third-largest economic hub (SCC), compared with the base year. However, other areas experienced some improvement in EC, notably CH and SE. These two regions have the lowest efficiency scores, thus probably having little difficulty enhancing their EC (Figure 3, the bottom right panel).

The middle two panels show changes in the cumulative TC. They were substantial in MRD during 2002-2015, indicating advancement in technology. The result makes sense since this region has the most significant comparative advantage in producing rice in the country. Some progress in technology can also be observed in SCC and SE, which borders MRD, during the early 2000s. Other areas experienced regression in technology, and the trend has worsened since 2011.

The bottom two panels of Figure 3 present adjusted cumulative MPI, which, in effect, is a combination of EC and TC, with adjustment for regional initial efficiency scores. The most notable improvement is seen in SE and CH thanks to the dramatic increase in EC. The trends in other areas are either flat or even downward sloping, indicating little or regression in productivity.

In summary, the terms of trade for rice has been steadily decreasing, which tend to reduce farm income. Meanwhile, the Malmquist productivity index has been falling in most regions due to the decline in technical change and little improvement in technical efficiency.

5.2. Stochastic frontier analysis

In this subsection, we first select an appropriate model specification. We then present estimation results for the production frontier and inefficiency models. All estimates are obtained using the Frontier package in R (Coelli and Henningsen, 2019).

5.2.1. Model specification tests

Table 2 presents likelihood ratio tests for model selection. As can be seen, we reject all null hypotheses at the 1% level and select a model, as shown in equation 6. Specifically, the first three tests focus on the production model. We first test whether a translog model is favored against the null of having a Cobb-Douglas functional form. Put differently, does adding the third term in equation 6 sufficiently improve the likelihood ratio compared to the case without them? The second and third tests check whether technical change is non-neutral. That is, whether TFP and returns to individual inputs statistically change over time? In essence, we test the fourth and fifth terms in equation 6. The remaining four tests focus on the inefficiency model. We reject the nulls that technical inefficiency effects are absent in the fourth test, non-stochastic in the fifth test and follow a half-normal distribution in the sixth test. The seventh test rejects the null that all the explanatory variables in the inefficiency model are not statistically significant.

5.2.2. Results of the production model

There are four different specifications of the production model, in which the outcomes take either quantity or value, and the prices are deflated using either RCPI or SCOLI (see Table 3). As estimates of the four model specifications are quite robust, we focus our attention on the ones that use RCPI since RCPI was available for both surveys while SCOLI value was imputed for the 2004 survey.

Table 3 reveals a fall in TFP, as seen in the negative sign of the time dummy coefficients. It is worth noting that the fall in the quantity output model is twice as much that of the value output model, suggesting a shift towards enhancing rice quality among Vietnamese farmers. Regardless of being measured in monetary or physical terms, the fall in TFP is significant, corroborating, and further elaborating on the aggregate trends discussed earlier. On the surface, this fall can be explained, in part, by the water shortage induced by climate change, which has accelerated in recent years, and the water conflicts with upstream countries that cause ongoing water pressure for rice production (Sebesvari et al., 2012; Chea et al., 2016; Nguyen et al., 2017). Besides, the frequency of natural hazards such as floods, droughts, and storms has increased recently in Vietnam – one of the most climate-change vulnerable countries (MONRE, 2010; Hoang and Meyers, 2015). However, at a deeper level, there are more fundamental issues brought about by the government's social objectives in designing rice policies and the transition of the economy, which we will discuss in detail in the next subsection.

In parallel, the returns to land decreased while those to pesticide and hired labor increased over the two periods, as seen in their interactions with the time dummies. Lower returns to land are likely due to the reduction of fertile land, especially in the deltas. This reduction is due to industrialization and economic growth (e.g. Huu et al., 2015), the depletion of soil nutrients due to long-lasting rice monoculture (Tran Ba et al., 2016; Tran Dung et al., 2018), and the heavy reliance on chemical fertilizer in producing high-yielding varieties (HYV) – a factor that deteriorates soil fertility (Savci, 2012). In addition, the increasing importance of labor-saving pesticides in rice production is consistent with factor substitution induced by rising real wage rates. Finally, higher returns to hired labor over time reflect an unavoidable and increasing reliance on the labor market in farm production as the economy grows. Our findings on pesticide and hired labor are in line with the recent literature (e.g. Liu et al., 2020).

We further analyze the elasticities of the output with respect to inputs. Most of them are statistically significant for the model outcomes. Two exceptions are pesticide and hired labor, despite their rising importance over the time as discussed earlier.

Since the translog functional form implies non-linearity in elasticities, it is essential to estimate them at a specific point of the distribution. Figure 4a further confirms a lack of sensitivity in estimates between the models with output quantity and output value as an outcome. At the sample means of inputs, output responds the most to fertilizer, followed by land, capital, and pesticide. The impact of labor is relatively small. Across three quartiles, capital elasticities are similar, indicating limited changes in the impact of mechanization on output when production scale increases (Figure 4b). However, large farms' output is much more responsive to pesticides and hired labor and much less so to land, compared with small and medium farms. This result implies that large farms have been using cheaper and more readily available chemicals to substitute for increasingly expensive labor.

5.2.3. Results of the inefficiency model

All variables in the inefficiency model are statistically significant (Table 3). It is worth noting that the negative coefficient of a variable in the inefficiency model means that efficiency will be improved when the variable increases and vice versa.

All variables help increase productivity, except for the land fragmentation index (FRA) and the ratio of old household labor (MAT). Among the productivity-enhancing variables, the ratio of irrigated land (IRR) has the most impact. The result makes sense in the context of Vietnam's prevalent use of HYV, which relies mostly on irrigation and fertilizer. Likewise, as expected, a higher share of land classified as having favorable conditions for agricultural production (TYP) results in better rice quantity and revenues. Similarly, households with a bigger fraction of land area being granted land-use certificates (LUC) are more efficient since they can use LUC as collateral for loans and have stronger incentives to invest in their owned farms.

In the same vein, most of the demographic attributes also contribute to increasing efficiency. Among these variables, having a male head (GEN) implies the largest impact. The result reflects not only the suitability of men in rice production but also the premium of being a man in the male-dominant culture of rural Vietnam. Having additional years of education (EDU) also helps farmers to raise their production outcomes, albeit marginally.

Finally, age (AGE) also has a positive, but small, and slightly decreasing impact on efficiency.

On the other hand, the higher land fragmentation (FRA), the lower is farm efficiency. Put differently, larger farms are more efficient. A similar finding is reported recently by Pedroso et al. (2018). So putting it all together, there is strong evidence that land fragmentation remains a severe factor that hampers efficiency in rice production, even though more than ten years have elapsed since this impediment was first documented in the empirical literature (e.g. Pham et al., 2007; Kompas et al., 2012). While the evidence highlights the importance of land accumulation to farm production efficiency, it also underscores the slow progress in land consolidation in Vietnam, especially over the last decade. The government's support to rice farmers has likely hindered land amalgamation by making it cheap, if not free, to keep land idle or maintain subsistent production. This impact is further amplified by the tendency of holding land tightly to pass it on to children as an inheritance, particularly in the North of Vietnam (Pham et al., 2007). To this end, the resulting widespread and persistent production at the subsistence scale has led to little or regression in both EC and TC observed across most of the regions, as discussed earlier.

On top of this, we observe an emerging factor that curbs productivity in rural Vietnam when most able-bodied farmers have probably left agriculture to find off-farm jobs. Specifically, the higher the ratio of labor being 55 years old or older (MAT), the less efficient is the farm[4]. The result is plausible since elderly people have few options to move out of agriculture due to their mature age and a lack of skills for more modern jobs. Furthermore, they might be expected to stay home to take care of their grandchildren and conduct cultural practices. The semi-structured interviews with farmers in key rice-producing provinces reveal that two-thirds of them would maintain the same (subsistence) rice production for food security and employment for elderly people (Nguyen et al., 2020). Meanwhile, household data show that the MAT ratio is higher and has increased in the main delta regions and economic hubs (RRD, MRD, SCC and SE), where young and skilled labor is much dearer, and it is easier to migrate (see Appendix

[4]We follow GSO (2018) in defining the group of mature labor at the age of 55 or older as distinct from other labor groups.

C). This phenomenon reflects a feature of a transitional economy, often referred to as 'greying' agriculture in the literature (e.g. Ye, 2015). As the economy continues to grow rapidly, and the government plans to use rice policy for social equity and food security purposes, alongside with relaxing constraints to labor mobility, the issue of 'left-behind' elderly will continue to rein for many years to come. Thus, lower productivity is expected due to extensification of land use, less multiple cropping and land abandonment. Land accumulation and capital investment would thus be slow, while the application of new technology and the leverage of economies of scale would be obstructed.

6. Conclusion

Increasing productivity in agriculture is often deemed necessary to enhance rural income and ultimately narrow the urban-rural income disparity in transitional economies. This paper investigates the case of Vietnam during the high economic growth period (2000-2016), in which the country introduced policies to increase efficiency in rice production and income for rice farmers.

6.1. Findings and policy implications

We find a steadily decreasing trend in the TOT for rice, indicating regression in farm income. Meanwhile, the Malmquist productivity index has been falling in most regions due to the decline in technical change, along with little improvement in technical efficiency. The underlying reasons for these results are the high ratio of left-behind elderly farmers, in addition to previously-documented land-related issues such as land fragmentation and delay in the issuance of land-use certificates. We document, for the first time, evidence of Vietnam's 'greying agriculture.' It also confirms a seemingly inevitable trend as the economy develops – an experience observed in other more developed countries such as European countries, Japan and China.

The rise in the urban-rural gap is expected when the industry and services sectors grow faster than agriculture. Vietnam is not an exception in this regard. To curb this trend, the country has followed the lead of many more developed countries to move from taxing to subsidizing agriculture (Anderson et al., 2013). In the absence of an adequate social safety net, rice policy has become an ad-hoc equity-targeting tool for the government. This approach, however, likely hinders land accumulation and limits enhanced productivity. Thus the goals of achieving economic efficiency and social equity appear contradictory to each other in Vietnam's rice policies, posing a significant development challenge for the country's current and likely future development.

6.2. Contribution, limitations and future research

This paper contributes to the now influential literature that tries to explain cross-country productivity differences in agriculture by providing detailed insights from Vietnam. This case is particularly interesting since Vietnam is a remarkably successful transitional economy with high economic growth, moderate (albeit increasing) inequality, and outstanding achievement in meeting development goals. The combination of detailed time-series and plot-level farm data, alongside interviews with farmers, makes this paper distinct from the existing literature. From this perspective, and although this paper presents the experience of Vietnam at a particular period in time, it is hoped that general lessons can be drawn and applied to similar development contexts.

Nevertheless, additional data would certainly enhance the analysis. Factors such as access to credit, extension services, and the market itself can affect farm inefficiency. These are currently controlled via regional dummies in our model due to a lack of detailed information. Although having this information may not necessarily affect the quality of our model estimates, given the time and fixed effects that we have controlled for, it would no doubt enrich the policy implications, and thus be worth considering in future research.

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References

Adamopoulos, T., Restuccia, D., 2014. The size distribution of farms and international productivity differences. The American Economic Review 104 (6), 1667–1697.

Aigner, D., Lovell, C. K., Schmidt, P., 1977. Formulation and estimation of stochastic frontier production function models. Journal of Econometrics 6 (1), 21–37.

An Giang DARD, 2012-2014. Rice production cost surveys. Unpublished work, An Giang, Viet Nam.

Andersen, P., Petersen, N. C., 1993. A procedure for ranking efficient units in data envelopment analysis. Management Science 39 (10), 1261–1264.

Anderson, K., Rausser, G., Swinnen, J., 2013. Political economy of public policies: insights from distortions to agricultural and food markets. Journal of Economic Literature 51 (2), 423–477.

Anik, A., Rahman, S., Sarker, J., 2017. Agricultural productivity growth and the role of capital in south asia (1980–2013). Sustainability 9 (3), 470.

Bales, S., 2001. Vietnam Living Standards Survey (VLSS), 1997-98: Basic Information. Poverty and Human Resources Division, World Bank.

Battese, G. E., Coelli, T. J., 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical Economics 20 (2), 325–332.

Baulch, B., Hansen, H., Trung, L. D., Tam, T. N. M., 2008. The spatial integration of paddy markets in vietnam. Journal of Agricultural Economics 59 (2), 271–295.

Bogetoft, P., Otto, L., 2010. Benchmarking with Dea, Sfa, and R. Vol. 157. Springer Science & Business Media.

Bordey, F., Moya, P., Beltran, J., DC, D., 2016. Competitiveness of Philippine Rice in Asia. Science City of Muoz (Philippines): Philippine Rice Research Institute and Manila (Philippines): International Rice Research Institute.

Bui, B. B., Nguyen, V. B., Bui, C. B., 2010. Vietnam Fifty years of Rice Research and Development. The Ministry of Agriculture and Rural Development of Viet Nam.

Charnes, A., Cooper, W. W., Rhodes, E., 1978. Measuring the efficiency of decision making units. European Journal of Operational Research 2 (6), 429–444.

Che, T. N., Kompas, T., Vousden, N., 2001. Incentives and static and dynamic gains from market reform: rice production in Vietnam. Australian Journal of Agricultural and Resource Economics 45 (4), 547–572.

Chea, R., Grenouillet, G., Lek, S., 2016. Evidence of water quality degradation in lower Mekong basin revealed by self-organizing map. PloS one 11 (1), e0145527.

Christensen, L. R., Jorgenson, D. W., Lau, L. J., 1973. Transcendental logarithmic production frontiers. The Review of Economics and Statistics, 28–45.

Chu, L., Nguyen, H. T. M., Kompas, T., Dang, K., Trinh, B., 2017. Optimal rice land protection in a command economy. Crawford School Research Paper No. 1707.

Coelli, T., Henningsen, A., 2019. Frontier: Stochastic frontier analysis-R package version 1.1-6. Available at: https://CRAN.R-Project.org/package=frontier [Accessed: 10/5/2019].

Coelli, T. J., Battese, G. E., 1996. Identification of factors which influence the technical inefficiency of indian farmers. Australian Journal of Agricultural Economics 40 (2), 103–128.

Cunningham, W., Pimhidzai, O., 2019. Vietnam's future jobs: leveraging mega-trends for greater prosperity . Hanoi: World Bank.

Department of Crop Production, 2015. Rice varieties report. Unpubished report, the Ministry of Agriculture and Rural Development. Hanoi, Viet Nam.

Diep, T. T., 2013. Changes in the technical and scale efficiency of rice production activities in the Mekong delta, Vietnam. Agricultural and Food Economics 1 (1), 16.

Dong Thap DARD, 2009-2014. Rice production cost surveys. Unpublished work, Dong Thap, Viet Nam.

FAO, 2019. Faostat. Available from http://faostat3.fao.org/home/E [Accessed: 23 March, 2019].

Foster, A. D., Rosenzweig, M. R., 2004. Agricultural productivity growth, rural economic diversity, and economic reforms: India, 1970–2000. Economic Development and Cultural Change 52 (3), 509–542.

General Statistic Office, 2013. Statistical Yearbook of Vietnam 2012. Hanoi: Statistical Publishing House, Hanoi.

Ghatak, M., Roy, S., 2007. Land reform and agricultural productivity in india: a review of the evidence. Oxford Review of Economic Policy 23 (2), 251–269.

Gibson, J., 2009. Regional Price Deflators for VHLSS 2008-2010 and GSO Capacity Building for Spatial Cost of Living Index. Tech. rep., World Bank, Washington, DC.

Giesecke, J. A., Tran, N. H., Corong, E. L., Jaffee, S., 2013. Rice land designation policy in Vietnam and the implications of policy reform for food security and economic welfare. The Journal of Development Studies 49 (9), 1202–1218.

Gollin, D., Lagakos, D., Waugh, M. E., 2014. The agricultural productivity gap. The Quarterly Journal of Economics 129 (2), 939–993.

Gong, B., 2018. Agricultural reforms and production in china: Changes in provincial production function and productivity in 1978–2015. Journal of Development Economics 132, 18–31.

GSO, 2002. Results of the rural, agricultural, and fishery census of Viet Nam 2001. Statistical Publishing House, Hanoi, Viet Nam.

GSO, 2007. Results of the rural, agricultural, and fishery census of Viet Nam 2006. Statistical Publishing House, Hanoi, Viet Nam.

GSO, 2012. Results of the rural, agricultural, and fishery census of Viet Nam 2011. Statistical Publishing House, Hanoi, Viet Nam.

GSO, 2017. Results of the rural, agricultural, and fishery census of Viet Nam 2016. Statistical Publishing House, Hanoi, Viet Nam.

GSO, 2018. Labor force survey. General Statistical Office of Viet Nam, Hanoi, Viet Nam. Available at: https://www.gso.gov.vn/default.aspx?tabid=512&idmid=5&ItemID=18993 [Accessed: 23 April, 2019].

Ha, H., 2016. "Thu s dng t nng nghip: Min n nm 2020" (Agricultural land tax: waver until 2020). Available at https://enternews.vn/index.php/thue-su-dung-dat-nong-nghiep-mien-den-nam-2020-103565.html, accessed on 14-07-2020.

Hoang, H. K., Meyers, W. H., 2015. Price stabilization and impacts of trade liberalization in the Southeast Asian rice market. Food Policy 57, 26–39.

Huu, T. P., Phuc, N. Q., Westen, G., 2015. Vietnam in the debate on land grabbing: conversion of agricultural land for urban expansion and hydropower development. Dilemmas of hydropower development in Vietnam: between dam-induced displacement and sustainable development. Eburon Academic Publishers, 135–151.

Huynh, V. K., Yabe, M., 2011. Technical efficiency analysis of rice production in Vietnam. Journal of International Society for Southeast Asian Agricultural Sciences 17 (1), 135–146.

Kodde, D. A., Palm, F. C., 1986. Wald criteria for jointly testing equality and inequality restrictions. Econometrica: Journal of the Econometric Society, 1243–1248.

Kompas, T., Che, N. T., Nguyen, H. T. M., Nguyen, H. Q., 2012. Productivity, net returns and efficiency: Land and market reform in vietnamese rice production. Land Economics 88 (3), 478–495.

Kompas, T., Nguyen, H. T. M., Van, D. K., 2011. Protecting the rural poor: evaluating containment measures against foot-and-mouth disease in Vietnam. Poverty, vulnerability and social protection in Vietnam: Selected issues, 220.

Kumbhakar, S. C., Wang, H.-J., Horncastle, A. P., 2015. A practitioner's guide to stochastic frontier analysis using Stata. Cambridge University Press.

Kuznets, S., 1971. Economic Growth of Nations: Total Output and Production Structure. Belknap Press of Harvard University Press.
URL https://books.google.com.au/books?id=bjB7Ad8in4MC

Lagakos, D., Waugh, M. E., 2013. Selection, agriculture, and cross-country productivity differences. American Economic Review 103 (2), 948–80.

Lamers, M., Anyusheva, M., La, N., Nguyen, V. V., Streck, T., 2011. Pesticide pollution in surface- and groundwater by paddy rice cultivation: A case study from northern vietnam. CLEAN Soil, Air, Water 39 (4), 356–361.

Lim, D.-J., 2020. Distance measure based judgment and learning - package djl. Available at: `https://cran.r-project.org/web/packages/DJL/index.html` [Accessed: 10/7/2020].

Linh, V. H., 2012. Efficiency of rice farming households in vietnam. International Journal of Development Issues 11 (1), 60–73.

Liu, Y., Barrett, C. B., Pham, T., Violette, W., 2020. The intertemporal evolution of agriculture and labor over a rapid structural transformation: Lessons from vietnam. Food Policy 94, 101913.

Malmquist, S., 1953. Index numbers and indifference surfaces. Trabajos de estadística 4 (2), 209–242.

MARD, 2011. Statistical data of agriculture and rural development. Agricultural Publishing House, Hanoi, Viet Nam.

MARD, 2013. Statistical data of agriculture and rural development. Agricultural Publishing House: Hanoi.

MARD, 2017. Statistical data of agriculture and rural development. Agricultural Publishing House, Hanoi, Viet Nam.

MARD, 2018a. Annual statistics on animal, poultry headcounts and meat production. Hanoi, Viet Nam. Available at: https://channuoivietnam.com/thong-ke-chan-nuoi/ [Accessed: 10/10/2018].

MARD, 2018b. Report on processing and mechanization improvements in crop production. Unpublished work, Hanoi, Viet Nam.

Markussen, T., Tarp, F., Van den Broeck, K., 2011. The forgotten property rights: Evidence on land use rights in Vietnam. World Development 39 (5), 839–850.

Meeusen, W., van Den Broeck, J., 1977. Efficiency estimation from cobb-douglas production functions with composed error. International Economic Review 18 (2), 435–444.

MONRE, 2010. Viet Nam's second national communication to the United Nations Framework Convention on Climate Change. The Ministry of Natural Resource and Environment, Hanoi, Viet Nam.

Narciso, D., 2017. Labour and migration. Growth, Structural Transformation, and Rural Change in Viet Nam: A Rising Dragon on the Move, 139–157.

National Assembly, 2003. Resolution No.15/2003/QH11 on agricultural land tax reductions. Available at: https://thuvienphapluat.vn/van-ban/Thue-Phi-Le-Phi/Nghi-quyet-15-2003-QH11-mien-giam-thue-su-dung-dat-nong-nghiep-51065.aspx [Accessed: 23 April, 2019].

National Assembly, 2010. Resolution No.55/2010/QH12 on agricultural land tax reductions. Available at: https://thuvienphapluat.vn/van-ban/Thue-Phi-Le-Phi/Nghi-quyet-55-2010-QH12-mien-giam-thue-su-dung-dat-nong-nghiep-115442.aspx [Accessed: 23 April, 2019].

Nghiem, S. H., Coelli, T., 2002. The effect of incentive reforms upon productivity: evidence from the Vietnamese rice industry. Journal of Development Studies 39 (1), 74–93.

Nguyen, H.-T.-M., Do, H., Kay, A., Kompas, T., 2020. Rice policy in a transitional economy: balancing the social and political objectives. Food Security.

Nguyen, V. K., Vo, V. V., Huynh, D. N., et al., 2015. Comparing the costs and benefits of floating rice-based and intensive rice-based farming systems in the Mekong Delta. Asian Journal of Agriculture and Rural Development 5 (9), 202.

Nguyen, Y. T. B., Kamoshita, A., Matsuda, H., Kurokura, H., et al., 2017. Salinity intrusion and rice production in Red River Delta under changing climate conditions. Paddy and Water Environment 15 (1), 37–48.

Pedroso, R., Tran, D. H., Viet, T. Q., Van Le, A., Dang, K. T., Le, K. P., 2018. Technical efficiency of rice production in the delta of the Vu Gia Thu Bon river basin, Central Vietnam. World Development Perspectives 9, 18–26.

Pham, V. H., MacAulay, T. G., Marsh, S. P., 2007. The economics of land fragmentation in the north of Vietnam. Australian Journal of Agricultural and Resource Economics 51 (2), 195–211.

Phuong, T., Tam, N., Nguyet, T., Oostendorp, R., et al., 2008. Determinants and impacts of migration in viet nam. Market, Policy and Poverty Reduction in Vietnam, 59–92.

Prime Minister, 2001. Decision No.199/2001/Q-TTg on agricultural land tax reductions. Available at: https://thuvienphapluat.vn/van-ban/Thue-Phi-Le-Phi/Quyet-dinh-199-2001-QD-TTg-mien-giam-thue-su-dung-dat-nong-nghiep-48789.aspx [Accessed: 23 April, 2019].

Rahman, S., Salim, R., 2013. Six decades of total factor productivity change and sources of growth in bangladesh agriculture (1948–2008). Journal of Agricultural Economics 64 (2), 275–294.

Savci, S., 2012. An agricultural pollutant: chemical fertilizer. International Journal of Environmental Science and Development 3 (1), 73.

Sebesvari, Z., Le, H. T. T., Van Toan, P., Arnold, U., Renaud, F. G., 2012. Agriculture and water quality in the Vietnamese Mekong Delta. In: The Mekong Delta System. Springer, pp. 331–361.

Simpson, E. H., 1949. Measurement of diversity. Nature 163 (4148), 688–688.

Tarp, F., 2017. Growth, Structural Transformation, and Rural Change in Viet Nam: A Rising Dragon on the Move. Oxford University Press.

Temoso, O., Hadley, D., Villano, R., 2018. Sources of efficiency, productivity and output growth in botswana agriculture. Review of Development Economics 22 (3), 1105–1124.

Toan, P. V., Sebesvari, Z., Blsing, M., Rosendahl, I., Renaud, F. G., 2013. Pesticide management and their residues in sediments and surface and drinking water in the mekong delta, vietnam. Science of The Total Environment 452-453, 28 – 39.

Tone, K., 2002. A slacks-based measure of super-efficiency in data envelopment analysis. European Journal of Operational Research 143 (1), 32 – 41.

Tone, K., Tsutsui, M., 2017. Malmquist productivity index models. Advances in DEA Theory and Applications: With Extensions to Forecasting Models, 40.

Tornqvist, L., 1936. The bank of finland's consumption price index. Bank of Finland Monthly Bulletin 10, 1 – 8.

Tran Ba, L., Le, V. K., Van Elsacker, S., Cornelis, W. M., 2016. Effect of cropping system on physical properties of clay soil under intensive rice cultivation. Land Degradation & Development 27 (4), 973–982.

Tran Dung, D., van Halsema, G., Hellegers, P. J., Ludwig, F., Wyatt, A., 2018. Questioning triple rice intensification on the Vietnamese mekong delta floodplains: An environmental and economic analysis of current land-use trends and alternatives. Journal of Environmental Management 217, 429–441.

Trong, P. H., Napasintuwong, O., 2015. Profit inefficiency among hybrid rice farmers in central Vietnam. Agriculture and Agricultural Science Procedia 5, 89–95.

VASS, 2011. Poverty Reduction in Vietnam: Achievements and Challenges. The Gioi Publisher.

Wang, H.-J., Schmidt, P., 2002. One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels. journal of Productivity Analysis 18 (2), 129–144.

World Bank, 2003. Poverty. Hanoi: World Bank.

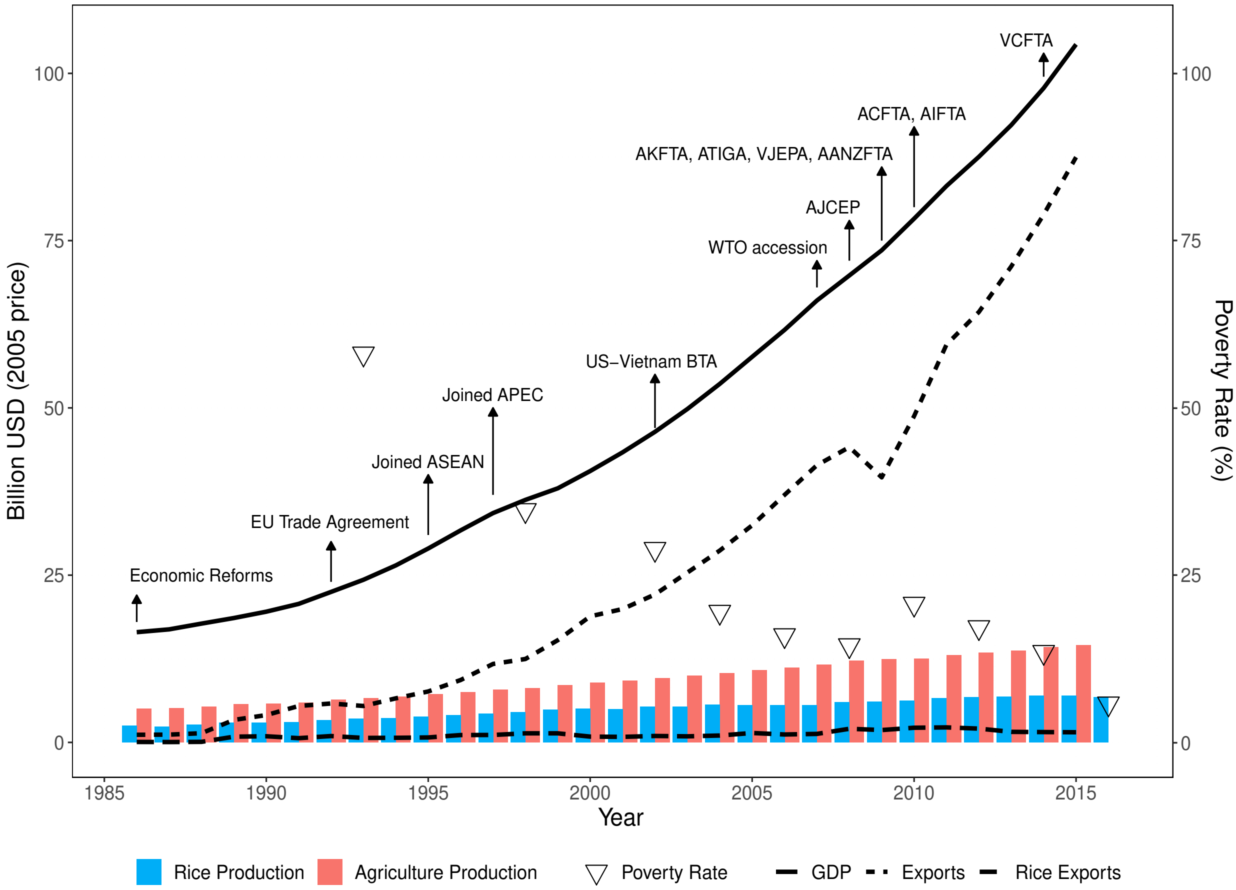
World Bank, 2012. Well begun, not yet done: Vietnam's remarkable progress on poverty reduction and the emerging challenges. World Bank Report No. 70798-VN. Hanoi: World Bank.

World Bank, 2018. Climbing the ladder: Poverty Reduction and Shared Prosperity in Vietnam. Hanoi: World Bank.

Ye, J., 2015. Land Transfer and the Pursuit of Agricultural Modernization in China. Journal of Agrarian Change 15 (3), 314–337.

List of Figures and Tables

Figure 1: Pro-poor export-led growth in Vietnam



Notes: GDP = Gross Domestic Product; VCFTA= Vietnam Chile Free Trade Agreement (FTA); ACFTA=Association of Southeast Asian Nations (ASEAN) China FTA; AIFTA = ASEAN India FTA; AKFTA = ASEAN Korea FTA; ATIGA = ASEAN Trade in Goods Agreement; VJEPA = Vietnam Japan Economic Partnership Agreement; AANZFTA = ASEAN Australia New Zealand FTA; WTO = World Trade Organization; EU = European Union;
Sources: Poverty rates are from VASS (2011); World Bank (2018) and other data are from FAO (2019).

Figure 2: Terms of trade, indices of input, output and labor prices in rice production

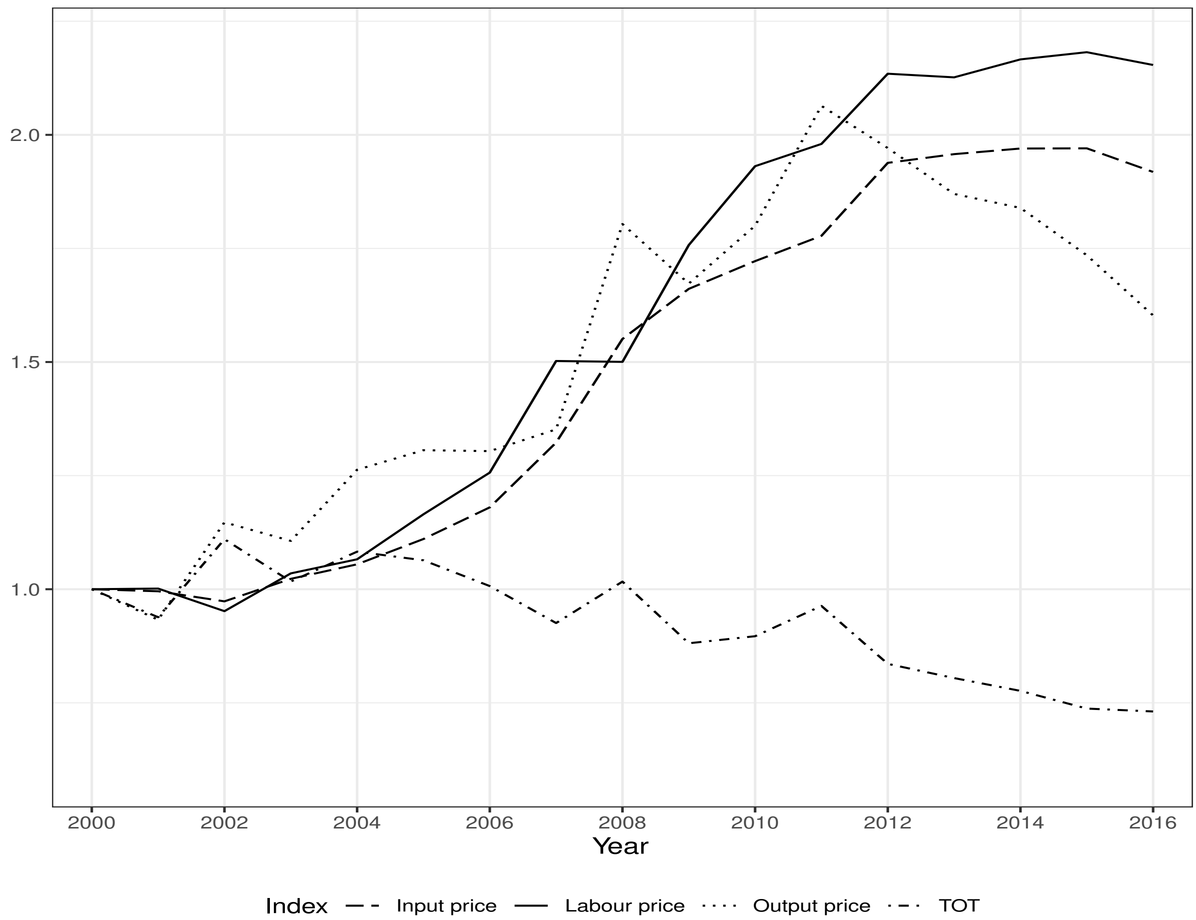


Figure 3: The Malmquist productivity index

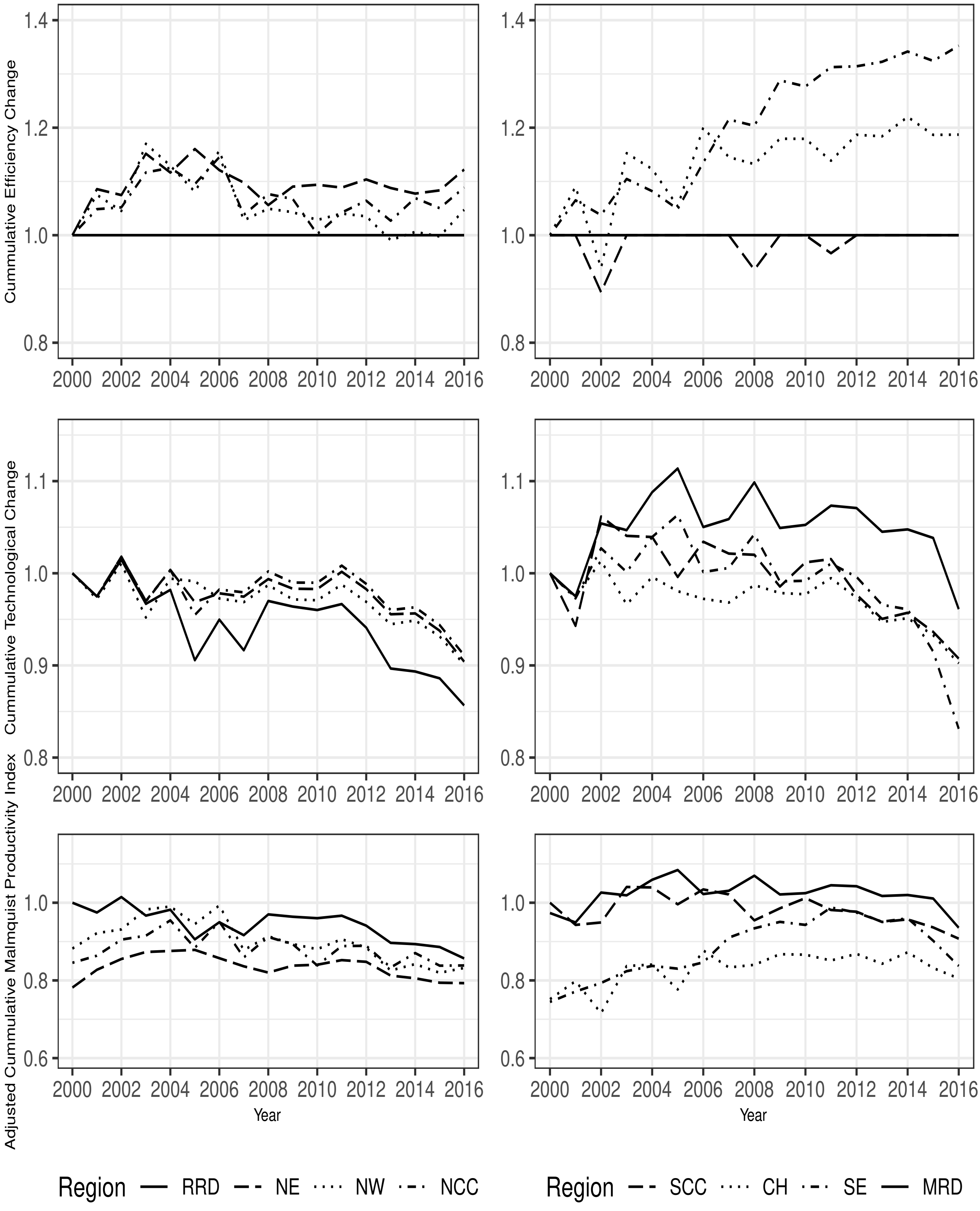
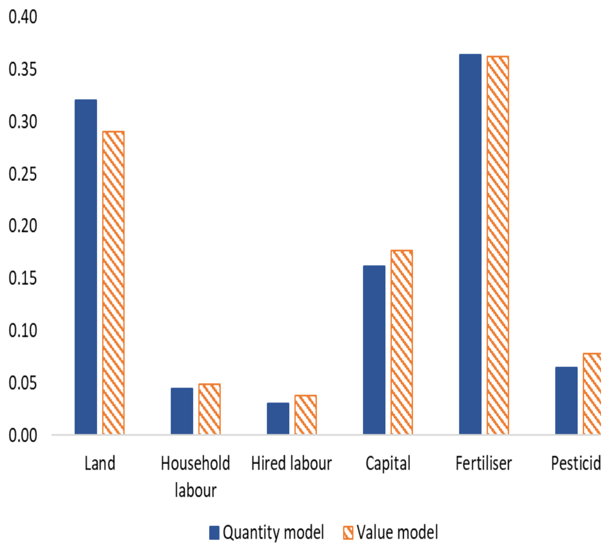
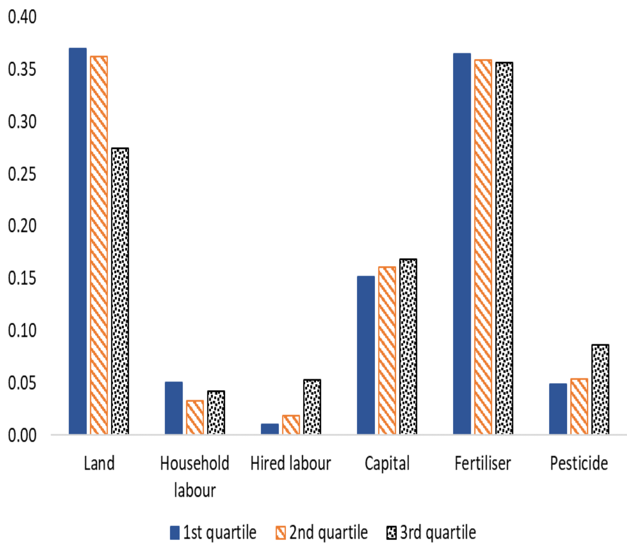


Figure 4: Elasticities of production inputs with respect to output



(a) Quantity versus Value: elasticities at means



(b) Quantity model: elasticities at different quartiles

Table 1: Summary statistics

Variable	Unit	2004 sample	2014 sample	Pooled sample			
		mean	mean	mean	25th percentile	median	75th percentile
		(1)	(2)	(3)	(4)	(5)	(6)
Model outcome							
Rice quantity	tonnes	3.95 (6.2)	4.88 (9.67)	4.31 (7.75)	1.28	2.11	3.63
Rice value	million VND	15.31 (22.2)	21.08 (37.26)	17.57 (29.05)	5.72	9.53	16.16
Stochastic frontier							
Land area (LAN)	hectares	0.51 (0.66)	0.54 (0.7)	0.52 (0.68)	0.20	0.32	0.62
Household labor (FLAB)	days	378 (254)	289 (195)	343 (233)	180	300	480
Hired labor (HLAB)	million VND	0.66 (2.17)	0.84 (2.42)	0.73 (2.27)	0.00	0.00	0.57
Capital (CAP)	million VND	1.26 (2.22)	2.65 (5.14)	1.8 (3.65)	0.38	0.77	1.58
Fertilizer (FER)	million VND	2.36 (3.61)	3.7 (7.59)	2.89 (5.52)	0.74	1.39	2.58
Pesticide (PES)	million VND	0.77 (1.94)	1.65 (5.33)	1.11 (3.66)	0.10	0.25	0.59
Inefficiency model							
Land in good conditions (TYP)	ratio	0.4 (0.43)	0.29 (0.44)	0.36 (0.43)	0.00	0.00	0.82
Land with land-use certificates (LUC)	ratio	0.75 (0.39)	0.66 (0.44)	0.71 (0.41)	0.36	1.00	1.00
Irrigated land (IRR)	ratio	0.88 (0.27)	0.79 (0.36)	0.84 (0.31)	0.76	1.00	1.00
Land fragmentation (FRA)	index [0,1]	0.54 (0.3)	0.42 (0.31)	0.49 (0.3)	0.32	0.59	0.74
Household head gender (GEN)	1=male	0.83 (0.38)	0.83 (0.38)	0.83 (0.38)	1.00	1.00	1.00
Household head age (AGE)	years	46.43 (12.48)	48.96 (12.26)	47.42 (12.39)	38.00	46.00	55.00
Household head education (EDU)	years	7.29 (3.54)	7.41 (3.65)	7.34 (3.58)	5.00	8.00	9.00
Old household labor (MAT)	ratio	0.18 (0.34)	0.28 (0.42)	0.22 (0.37)	0.00	0.00	0.33
Observations		3600	2321	5921			

Notes: Standard deviations are in brackets. Means and standard deviations are weighted using household weights in corresponding years. Monetary variables are measured in 2010 prices and adjusted for regional price differences.

Table 2: Specification test results

Hypothesis	Likelihood ratio	$X^2_{0.99}$ value	Decision
1. H_0: CD production function	634.01	46.35	Reject H_0
2. H_0: β_t=β_{1t}=β_{2t}=β_{3t}=β_{4t}=β_{5t}=β_{6t}=0	501.66	17.76	Reject H_0
3. H_0: β_{1t}=β_{2t}=β_{3t}=β_{4t}=β_{5t}=β_{6t}=0	23.06	16.07	Reject H_0
4. H_0: γ=δ_0=δ_1=δ_2=δ_3=δ_4=δ_5=δ_6=δ_7=δ_8=0	1132.34	22.52	Reject H_0
5. H_0: γ=δ_0=0	709.33	8.27	Reject H_0
6. H_0: δ_0=δ_1=δ_2=δ_3=δ_4=δ_5=δ_6=δ_7=δ_8=0	913.65	20.97	Reject H_0
7. H_0: δ_1=δ_2=δ_3=δ_4=δ_5=δ_6=δ_7=δ_8=0	773.79	19.38	Reject H_0

Notes: The critical values are obtained from Kodde and Palm (1986). Test results are from models, in which output volume is the dependent variable. Similar results are found in models, in which output value is the dependent variable, thus not being presented for brevity.

Table 3: Parameter estimates

Variables	RCPI				SCOLI			
	Quantity		Value		Quantity		Value	
	Coef	SE	Coef	SE	Coef	SE	Coef	SE
Production Model								
Constant	$0.437^{(b)}$	(0.178)	$2.0299^{(c)}$	(0.182)	$0.339^{(a)}$	(0.182)	$2.024^{(c)}$	(0.185)
ln(x1) (Land-LAN)	-0.095	(0.058)	$-0.1251^{(b)}$	(0.058)	$-0.097^{(a)}$	(0.059)	$-0.126^{(b)}$	(0.059)
ln(x2) (Hhold labor-FLAB)	$0.227^{(c)}$	(0.056)	$0.1998^{(c)}$	(0.058)	$0.235^{(c)}$	(0.057)	$0.205^{(c)}$	(0.058)
ln(x3) (Hired labor-HLAB)	0.074	(0.045)	$0.1253^{(c)}$	(0.046)	$0.079^{(a)}$	(0.047)	$0.121^{(b)}$	(0.047)
ln(x4) (Capital-CAP)	$0.371^{(c)}$	(0.046)	$0.4083^{(c)}$	(0.046)	$0.383^{(c)}$	(0.046)	$0.407^{(c)}$	(0.047)
ln(x5) (Fertilizer-FER)	$0.499^{(c)}$	(0.057)	$0.4699^{(c)}$	(0.058)	$0.483^{(c)}$	(0.058)	$0.458^{(c)}$	(0.058)
ln(x6) (Pesticide-PES)	0.026	(0.039)	0.0408	(0.039)	0.008	(0.039)	0.049	(0.04)
ln(x1)ln(x1)	$-0.116^{(c)}$	(0.012)	$-0.1023^{(c)}$	(0.012)	$-0.119^{(c)}$	(0.012)	$-0.094^{(c)}$	(0.012)
ln(x1)ln(x2)	$0.061^{(c)}$	(0.009)	$0.062^{(c)}$	(0.009)	$0.061^{(c)}$	(0.009)	$0.061^{(c)}$	(0.009)
ln(x1)ln(x3)	$0.048^{(c)}$	(0.008)	$0.0545^{(c)}$	(0.008)	$0.045^{(c)}$	(0.008)	$0.055^{(c)}$	(0.008)
ln(x1)ln(x4)	$0.037^{(c)}$	(0.007)	$0.0267^{(c)}$	(0.007)	$0.035^{(c)}$	(0.006)	$0.024^{(c)}$	(0.007)
ln(x1)ln(x5)	$-0.043^{(c)}$	(0.008)	$-0.0452^{(c)}$	(0.008)	$-0.041^{(c)}$	(0.008)	$-0.046^{(c)}$	(0.008)
ln(x1)ln(x6)	-0.001	(0.006)	-0.0084	(0.006)	0.002	(0.006)	$-0.01^{(a)}$	(0.006)
ln(x2)ln(x2)	$-0.02^{(b)}$	(0.01)	-0.0154	(0.01)	$-0.019^{(b)}$	(0.01)	-0.016	(0.01)
ln(x2)ln(x3)	-0.001	(0.007)	-0.0076	(0.007)	-0.001	(0.008)	-0.005	(0.008)
ln(x2)ln(x4)	$-0.026^{(c)}$	(0.007)	$-0.0299^{(c)}$	(0.007)	$-0.028^{(c)}$	(0.007)	$-0.03^{(c)}$	(0.007)
ln(x2)ln(x5)	$-0.039^{(c)}$	(0.009)	$-0.034^{(c)}$	(0.009)	$-0.039^{(c)}$	(0.009)	$-0.033^{(c)}$	(0.009)
ln(x2)ln(x6)	0.004	(0.006)	0.0032	(0.006)	0.007	(0.006)	0.003	(0.006)
ln(x3)ln(x3)	0.01	(0.01)	0.0108	(0.01)	0.015	(0.01)	$0.019^{(a)}$	(0.01)
ln(x3)ln(x4)	$-0.025^{(c)}$	(0.007)	$-0.0261^{(c)}$	(0.007)	$-0.024^{(c)}$	(0.007)	$-0.025^{(c)}$	(0.007)
ln(x3)ln(x5)	-0.003	(0.008)	-0.0016	(0.008)	-0.006	(0.009)	-0.005	(0.009)
ln(x3)ln(x6)	0.001	(0.006)	0.0014	(0.006)	0.002	(0.006)	-0.001	(0.006)
ln(x4)ln(x4)	$0.071^{(c)}$	(0.007)	$0.0872^{(c)}$	(0.007)	$0.071^{(c)}$	(0.007)	$0.091^{(c)}$	(0.007)
ln(x4)ln(x5)	$-0.05^{(c)}$	(0.007)	$-0.0569^{(c)}$	(0.007)	$-0.05^{(c)}$	(0.007)	$-0.059^{(c)}$	(0.007)
ln(x4)ln(x6)	$-0.01^{(b)}$	(0.004)	$-0.0109^{(b)}$	(0.004)	$-0.009^{(b)}$	(0.004)	$-0.012^{(c)}$	(0.004)
ln(x5)ln(x5)	$0.111^{(c)}$	(0.01)	$0.1101^{(c)}$	(0.01)	$0.111^{(c)}$	(0.01)	$0.11^{(c)}$	(0.01)
ln(x5)ln(x6)	$0.012^{(b)}$	(0.005)	$0.0159^{(c)}$	(0.005)	$0.01^{(a)}$	(0.005)	$0.015^{(c)}$	(0.005)
ln(x6)ln(x6)	0.004	(0.006)	0.0064	(0.006)	0.005	(0.006)	$0.011^{(a)}$	(0.006)
d2014 (Time dummy)	$-0.294^{(c)}$	(0.069)	$-0.1627^{(b)}$	(0.07)	$-0.241^{(c)}$	(0.07)	$-0.173^{(b)}$	(0.07)
ln(x1)d2014	$-0.039^{(c)}$	(0.012)	$-0.0417^{(c)}$	(0.012)	$-0.032^{(c)}$	(0.012)	$-0.041^{(c)}$	(0.012)
ln(x2)d2014	0.015	(0.011)	0.0174	(0.012)	0.011	(0.012)	0.017	(0.012)
ln(x3)d2014	$0.021^{(a)}$	(0.011)	$0.025^{(b)}$	(0.011)	$0.023^{(b)}$	(0.011)	$0.026^{(b)}$	(0.011)
ln(x4)d2014	-0.013	(0.01)	$-0.0234^{(b)}$	(0.01)	-0.011	(0.01)	$-0.025^{(b)}$	(0.01)
ln(x5)d2014	-0.002	(0.012)	-0.0039	(0.012)	0	(0.012)	-0.001	(0.012)
ln(x6)d2014	$0.026^{(c)}$	(0.008)	$0.0232^{(c)}$	(0.008)	$0.034^{(c)}$	(0.008)	$0.021^{(b)}$	(0.008)
Inefficiency Model								
Constant	$1.612^{(c)}$	(0.249)	$1.6638^{(c)}$	(0.26)	$1.511^{(c)}$	(0.236)	$1.615^{(c)}$	(0.246)
Land fragmentation (FRA)	$0.217^{(c)}$	(0.052)	$0.2328^{(c)}$	(0.053)	$0.19^{(c)}$	(0.051)	$0.241^{(c)}$	(0.055)
Good land (TYP)	$-0.703^{(c)}$	(0.125)	$-0.8882^{(c)}$	(0.138)	$-0.691^{(c)}$	(0.101)	$-0.857^{(c)}$	(0.143)
Land with certificates (LUC)	$-0.149^{(c)}$	(0.031)	$-0.2099^{(c)}$	(0.046)	$-0.148^{(c)}$	(0.034)	$-0.201^{(c)}$	(0.043)
Irrigated land (IRR)	$-1.348^{(c)}$	(0.145)	$-1.5108^{(c)}$	(0.23)	$-1.314^{(c)}$	(0.153)	$-1.456^{(c)}$	(0.228)
Gender (GEN)	$-0.129^{(c)}$	(0.035)	$-0.2033^{(c)}$	(0.047)	$-0.123^{(c)}$	(0.035)	$-0.203^{(c)}$	(0.049)
Age (AGE)	$-0.038^{(c)}$	(0.011)	$-0.0403^{(c)}$	(0.011)	$-0.034^{(c)}$	(0.01)	$-0.039^{(c)}$	(0.01)
AGE squared	$0^{(c)}$	(0)	3e-04$^{(c)}$	(0)	$0^{(c)}$	(0)	$0^{(c)}$	(0)
Education (EDU)	$-0.053^{(c)}$	(0.008)	$-0.0603^{(c)}$	(0.012)	$-0.049^{(c)}$	(0.009)	$-0.06^{(c)}$	(0.012)
Old hhold labor (MAT)	$0.241^{(c)}$	(0.048)	$0.2553^{(c)}$	(0.059)	$0.245^{(c)}$	(0.053)	$0.256^{(c)}$	(0.06)
Sigma squared	$0.377^{(c)}$	(0.048)	$0.4273^{(c)}$	(0.066)	$0.367^{(c)}$	(0.047)	$0.412^{(c)}$	(0.066)
Gamma	$0.909^{(c)}$	(0.012)	$0.914^{(c)}$	(0.013)	$0.903^{(c)}$	(0.013)	$0.908^{(c)}$	(0.014)
Log-likelihood	-708.16		-688.85		-715.8		-694.04	
Mean efficiency	0.8		0.81		0.8		0.81	
Observations	5921		5921		5921		5921	

Notes:$^{(a)}$: $p<0.1$; $^{(b)}$: $p<0.05$; $^{(c)}$: $p<0.01$

Appendices

Appendix A. Spatial deflators

Vietnam is an elongated state, and the market is not fully integrated even for a staple like rice (Baulch et al., 2008). Thus, it is vital to consider spatial differences in prices or spatial deflators fully.

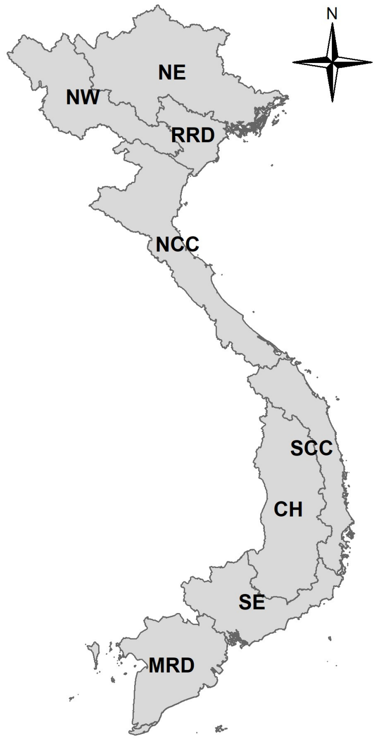
There exist two spatial deflators: the Regional Consumer Price index (RCPI) and the Spatial Cost of Living index (SCOLI), both provided by GSO. The former is calculated based on CPI data and disaggregated by region and urban/rural. It is constructed as an overall price index, and separate ones for food and non-food (Bales, 2001). This feature makes RCPI for food particularly suitable for this study which concerns rice, a main staple in the Vietnamese diet. RCPI is available for all rounds of biennial VHLSS from 2002 to 2016.

The latter, SCOLI, has been proposed as a replacement for RCPI recently by Gibson (2009). He argues that the changes in data collection to estimate CPI from 2002 make RCPI less relevant to represent regional differences in prices. That is, data for CPI calculation were collected using a price survey which is separated from VHLSS since 2002; meanwhile, it used to be collected from a community market survey as part of the Viet Nam Living Standards Surveys (VLSS) in the 1990s. Since 2010, SCOLI has been consistently constructed based on the price data collected from a sub-sample of VHLSS locations. It is therefore deemed to better reflect the spatial differences in prices among regions and provinces. The downsize of SCOLI, however, is that it is not available separately for food and non-food.

Given the pros and cons of the two indices, we use both of them in our research. As SCOLI is not available for the year 2004, we impute it using the SCOLI value for 2016 and the relative differences in RCPI between the two periods.

Appendix B. Terms of trade and the Malmquist productivity index: data compilation and adjustment

Calculating TOT and MPI requires data on quantities and prices of output and inputs at the regional level. There are 63 provinces, being grouped into eight regions in Vietnam, as follows:



1. RRD (Red River Delta): Ha Noi (including old Ha Tay), Vinh Phuc, Bac Ninh, Hai Duong, Hai Phong, Hung Yen, Thai Binh, Ha Nam, Nam Dinh, Ninh Binh
2. NE (North East): Quang Ninh, Ha Giang, Cao Bang, Bac Kan, Tuyen Quang, Lao Cai, Yen Bai, Thai Nguyen, Lang Son, Bac Giang, Phu Tho
3. NW (North West): Dien Bien, Lai Chau, Son La, Hoa Binh
4. NCC (North Central Coast): Thanh Hoa, Nghe An, Ha Tinh, Quang Binh, Quang Tri, Thua Thien Hue
5. SCC (South Central Coast): Da Nang, Quang Nam, Quang Ngai, Binh Dinh, Phu Yen, Khanh Hoa
6. CH (Central Highlands): Kon Tum, Gia Lai, Dak Lak, Dak Nong, Lam Dong
7. SE (South East): Ninh Thuan, Binh Thuan, Binh Phuoc, Tay Ninh, Binh Duong, Dong Nai, Ba Ria - Vung Tau, Ho Chi Minh
8. MRD (Mekong River Delta): Long An, Tien Giang, Ben Tre, Tra Vinh, Vinh Long, Dong Thap, An Giang, Kien Giang, Can Tho, Hau Giang, Soc Trang, Bac Lieu, Ca Mau

Data on quantities

Data on output and land quantities are readily available in the statistical yearbooks published by GSO (e.g. General Statistic Office, 2013). The data are reported at the provincial level. We aggregate them by region.

Labor quantity is the product of labor man-day per planted hectare and planted area. Unfortunately, we only have information on the labor man-day per planted hectare for one year, 2006, using the rural, agricultural, and fishery census of Viet Nam (Agrocensus) in 2006 (GSO, 2007). Thus we need estimates for other years. To do so, we adjust the information for 2006 using the relative change of labor quantity in agriculture reported by the Ministry of Agriculture and Rural Development (MARD) (MARD, 2011, 2017).

Physical capital is the combined capacity of tractors and buffalo-equivalent power. The number of tractors and their capacity in horsepower (hp) are available from Agrocensus in 2001, 2006, 2011, and 2016 (GSO, 2002, 2007, 2012, 2017). The numbers of ploughing cattle and buffalo are reported in annual statistical yearbooks by GSO and annual reports by the Department of Livestock Production under MARD (MARD, 2018a). A cattle/buffalo, having an average weight of 250 kilograms, is considered equivalent to one hp (Kompas et al., 2011, 2012). Temporal changes in the physical capital are made with the aid of the statistics supplied by the Department of Agroforestry Processing and Salt Industry under MARD (MARD, 2018b).

Material inputs consist of chemical fertilizer, pesticide, and seeds. Quantities of each component in the materials are products of their corresponding amounts per planted hectare and the total planted area. The amount of fertilizer per planted hectare is calculated using the data of the Vietnam Living Standard Surveys (VLSS 1993 and 1998) and VHLSS (carried out biennially since 2002). The amount of pesticide per planted hectare is from Kompas et al. (2012), being 5.8 kg and 7.6 kg in the North and South until 2006. Since 2007, we increase this amount by 50 percent based on the information from the field survey in MRD of Viet Nam by Bordey et al. (2016) in 2011. The amount of seeds per planted hectare is from Agrocensus in 2006 (GSO, 2007) and updated for other periods using the survey data in An Giang and Dong Thap (An Giang DARD, 2012-2014; Dong Thap DARD, 2009-2014), Nguyen et al. (2015), and Bordey et al. (2016).

Data on prices

Output prices are the farm gate prices of paddy collected monthly by Department of Trade and Prices, GSO, in 36 provinces during 2000-2016. These provinces include Ha Noi (including old Ha Tay), Hai Duong, Hai Phong, Thai Binh, Ha Nam, Ninh Binh, Cao Bang, Yen Bai, Thai Nguyen, Phu Tho, Son La, Hoa Binh, Thanh Hoa, Nghe An, Ha Tinh, Quang Tri, Thua Thien Hue, Quang Nam, Binh Dinh, Phu Yen, Khanh Hoa, Dac Lak, Lam Dong, Ninh Thuan, Binh Thuan, Binh Phuoc, Dong Nai, Long An, Tien Giang, Ben Tre, Vinh Long, Dong Thap, An Giang, Kien Giang, Can Tho, Bac Lieu.

Calculating land prices for planted land is challenging since the regional data on planted land have no information on land quality, based on which the land tax is levied. Thus we use the government estimate of 53.5 billion VND for 93,917 ha of physical land to get the average land tax rate of VND 569,652 (Ha, 2016). Combined with the information on the farm-gate price, we get an average land tax rate of 95kg paddy per physical land hectare or 50 kg paddy per planted land hectare. Here we use the conversion rate from a physical land hectare into a planted land hectare is about 1.9 for rice, based on the statistical yearbooks of GSO.

Since the government of Vietnam has gradually reduced the land tax rate since the early 2000s, we use this information to estimate the land tax rate for each year. In particular, the land tax rate is 50kg/planted hectare in 2000-2001; 25kg/planted hectare in 2002; 17.5kg/planted hectare during 2003-2010 and 2.5 during 2011-2016. This estimation is made based on the following: land taxes reduced by 50 percent for land within the allocation limits and were free for poor households and households in communes classified as poor by the government in 2002 (Decision No.199/2001/QD-TTg dated 28 December 2001) (Prime Minister, 2001). Between 2003 and 2010, taxes were exempted for land within the allocation limits for all households (Resolution No.15/2003/QH11 dated 17 June 2003) (National Assembly, 2003). Since 2010, a further 50 percent reduction has been applied for land within accumulation limits (Resolution No.55/2010/QH12 dated 24 November 2010) (National Assembly, 2010).

Labor prices are drawn from VHLSS data sets from 2002 to 2016. They are average man-day wage paid for adult laborers on agricultural activities including land preparation, planting, tending, and harvesting. Prices are cross-checked with the data from rice production cost surveys carried out by the Department of Agricultural and Rural Development (DARD) in An Giang and Dong Thap provinces in the MRD between 2009 and 2014 (An Giang DARD, 2012-2014; Dong Thap DARD, 2009-2014).

The price of capital is the price of cattle as per Decision No.738/QD-TTg dated 18 May 2006 and Decision No.719/QD-TTg dated 5 June 2008.

The price of materials can be worked out using three sources of information. The first is that fertilizer accounts for about 60 percent of the total cost on materials, based on VHLSS data. The second is that we can calculate the price of fertilizer using VHLSS data, and therefore, we can find the value of materials. Finally, we get this value to divide by the quantity discussed earlier to get the price.

All price data in our research is in constant VND 2010 price and adjusted for regional and spatial differences (Appendix A).

Appendix C. Summary statistics by region

	2004								2014							
Variable	RRD	NE	NW	NCC	SCC	CH	SE	MRD	RRD	NE	NW	NCC	SCC	CH	SE	MRD
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Model outcome																
Rice quantity	2.31	2.01	1.92	2.34	2.38	3.81	4.94	11.83	2.22	1.7	1.79	2.13	2.39	3.23	9.26	19.03
	(1.3)	(1.08)	(1.2)	(1.65)	(3.08)	(4.11)	(4.35)	(11.71)	(1.45)	(1.05)	(1.52)	(1.55)	(2.16)	(4.35)	(8.52)	(18.32)
Rice value	10.56	8.8	8.05	9.59	9.14	13.91	17.58	41.65	12.8	8.94	9.01	9.99	10.2	12.62	34.25	74.42
	(5.96)	(4.77)	(5.17)	(6.86)	(14.29)	(15.44)	(15.84)	(42.34)	(8.65)	(5.71)	(9.74)	(7.06)	(9.15)	(16.76)	(28.85)	(71.15)
Production Frontier variables																
Land area (LAN)	0.24	0.38	0.99	0.34	0.37	1.01	0.85	1.13	0.25	0.38	0.82	0.37	0.35	0.8	0.91	1.29
	(0.13)	(0.31)	(1.09)	(0.27)	(0.52)	(0.87)	(0.87)	(1.04)	(0.18)	(0.36)	(0.9)	(0.43)	(0.36)	(0.71)	(0.83)	(1.15)
Household labor (FLAB)	292	514	606	400	293	511	416	336	207	356	458	285	228	405	323	280
	(195)	(291)	(373)	(230)	(184)	(298)	(247)	(221)	(121)	(208)	(237)	(207)	(161)	(230)	(171)	(173)
Hired labor (HLAB)	0.17	0.09	0.08	0.17	0.44	0.4	1.16	2.85	0.51	0.23	0.21	0.39	0.5	0.53	1.68	3.12
	(0.31)	(0.23)	(0.19)	(0.45)	(0.96)	(0.91)	(1.57)	(4.57)	(0.88)	(0.58)	(0.48)	(0.69)	(0.73)	(1.43)	(1.93)	(5.28)
Capital (CAP)	0.74	0.5	0.45	0.73	0.72	1.07	1.61	3.98	1.48	0.89	0.81	1.33	1.46	1.38	4.91	9.77
	(0.49)	(0.43)	(0.51)	(0.63)	(1.17)	(1.65)	(1.59)	(4.22)	(1.05)	(0.7)	(0.75)	(1.16)	(1.52)	(1.94)	(4.75)	(9.96)
Fertilizer (FER)	1.54	1.38 (1)	0.66	1.58	1.5	2.04	3.18	6.45	1.85	1.41	1.03	1.71	2.06	2.05	7.44	13.84
	(0.91)		(0.67)	(1.25)	(1.67)	(2.99)	(3.42)	(6.96)	(1.3)	(1.03)	(1.91)	(1.4)	(2.2)	(3.27)	(7.81)	(14.99)
Pesticide (PES)	0.36	0.18	0.1	0.22	0.39	0.34	1.2	3.07	0.56	0.25	0.23	0.27	0.41	0.33	2.58	8.33
	(0.3)	(0.17)	(0.19)	(0.25)	(0.38)	(0.51)	(1.68)	(3.91)	(0.54)	(0.26)	(0.54)	(0.29)	(0.49)	(0.51)	(3.34)	(11.33)
Technical Inefficiency Model variables																
Land in good conditions (TYP)	0.62	0.21	0.18	0.38	0.32	0.24	0.2	0.38	0.45	0.2	0.14	0.35	0.14	0.16	0.19	0.25
	(0.38)	(0.35)	(0.31)	(0.4)	(0.42)	(0.4)	(0.39)	(0.48)	(0.48)	(0.38)	(0.32)	(0.46)	(0.32)	(0.36)	(0.38)	(0.43)
Land with land-use certificates (LUC)	0.67	0.82	0.65	0.71	0.81	0.36	0.72	0.93	0.5	0.78	0.56	0.58	0.78	0.4	0.72	0.84
	(0.43)	(0.33)	(0.4)	(0.41)	(0.33)	(0.43)	(0.41)	(0.24)	(0.47)	(0.38)	(0.47)	(0.47)	(0.37)	(0.44)	(0.44)	(0.33)
Irrigated land (IRR)	0.98	0.84	0.54	0.85	0.79	0.56	0.78	0.96	0.95	0.69	0.52	0.78	0.74	0.46	0.81	0.87
	(0.1)	(0.28)	(0.41)	(0.3)	(0.33)	(0.4)	(0.39)	(0.18)	(0.18)	(0.38)	(0.44)	(0.37)	(0.39)	(0.42)	(0.38)	(0.33)
Land fragmentation (FRA)	0.65	0.64	0.63	0.62	0.53	0.45	0.27	0.2	0.46	0.55	0.49	0.44	0.48	0.36	0.13	0.19
	(0.22)	(0.26)	(0.22)	(0.25)	(0.27)	(0.25)	(0.28)	(0.27)	(0.31)	(0.26)	(0.25)	(0.29)	(0.3)	(0.22)	(0.25)	(0.26)
Household head gender (GEN)	0.8	0.88	0.93	0.86	0.71	0.82	0.85	0.82	0.78	0.86	0.89	0.85	0.82	0.78	0.75	0.82
	(0.4)	(0.32)	(0.25)	(0.34)	(0.46)	(0.38)	(0.36)	(0.39)	(0.41)	(0.34)	(0.31)	(0.36)	(0.39)	(0.42)	(0.44)	(0.38)
Household head age (AGE)	47.9	44.22	40.92	45.79	48.36	46.12	45.01	47.31	52.43	45.77	41.76	49.96	49.96	42.93	52.04	49.24
	(11.67)	(11.87)	(11.05)	(11.86)	(14.72)	(13.67)	(12.31)	(13.19)	(10.76)	(11.69)	(11.25)	(12.24)	(13.03)	(12.44)	(13.74)	(11.97)
Household head education (EDU)	8.38	7.38	5.5	8.61	6.08	4.28	5.93	5.48	8.83	7.04	5.36	8.51	7.04	4.78	5.16	6.07
	(3.13)	(3.32)	(3.86)	(3.03)	(3.35)	(3.77)	(3.49)	(3.51)	(2.93)	(3.67)	(3.99)	(3.28)	(3.76)	(3.89)	(3.67)	(3.49)
Ratio of old household labor (MAT)	0.22	0.14	0.06	0.16	0.29	0.13	0.17	0.15	0.39	0.16	0.08	0.28	0.42	0.17	0.4	0.26
	(0.38)	(0.28)	(0.16)	(0.32)	(0.42)	(0.27)	(0.32)	(0.3)	(0.47)	(0.33)	(0.23)	(0.41)	(0.48)	(0.35)	(0.47)	(0.41)
Observations	944	741	274	533	306	118	113	571	485	622	223	338	173	76	64	340

Notes: Standard deviations are in brackets. Statistics are calculated taking into account the underlying sampling design.