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Productivity, Net Returns and Efficiency:
Land and Market Reform in Vietnamese Rice
Production

Tom Kompas*

Crawford School of Economics and Government
Australian National University
tom.kompas@anu.edu.au

Tuong Nhu Che

Australian Bureau of Agricultural and Resource Economics
nhu.che@abare.gov.au

Hoa Thi Minh Nguyen

Centre for Analysis and Forecasting
Vietnam Academy of Social Sciences
hoathiminhnguyen75@yahoo.com

Quang Ha Nguyen

Forestry University of Vietnam
qhnguyenfuv@yahoo.com.au

April 2009

Abstract

Extensive land and market reform in Vietnam has resulted in dramatic increases in rice output over the past thirty years. The land and market reforms in agriculture were pervasive, moving the system of rice production from commune-based public ownership and control to one with effective private property rights over land and farm assets, competitive domestic markets and individual decision making over a wide range of agricultural activities. The effect of this reform period and beyond is detailed with measures of total factor productivity (TFP), terms of trade and net returns in rice production in Vietnam from 1985 to 2006. Results show that TFP rises considerably in the major rice growing areas (the Mekong and Red River Delta areas) during the early years of reform, and beyond, but also that there is clear evidence of a productivity ‘slow-down’ since 2000. The differences over time and by region speak directly to existing land use regulations and practices, suggesting calls for further land and market reform. To illustrate this, additional frontier and efficiency model estimates detail the effects of remaining institutional and policy constraints, including existing restrictions on land consolidation and conversion and poorly developed markets for land and capital. Estimates show that larger and less land-fragmented farms, farms in the major rice growing areas, and those farms that are better irrigated, have a greater proportion of capital per unit of cultivated land, a clear property right or land use certificate and access to agricultural extension services are more efficient.

*Contact author: Tom Kompas, Crawford School of Economics and Government, Crawford Building (013), Australian National University, Canberra, ACT, 2601, Australia. E-mail: tom.kompas@anu.edu.au, Phone: +61 2 6125 6566, Fax: +61 2 6125 5570.

Acknowledgements: Funding for this research from the Ford Foundation, the World Bank and AusAID is gratefully acknowledged, as is financial support from the Crawford School of Economics and Government in order to obtain farm survey data. Thanks to Thang Nguyen and participants at the Workshop on Poverty Assessment at Centre for Analysis and Forecasting in Hanoi for helpful comments.

JEL Classification: O13, O47, Q10

Keywords: market and land reform, total factor productivity, terms of trade, frontiers and efficiency, rice production in Vietnam

1 Introduction

Vietnam has achieved remarkable progress in reducing rural poverty in the last thirty years, due largely to a series of extensive market and land reforms in agriculture, along with impressive increases in economic growth at the national level. The land and market reforms in agriculture were pervasive, moving the system of rice production in particular from commune-based public ownership and control to one with effective private property rights over land and farm assets, competitive domestic markets and individual decision making over a wide range of agricultural activities. The substantial incentive effects created by these policy measures, inducing farmers to work harder and use land more efficiently, have been estimated to be as much as fifty per cent of the increase in total factor productivity (TFP) during the peak of the reform period (Che et al. 2006). Overall, given these reforms, Vietnam has gone from being a large importer of rice in 1976-80, to now the second largest exporter of rice in the world, with considerable increases in farm profitability and rural incomes and resulting rural poverty rates falling by over sixty percent from 1993 to 2004 alone (Hansen and Nguyen 2007).

However, much still remains to be done to increase living standards in rural areas and enhance general rural development. Like many reform processes, the early rapid increases in economic activity have dissipated over time, with the suggestion now of a TFP ‘slow down’ in rice production in many areas in Vietnam. In addition, many of the poor still farm small areas of land, constrained in use, often with fragmented or non-contiguous plots and with little or no human and physical capital accumulation or access to agricultural extension services. Much of this is due to remnants from past institutional arrangements, but also to continued constraints in land use, credit availability and the provision of rural services, all calling for further or renewed land policy and market reform.

This paper has two basic tasks. First, it assembles a data set from 1985 to 2006 to measure the changes in TFP, terms of trade and net returns in Vietnamese rice production, both in the principal rice growing areas and throughout the country. The results track the effects of the major land and market reform process, and beyond, and determine key differences in TFP and net returns over time and by region. All of this speaks directly to existing land use practices and is suggestive of needed policy response. With this in mind, the second task is to isolate the remaining institutional constraints and policy challenges that may be limiting increases in productivity and efficiency. For this purpose, three different stochastic frontier and inefficiency models, with varying samples and levels of aggregation, are estimated to determine the potential effects of ongoing issues over land use and the provision of credit, land fragmentation, less than secure property rights and the lack of rural education and support services.

Section 2 of the paper provides context, highlighting the nature and

extent of the past market and land reform process and the remaining institutional barriers and policy challenges in land use practice and rural development. Section 3 briefly summarizes the various data sets used in the paper, along with variable definitions and econometric specification. An extensive data appendix details the sources of the data, as well as data constructions and various adjustments. Section 4 provides the measures of TFP, terms of trade and net returns in rice production, while section 5 provides estimates for the stochastic frontier and inefficiency models. Three different models are estimated, in part due to limitations in the data, and in part to highlight different aspects of the constraints on inefficiency. Here, estimates for the primary provincial data set (1991-99), a period over which there is relative stability in estimated input coefficients, is augmented with estimates drawn from two farm and household surveys for the year 2004. Section 6 concludes.

2 Context

Rice continues to dominate agricultural production in Vietnam, with nearly 73 per cent of the population still living in rural areas, and rice accounting for nearly 90 per cent of the output of food grains and almost two-thirds of rural farm income (SDAFF 2006). Although rice is produced in every one of the 60 (recently defined as 64) provinces in Vietnam, the Red River Delta (RRD) and the Mekong River Delta (MRD) are the main rice growing regions. The smallest producers of rice (less than 100,000 tons per year) are in Binh Phuoc province, which is relatively small in area, and contains the principal coffee growing (Gialai Kontum) and mining (Cao Bang, Bac Kan) areas. Provinces with the largest rice output (more than a million tonnes per year) are located in the MRD (Tien Giang, Soc Trang, Long An, Kien Giang and An Giang), which as a whole accounts for roughly half of Vietnam's output of rice and most of its international exports. In terms of natural conditions, the MRD and the RRD are the most favorable for growing rice, with many areas naturally irrigated, producing up to three rice crops per year. Based on farm survey data for 2004 (as used below), the average farm size in the RRD (0.4 hectares per farm) is much smaller than in the MRD (1.4 hectares per farm). However, the number of threshing machines in the RRD is almost double that of the MRD. In the MRD, with a large volume of high-quality rice exports, rice processing takes place in mills rather than on the farm to maintain international standards.

As mentioned, rice output has increased dramatically during the major market and land reform periods, and by more than three times nationwide (10 million to nearly 34 million tons) from 1980 to 2004 (Kompas 2004). After a period of 'output share contracts' (from 1981-87), as a highly tentative move to limited property rights and domestic markets, a period of 'trade liberalization' (1988-94) brought major institutional change, allowing for ef-

fective private property rights over both land (initially 10–15 and later 20 year leases) and capital equipment. With reform, most production decisions were de-centralized, all farm income (after tax) was retained by the farmer and rice could be sold freely in competitive domestic markets. The result was an increase in rice prices (from the state controlled low prices prior to reform) and added profitability, which not only increased TFP considerably (Che et al. 2006) but also generated dynamic gains from trade reform from induced capital accumulation out of retained farm earnings (Che et al. 2001).

Since 1994, these dramatic market and land reforms have been solidified and in many cases extended in the ‘post-reform’ period. (For a detailed discussion of land policy reform in Vietnam, see Chu (1992), Che (1997), Fforde (1996), Marsh and MacAulay (2002) and Nguyen (2006).) Nevertheless, a number of concerns remain, and have been raised again recently in a ‘Participatory Poverty Assessment’ (PPA), with over 240 focus groups and 1,450 participants, undertaken by the Vietnam Academy of Social Sciences (VASS 2009). Chief among these are issues surrounding land title and use, land fragmentation and the lack of rural credit availability and supporting rural services, and especially so (for this paper) as they impact on productivity and efficiency gains.

Land title and use requirements are a good example of the challenges that remain. Although the Land Law of 1993 (amended and clarified in 1998, 2001 and 2003) allows “land use rights to be transferred, exchanged, leased, mortgaged and inherited” (Congress of Vietnam 1993), in practice considerable constraints remain in place regarding both land conversion (i.e., land transferred or converted to other uses) and land accumulation (i.e., trades and accumulation of land plots). For any land conversion, for example, the commune authorities have to first develop a plan, often based on or as minor amendments to past historical ‘blueprints’ for land use in that area, to submit to various levels of government for approval. The PPA reports that this process is often long and that transactions costs are high, making it difficult for poor farmers in particular to participate (VASS 2009). In addition, although land consolidation in Vietnam is occurring, with a number of important benefits (see Ravallion and van de Walle 2008), there are still restrictions on overall land size. In 2007, the Vietnamese government increased limits on the transfer of land use rights for annual agricultural land from 3 to 6 hectares for the South East, Mekong River Delta and Ho Chi Minh City and from 2 to 4 hectares for other cities and provinces. This is a welcome albeit modest change for many farmers, but in most cases rice farming outside of the MRD is still takes place on very small farms, at subsistence levels (GSO (VHLSS) 2004, VASS 2009).

Part of the obstacle to land consolidation is the lack of fully secure property rights. Land use title for agricultural land was extended from 15 to 20 years with the Land Law of 1993, but in many cases even 20

years is too short to provide secure rights in the shift to larger farms, or to a process where farm land is turned into use for small manufacturing or industry. Overall the process of land certification or entitlement itself has also been below expectations. Household survey data from 2004 (GSO (VHLSS) 2004) suggests that only 76 percent of agricultural land parcels, 68 percent of urban land parcels and 34 percent of forest land parcels have been granted land-use right certificates. In practice, this means about two third of the total parcels of Vietnam still lack a certificate (World Bank 2009). Even where land certificates do exist, there is a shortage of basic infrastructure for an effective operation of land administration, including cadastral mapping, transaction registrations and record management in the provision of land administration services. Problems are compounded by lack of information or public awareness and the apparent limited capacity of land administration staff, especially at the commune and district levels (World Bank 2009). It is perhaps for this reason that real estate markets have been slow to develop, with recent data indicating that the role of land rental markets in agriculture in rural areas remains thin (GSO (VHLSS) 2004), and that continued government restrictions often prevent low cost and efficiency enhancing transfers (Deininger and Jin 2008). Land rights that are not secure also clearly impact on credit availability and capital accumulation. The PPA reports that farms without land-use certificates, which would normally be used as collateral, are not able to obtain even short term loans, much less transfer land use entitlements. This is also often true for farms with land tenures that are close to expiry, as most currently are, given the 20 year leases initiated in 1993 (VASS 2009).

Land fragmentation occurs when farms have land use rights to a number of often small, non-contiguous plots. With reform and the resulting dissolution of the commune system in Vietnam, land was allocated to prior commune members in a roughly equalitarian manner: equal numbers of plots per household, with a distribution of plots throughout the commune so that no one household would have a concentration of plots in the most fertile parts of the commune, or near roads, water sources or other essential services. Immediately after the major reform process (1988-94), there were as many as 75 to 100 million parcels or plots of land in Vietnam and on average about seven to eight plots per household (World Bank 2003 and Hung et al. 2007), of which about 10 per cent of these plots had an area of only 100 square meters or less (Phien 2001). Evidence suggests that plot numbers have been falling recently with land consolidation (nationwide, falling to 4.3 plots per household with the fall in the north from 6.0 to 4.9 plots (GSO (VHLSS) 2004), but the problem is still common. Fragmentation levels, for example, continue to remain high in the RRD, the most populated region, with 90 percent of the households having rice farm sizes of roughly 0.2 to 0.5 of a hectare (Chu 2008) and an average of 4.6 plots per farm (GSO (VHLSS) 2004). The number of plots per farm in the MRD, by contrast,

is only 1.6. In some cases (e.g., risk spreading), fragmentation may be an advantage (see Marsh et al. 2006), but for the most part small and scattered land holdings hamper mechanization, the use of buffaloes and tractors and technological adaptation, as well as generate additional time and labour for farming activities that must have been carried out in geographically distant plots. The embankments that separate plots alone have been estimated to reduce total agricultural land for cultivation in Vietnam by 2.4 to 4 per cent (Thanh 2008).

3 Data sources, variables and specifications

Four different data sets are used in this paper. The first is a provincial level data set on rice production in Vietnam, from 1985 to 2006, for 60 provinces, used to construct TFP, price and quantity indexes and net return measures, greatly improving on the basic TFP estimates (to 1994) provided in Che et al. (2006). This is an extensive data set on prices and quantities for all rice outputs and inputs, directly obtained as or aggregated to provincial averages. The key variables include paddy rice output, labour, land, material inputs (especially fertilizer, but also seeds and pesticide), capital (a measure of tractors and buffaloes), as well as input prices for labour, land, fertilizer, pesticides and capital used in rice production. (See the data appendix for detailed data sources, constructions and adjustments.) The second data set, used to construct a stochastic production frontier and inefficiency model, is a subset of the first, or a balanced panel data set for 60 provinces from 1991 to 1999. The key variables are rice output, capital, labour, land, fertilizer (and other material inputs) and measures of farm characteristics by location, size and the proportion of tractors used per area of cultivated rice land. The choice of using the sub-sample for 1991-99, rather than the entire sample 1985-2006, was made based on a series of Chow tests for structural breaks to test whether input elasticities were constant over time, with Goldfeld-Quandt tests confirming the hypothesis of different sub-sample variances, especially after the year 2000. The years 1991-99 thus provided the most consistent provincial-level data set with relatively stable input elasticities.

The third data set, also used to construct a stochastic production frontier and inefficiency model, is a farm survey data set, for 388 rice farms, conducted in 2004 in major rice growing regions (the MRD and RRD), designed especially to isolate the potential effects on inefficiency from land fragmentation. Key additional variables include measures of soil quality and irrigation, and the number of plots, as a proxy for land fragmentation, along with level of education of the head of the farm. The fourth data set uses the 2004 Vietnam Household Living Standards Survey (VHLSS) to partly confirm the results of the smaller farm survey data set, along with providing added estimates of the effects of secure property rights and access

to agricultural extension services. The VHLSS is a household survey data set of roughly 9,000 households in 2,216 communes, with cluster-sampling techniques to cover the entire country, conducted by the General Statistical Office (GSO) in Vietnam in selected years (i.e., 2002, 2004 and 2006). The 2004 data set, in particular, has separate components for land use and agricultural production. Sample size is reduced to 3865 households to isolate farms that are primarily rice producers.

For all stochastic production frontiers log-likelihood specifications tests were used to determine functional form and the presence of inefficiency effects. In all cases, standard OLS estimates are shown to be inappropriate and the functional form rejects a translog specification in favor of a more standard Cobb-Douglas production function. Tests on the cross-sectional data sets (the farm survey data set and the VHLSS data) also indicate that estimates of the stochastic frontiers using a random coefficients approach, allowing for ‘non-neutral’ shifts in the production frontier, following Kalirajan and Obwana (1994), resulted in little difference in estimated coefficients, with the inefficiency term adequately represented by a truncated half-normal distribution. Frontier and inefficiency estimates are obtained using Frontier 4.1 (see Coelli et al.1998) for the provincial and VHLSS data and Stata 10 for the farm survey data, so that distributional assumptions on the technical inefficiency terms could be more easily examined.

4 Total factor productivity, terms of trade and net returns

TFP is a measure of outputs to inputs over any two time periods. Results for Vietnamese rice production are generated using Tornqvist quantity (and price) indexes given by

$$\ln Q_{st} = \sum_{i=1}^N \left(\frac{\omega_{is} + \omega_{it}}{2} \right) (\ln q_{it} - \ln q_{is}) \quad (4.1)$$

or

$$\ln Q_{st} = \prod_{i=1}^N \left(\frac{q_{it}}{q_{is}} \right)^{\frac{\omega_{is} + \omega_{it}}{2}} \quad (4.2)$$

for N quantities q inputs or outputs (depending on context), periods s and t and weights

$$\omega_{is} = p_{is}q_{is} / \sum_{i=1}^N p_{is}q_{is} \quad (4.3)$$

for time period s , for example. TFP, for outputs y and inputs x is thus given by

$$\ln TFP_{is} = \frac{1}{2} (\omega_{is} + \omega_{it}) (\ln y_{it} - \ln y_{is}) - \frac{1}{2} (v_{is} + v_{it}) (\ln x_{it} - \ln x_{is}) \quad (4.4)$$

for input weighted shares v_i for periods s and t . For convenience, results are summarized across eight regions, as officially defined in Vietnam: the Red River Delta (RRD) (1), the Northeast (2), the Northwest (3); the North Central Coast (4), the South Central Coast (5), the Central Highlands (6), the Southeast (7) and the Mekong River Delta (MRD) (8). As mentioned, the RRD and the MRD are the major rice growing regions in the country. Region 7 is largely industrial, and regions 2, 3 and 6 are the poorest by conventional measures.

There is little doubt that the increase in rice production in Vietnam has been substantial, especially after the ‘output share contracts’ period (1981-87), or under the major land and market reforms (1981-94 and forward). For the country as a whole, the indexed value of paddy rice output shows an average annual increase of 3.5 per cent, as a fitted linear trend (see figure 1). The largest increases in rice output occur during the period of ‘trade liberalization’ (1987-94), and continue (virtually unabated) in the ‘post-reform’ period to 2006. However, trends in TFP vary markedly between regions in the country. Figure 2 shows that not only is TFP higher in the MRD, and especially so compared to regions (2) to (7), but also that the growth in TFP is substantially larger in the MRD compared to the RRD and other regions. As a fitted annual trend the growth in TFP in the MRD is 4.42 per cent, while in the RRD it is 2.25 and in all other regions 1.36 per cent per year. This poor TFP performance is added concern in the poorest regions of the country (regions 2, 3 and 6), where the average annual increase in TFP is less than 1.3 per cent. In total, the MRD remains a stand-out in both the level and growth of TFP.

In all cases, except for the MRD, there is also evidence of a ‘slow down’ in productivity after the year 2000. This is an added problem, again, in poor regions (which generally do not have a natural advantage in rice production, or sufficient water resources for ‘wet land’ rice), but it is also a concern in the RRD, a major rice growing area, where farms remain relatively small and fragmented.

Figures 3 and 4 build the terms of trade (TOT) in rice production. With the ‘trade liberalization’ reform process, the indexed price of rice increases (from the state-controlled low price in the ‘communal period’ to the partially controlled price during the output share contracts period) throughout 1989 to 1994 and beyond (see figure 3). During the trade liberalization period all controls over the domestic price were removed, and prices rose rapidly. After 1996 the domestic price of rice partially reflects world prices for rice on international markets, and fluctuates accordingly.

As a product of both rapid increases in the output of rice and economic development, figure 4 shows the (roughly uniform) increase in the indexed value of input prices over the period. Much of this is dominated by increases in the price of fertilizer (albeit with considerable volatility), due to the rapid increase in rice output, but farm wage rates also increase at an average

annual rate of 1.44 per cent. The TOT, finally, is summarized in figure 5, and clearly shows that except for the period from 1989 to 1998 (excluding 1993), the TOT has worsened relative to the 1985 starting point. If nothing else, this highlights the importance of TFP increases to partly offset this trend, since increases in productivity will generate proportionally more revenues for given input use.

Figure 6 is the key graphic, in effect combining all price, quantity and productivity indexes together. It shows both the indexed value of paddy rice output (i.e., the indexed price multiplied by the indexed quantities of rice) and the indexed value of input expenditures (i.e., the indexed input prices multiplied by the indexed quantities of inputs). The gap or wedge between the two lines provides a measure of ‘net income’ in rice production over time. For Vietnam as a whole, land and market reform generates a substantial wedge, or considerable increases in net income from 1989 to 2000, and especially so in the years 1992 to 1999. In 2001, both the domestic and international price of rice fall dramatically, and the wedge closes.

The wedge for the years 1992-99 provides an essential story of economic development, and also coincides with well documented falls in the rural poverty rate in Vietnam. Increases in the price of price, output and productivity, on the one hand, and increases in the farm wage rate on the other, result in substantial increases in farm and rural income. It is roughly during this period, or from 1993 to 2004, as mentioned above, that the defined share of poor people in Vietnam “dropped by two thirds and approximately 30 million people were lifted out of poverty” (Hansen and Nguyen, 2007). Not all of this poverty reduction was due to rice production, of course, but given the large share of the population in rural areas and the predominance of rice production in rural agriculture, there is little doubt that the reform and post-reform periods had a major impact on overall living standards. (See Glewwe et al. (2002) for the distributional effects of poverty reduction in Vietnam, based on early household surveys in 1993 and 1998, and Ravallion and van de Walle (2008) for recent welfare impacts of land reform).

Nevertheless, it is also clear that these gains are not shared equally across regions or the country. Figure 7 shows the indexed ratio of the value of revenues to the value of input costs for paddy rice production, for selected regions, as a measure of ‘net returns’. Relative to the starting point, all regions do well from 1992 to 1999, but after 1999 both the RRD and all other regions fall (in some cases) far below the starting point. For the years 1999-2004, net returns are even less than one for areas outside of the MRD and RRD. Only the MRD does consistently well, both in terms of levels (compared to all other regions) and in terms of years with relatively large net returns.

5 Frontiers and efficiency

The importance of TFP levels and increases in resulting measures of net income highlight the importance of potential efficiency gains that accompany further land and market reform. The following sections use stochastic production frontiers and inefficiency models to isolate the key constraints on efficiency gains (as a component of TFP), and what policy measures might be most suitable.

5.1 Stochastic frontiers and inefficiency

Stochastic production frontiers were first developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). The specification allows for a non-negative random component in the error term to generate a measure of technical inefficiency, or the ratio of actual to expected maximum output, given inputs and the existing technology. The idea can be readily applied to panel data, following Battese and Coelli (1995). Indexing firms by $i = 1, 2, \dots, n$, the stochastic output frontier is given by

$$Y_{it} = f(X_{it}, \beta) e^{v_{it} - u_{it}} \quad (5.1)$$

for time $t = 1, 2, \dots, T$, Y_{it} output, X_{it} a $(1 \times k)$ vector of inputs and β a $(k \times 1)$ vector of parameters to be estimated. Cross-sectional estimates (as with the farm survey data below) drop the index for time, of course. As usual, the error term v_{it} is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$ and captures random variation in output due to factors beyond the control of firms. The error term u_{it} captures firm-specific technical inefficiency in production, specified by

$$u_{it} = z_{it}\delta + w_{it} \quad (5.2)$$

for z_{it} a $(1 \times m)$ vector of explanatory variables, δ a $(m \times 1)$ vector of unknown coefficients and w_{it} a random variable such that u_{it} is obtained by a non-negative truncation of $N(z_{it}\delta, \sigma_u^2)$. Input variables may be included in both equations (5.1) and (5.2) as long as technical inefficiency effects are stochastic (see Battese and Coelli 1995).

The condition that $u_{it} \geq 0$ in equation (5.1) guarantees that all observations lie on or beneath the stochastic production frontier. A trend can also be included in equations (5.1) and (5.2) to capture time-variant effects. Following Battese and Corra (1977) and Battese and Coelli (1993), variance terms are parameterized by replacing σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$. The technical efficiency of the i -th firm in the t -th period for the basic case can be defined as

$$TE_{it} = \frac{E(Y_{it} \mid u_{it}, X_{it})}{E(Y_{it} \mid u_{it} = 0, X_{it})} = e^{-u_{it}} = \exp(-z_{it}\delta - w_{it}) \quad (5.3)$$

and clearly must have a value between zero and one. The measure of technical efficiency is thus based on the conditional expectation given by equation (5.3), given the values of $v_{it} - u_{it}$ evaluated at the maximum likelihood estimates of the parameters in the model, where the expected maximum value of Y_{it} is conditional on $u_{it} = 0$ (see Battese and Coelli, 1988). Efficiency can be calculated for each individual firm per year by

$$E[\exp(u_i) | v_i + u_i] = \frac{1 - \Phi(\alpha_a + \gamma(v_i + u_i)/\sigma_a)}{1 - \Phi(\gamma(v_i + u_i)/\sigma_a)} \exp[\gamma(v_i + u_i) + \sigma_a^2/2] \quad (5.4)$$

for $\sigma_a = \sqrt{\gamma(1 - \gamma)\sigma^2}$ and $\Phi(\cdot)$ the density function of a standard normal random variable (Battese and Coelli 1988). The value of $\gamma = 0$ when there are no deviations in output due to inefficiency and $\gamma = 1$ implies that no deviations in output result from random effects, or variance in v .

5.2 Econometric specification: provincial data (1990–99)

As mentioned, the first frontier estimate uses a provincial level data set from 1990-99. Summary statistics are reported in table 1. Note that all output and input measures (e.g., average farm size, labour, material inputs) are multiples of the number of crops per year. Generalized likelihood ratio tests are used to help confirm the functional form and specification. As a pre-test, the null hypothesis of a Cobb-Douglas form of the production function was tested against a general translog specification by setting the relevant parameters for squared and interaction terms in the translog form equal to zero. The resulting test statistic was $\chi_{10}^2 = 9.4$ compared to a critical value of 19.7. A Cobb-Douglas functional form was thus selected. Accordingly, equation (5.1) for unbalanced panel data set (1991–1999) for i province and t time period is specified by a production function in log-linear form, or

$$\ln Y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln LAB_{it} + \beta_3 \ln LAN_{it} + \beta_4 \ln IN_{it} + \beta_5 T + v_{it} - u_{it} \quad (5.5)$$

where Y is the output of rice, K the stock of capital (a combined tractor and buffalo measure, in horsepower), LAB labour in working days, LAN total land under cultivation, IN material inputs (fertilizer, seed, insecticide) and T is a time trend.

The provincial ‘farm-specific’ factors used in the technical inefficiency model, or equation (5.6) below, are average farm size ($SIZE$), the percentage of rice land in which tractors are used (TL), a variable indicating soil conditions ($SOIL$) as a binary variable for the main rice growing regions, or the MRD and the RRD, the number of threshing machines (MA) and the number of tractors (CA), so that

$$u_{it} = \delta_0 + \delta_1 \ln SIZE_{it} + \delta_2 \ln TL_{it} + \delta_3 SOIL_{it} + \delta_4 \ln MA_{it} + \delta_5 \ln CA_{it} + \omega_{it} \quad (5.6)$$

for $\omega_{it} \sim N(0, \sigma_\omega^2)$. As mentioned, specific input variables can be included in equation (5.6) as long as technical inefficiency effects are stochastic and input variables in the production function are exogenous to the composite error term (Battese and Coelli 1995, and also, Forsund et al., 1980 and Schmidt and Lovell 1979).

Additional likelihood ratio (LR) tests are summarized in table 2. Correct critical values from a mixed χ -squared distribution (at the 5 per cent level of significance) are drawn from Kodde and Palm (1986). The relevant test statistic is

$$LR = -2\{\ln[L(H_0)/L(H_1)]\} = -2\{\ln[L(H_0)] - \ln[L(H_1)]\} \quad (5.7)$$

where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the null and alternative hypotheses respectively. The null hypothesis of a deterministic time trend in equation (5.6) is rejected. The null hypothesis that technical inefficiency effects are absent ($\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$) and that farm-specific effects do not influence technical inefficiencies ($\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$) in equation (5.6) are both rejected, as is $\delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$. Finally, the null hypothesis that $\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2) = 0$, or that inefficiency effects are not stochastic, is rejected. All results indicate the stochastic effects and technical inefficiency matter and thus that traditional OLS estimates are not appropriate in this study. Additional LR tests reject non-constant returns to scale.

5.3 Results for provincial data

Table 3 summarizes the results for the stochastic production frontier and inefficiency models. The coefficients on capital, labour, land and material inputs are 0.17, 0.13, 0.24 and 0.51 respectively. A time trend also tests as significant at 1.1 per cent per year. Results show that farms in the main rice growing regions, those with larger farm size, and farms with a higher proportion of rice land ploughed by tractor are more efficient. The size of the binary variable *SOIL* is perhaps the least surprising. Superior conditions for growing rice in the MRD and RRD, compared especially to the highlands in the northwest or central areas (regions 3 and 6), are clearly reflected in provincial-wide measures of efficiency throughout the sample period. The MRD in particular consistently ranks best in efficiency, year-to-year, and the efficiency measures for the MRD and RRD (taken together) are 11 to 13 per cent higher throughout than the average for Vietnam as a whole. (Detailed results for each province and region by year are available from the authors on request.) The policy requirement, in the past, that rice be produced in every province of Vietnam, and the current practical restrictions on land use, as detailed in section 2 above, thus appear unwarranted, at least in terms of the potential loss in efficiency that results from producing rice outside of the Mekong and Red River Deltas.

The coefficient for the proportion of rice land ploughed by tractor (TL) is also substantial at -0.35, and remains large even when testing with the MRD and RRD taken separately. An increase in number of tractors in rice fields clearly increases efficiency. There are two policy concerns here. First, and most importantly, the absence of credit markets and, in some cases, less than secure property rights, as discussed in section 2 above, undoubtedly limits the amount of tractors in rice production. Transactions costs on loans in rural areas are prohibitive and when granted are often for terms of only one year or less. Indeed, much of the increase in agricultural capital in the reform periods, and after, is due to accumulation from retained earnings, and not from borrowing (see Che et al. 2001 and Kompas 2004). Second, land policy itself often makes it difficult to employ tractors in rice fields. Plots are often small and butt directly to adjoining plots (separated only by a mound of dirt) and practical restrictions against farm size and impediments to land consolidation that would help ensure contiguous or non-fragmented plots (especially in the north), often make the use of tractors impractical, or at least not without a good deal of cooperation among farmers.

The coefficient of average farm size is smaller than might be expected, but still indicates that restrictions on farm size limit efficiency. However, this value rises considerably when estimating over the RRD and MRD (regions of comparable fertility) taken separately. In these truncated data sets, the coefficient on average farm size in the technical inefficiency model is -2.7 in the RRD, while in the MRD it is -0.1, both significant at the one percent level. This is as expected. In the RRD, where restrictions on farm size are more severe and more broadly enforced, average farm size per crop is small at 0.4 hectare per farm, compared to 1.4 hectares per farm, per crop, in the MRD, so that efficiency gains are far from exhausted. The reason for smaller farm size in the RRD is usually attributed to a high population density in rural areas in the north combined with explicit legal and moral restrictions against ‘excessive land accumulation’, at least in practice. Moreover, although land can be leased for up to 20 years, there still are only limited markets for the exchange of land or land-leases (GSO (VHLSS) 2004). Thus, smaller farm size, the consequent smaller proportion of tractors used in rice fields, more restrictive land regulations and the slightly worse natural soil conditions in the RRD explain the lower levels of efficiency compared to the MRD.

The coefficient on the number of tractors, as opposed to the proportion of rice land ploughed by tractors, is positive for the simple reason that in most rural areas (other than the MRD and RRD) tractors are used for general transportation and for other industrial crops or small-scale industry. When testing for the MRD and RRD alone, where tractors are largely dedicated for rice production, the coefficient tests larger, at -0.18, as expected.

Finally, although average technical efficiency is low for Vietnam as a whole (59.2 percent) it is clear from Frontier 4.1 output that efficiency for rice farms in Vietnam and in the principal rice growing provinces (MRD and

RRD) has been rising over time, albeit slowly, from roughly 55 to 65 per cent in Vietnam as a whole and 66 to 78 per cent for the principal rice growing areas. The gradual increase in the amount of capital (tractors and buffalo) is undoubtedly one of the key explanations for this trend. The only exception is the year 1994 where all areas experienced a fall in efficiency and especially so in the MRD and RRD. The reason for this fall appears to be partly due to Resolution 5 (Nguyen 1995), outlined first in 1993, which further redivided farm size into smaller and non-contiguous plots, allocated now across prior family farm members, but perhaps mostly to the exceptional floods in that year in most of the principal rice growing regions. Program output shows that previous technical efficiency measures were not recovered until three of four years later, or in 1997 for Vietnam as a whole and 1998 for the principal rice growing areas.

5.4 Econometric specification: farm survey data (2004)

The second frontier estimate uses survey data obtained from a random selection of 338 farms producing rice from 32 communes across 8 provinces in the RRD and MRD, with a roughly equal split of farms and communes in each area. The survey was carried out from August to December 2004, with detailed collection of all rice output and input data, as well as farm specific characteristics. The main areas from which farms were selected in the MRD are Soc Trang, Tra Vinh, Vinh Long and Can Tho; and, in the RRD, from Ha Tay, Nam Dinh, Thai Binh and Nam Ha. Summary statistics are provided in table 4. Log likelihood ratio tests (available from the authors on request) confirm the specification given by

$$\ln Y_i = \beta_0 + \beta_1 \ln K_i + \beta_2 \ln LAB_i + \beta_3 \ln LAN_i + \beta_4 \ln F_i + \beta_5 \ln P_i + \beta_6 RRD_i + v_i - u_i \quad (5.8)$$

for Y the output of paddy in kilograms, K capital in machinery hours, as the sum of hours a farm uses tractors in land preparation and transportation, pumps and threshing machines, LAB working days, as the sum of family and hired labour, LAN total land size in hectares, F kilograms of fertilizer used, P pesticides in kilograms and RRD a binary variable for Red River Delta rice farms. The inefficiency model in this case is

$$u_i = \delta_0 + \delta_1 SIZE_i + \delta_2 PLOTS_i + \delta_3 SOIL_i + \delta_4 IRR_i + \delta_5 ED_i + \omega_i \quad (5.9)$$

for $SIZE$ the amount of cultivated rice land (both leased and directly controlled by the household), $PLOTS$ the number of plots of rice land in a given farm, as a proxy for land fragmentation and $SOIL$ a measure of soil quality, ranked in decreasing order (from 1 to 6), based mainly on the chemical composition of the soil. IRR is a measure of water availability (natural

and irrigated), ranked in decreasing order (from 1 to 4), obtained by asking farmers to rank their irrigation conditions, based on the level and difficulty of supplying water and drainage. The ranking from 1 to 4 is simply given by: very good, good, fair or poor. *ED* is the level of education of the farm decision maker, categorized by four levels: primary, secondary, high school and higher education.

5.5 Results for farm survey data

Results for the farm survey data set are reported in table 5. Given the nature of the data, the estimated input coefficients vary considerably with the results from the provincial data set. There are two reasons for this. First, the provincial data set is nation-wide, with large variations in rice production across 60 provinces, and especially so compared to farm survey data in the principal rice growing regions. Second, and perhaps more importantly, the measure of inputs in each data set is vastly different. For example, land in the farm survey data refers to the actual value of land cultivated, rather than a multiple of land cultivated over all rice crops during the course of a year, and capital is a value measure of all machines, rather than a constructed measure of buffaloes and tractors. The value of the binary variable *RRD* in the stochastic production, in table 5, alternatively, is straightforward and illustrates the advantages to growing rice in the south, compared to the north. This value is -0.184 and is consistent with the measured difference in TFP between the RRD and the MRD, illustrated in figure 2.

Of particular interest, however, are the inefficiency results. Soil and irrigation are as expected, since they are ranked in decreasing order of quality, implying that higher quality soil and better irrigation increase efficiency, and it is clear that more educated farmers are also more efficient. The coefficients on *SIZE* and *PLOTS* indicate the loss in efficiency from current land use practice, in a way that is not possible in the provincial data set, with provincial averages on farm size and no measure of plot numbers. The estimates clearly indicate that larger farms and farms with fewer plots are more efficient. The latter in particular indicates a potential issue with land fragmentation. Admittedly, simply counting the number of plots in a given farm is a crude indicator of fragmentation, since it lacks a measure of distance between plots or whether plots are contiguous or not, but it is also clear from the discussion in section 2 above that the more plots a farm has in Vietnam the more likely it is these plots are not contiguous. This is especially so in the north, where, as indicted above, small and highly fragmented farms predominate. Frontier estimates by Hung et al. (2007), on a smaller survey data set for 188 farms in the north only, near Hanoi in the RRD, in the year 2000, also show a negative relationship between the number of plots and farm efficiency.

5.6 Econometric specification: VHLSS data (2004)

The third frontier estimate uses VHLSS data for 3,865 households in 2004 largely engaged in rice production (from a total of more than 9000 households surveyed). Although not literally a pure sample of rice producers, the rice output of the households in this sub-sample accounts for more than 75 per cent of total household annual crops in terms of quantity, and more than 78 per cent in terms of value. Summary statistics are listed in table 6. Log-likelihood ratio tests (available from the authors on request) generate a specification for the stochastic production frontier of the form

$$\begin{aligned} \ln Y_i = & \beta_0 + \beta_1 \ln LAN_i + \beta_2 \ln LAB_i + \beta_3 \ln HLAB_i + \beta_4 \ln M_i \\ & + \beta_5 \ln MR_i + \beta_6 \ln F_i + \beta_7 \ln H_i + \beta_8 MRRD_i + v_i - u_i \end{aligned} \quad (5.10)$$

with an inefficiency model given by

$$\begin{aligned} u_i = & \delta_0 + \delta_1 PLOTS_i + \delta_2 ED_i + \delta_3 CERT_i \\ & + \delta_4 QUAL_i + \delta_5 EXT_i + \omega_i \end{aligned} \quad (5.11)$$

for Y the output of paddy in kilograms, produced over the twelve months prior to the survey date, and LAN the amount of area (in square meters) that the household uses for annual crop production, regardless of its ownership. Labour comes from two sources: LAB household labour (in hours) and $HLAB$ hired labour (in Vietnamese Dong). The values of machines (M), (i.e., tractors, tools and implements), rented machines (MR), fertilizer (F) and herbicide (H) are all measured in constant-value Vietnamese Dong. $MRRD$ is a binary variable for rice produced in the MRD and RRD.

In the inefficiency model, $PLOTS$ is the number of separate annual agricultural land plots in a household farm and ED is a rank for the education of the household head, given by numbers 0 to 5, or no schooling, primary, lower secondary, upper secondary, vocational training and college or university schooling. $CERT$ designates that a farm household holds a land certificate title (measured as a ratio of land under title to total land size), allowing for the sale or lease of all or some plots of land and $QUAL$ is a measure of land quality, based on the land tax system, and generally correlated with the amount of soil nutrients and the proportion of soil serviced by natural or irrigated water. Annual agricultural land is classified into 6 categories which serve as the basis for the government to collect agricultural taxes. In equation (5.11), $QUAL$ is specifically the ratio of the annual agricultural land area of the best two land types over total land holdings. EXT is a binary variable simply measured by a visit to an extension services office, attending meetings to seek advice or guidance on cultivation practices or raising livestock, or by being visited on farm by an extension staff officer.

5.7 Results for VHLSS data

Results for the VHLSS data set are reported in table 7. Estimated input coefficients are comparable to the results for the farm survey data set. The binary variable *MRRD* indicates the advantages of growing rice in the main delta areas. (A alternative specification, with *MRRD* in the technical inefficiency model, as in the estimates using the provincial data set above, generates similar results.) Results again indicate that increases in the number of plots (as a proxy for land fragmentation), decrease efficiency, and also that better educated farmers and higher quality soil (in terms of water availability and irrigation) increase efficiency across farms. In the VHLSS data land quality varies considerably and the mean is low (see table 6), indicating that rice is produced in many areas without the natural advantage of water availability or irrigation. This is in sharp contrast to the results for the farm survey data set above, drawn mostly from farms in the MRD and RRD ,where water is not as much of an issue, and average land quality by this measure is much higher (see table 4). Of added interest here are coefficient estimates on land use certificate and access to extension services. As mentioned, a proper land use certificate is essential not only for the ease of acquiring, selling or leasing land, but it also provides the often only ready source of collateral for farm loans. Those farms with a proper certificate are more efficient, as are those (nearly half the sample) that have access to agricultural extension services.

6 Closing Remarks

Extensive land and market reform in Vietnam has resulted in dramatic increases in rice output over the past thirty years. Results show that TFP increases considerably in the major rice growing areas (the Mekong and Red River Delta areas) during the early years of land and market reform, but with clear evidence of a productivity ‘slow-down’ since 2000 in all regions except the MRD. TFP in the MRD remains much higher than in the RRD, and TFP in other regions (and especially in poor areas) remains virtually unchanged throughout the entire period. Terms of trade and net returns are also favorable throughout the reform period, providing much of the explanation for increased incomes and poverty reduction during this time, but overall performance has worsened considerably since 2001. The differences over time and by region speak directly to existing land use regulations and practices and suggest calls for further land and market reform. In this regard, additional frontier and efficiency model estimates illustrate the remaining institutional and policy constraints, including existing restrictions on land consolidation and conversion and poorly developed markets for land and capital. Estimates show that larger and less land-fragmented farms, farms in the major rice growing areas, and those farms that are better irrigated,

have a greater proportion of capital per unit of cultivated land, a clear property right or land use certificate and access to agricultural extension services are more efficient.

With this in mind, it seems clear that growing rice in every province, at least terms of a narrowly defined efficiency criteria, is inappropriate. Productivity and efficiency are both substantially larger in the Mekong and Red River delta areas, where rice production has a clear comparative advantage. This shows up repeatedly in both TFP and related measures, as well as in frontier and inefficiency models, in terms of both the magnitude of binary variables for these regions (and their effects on output or efficiency), and coefficient estimates that measure the effects of irrigation or water availability on efficiency. Land policy (formal or in practice) which makes it difficult for land to be converted to other uses thus can not be justified on these grounds. The same can be said for land consolidation. If farms that are larger and less fragmented are more efficient, practical restrictions on land size needs to be relaxed and a more active real estate market for land needs to be provided, encouraging low-cost and efficiency enhancing land transfers. A necessary and straightforward pre-requisite for this is well-defined land use certificates, covering every parcel of land, something that Vietnam has yet not been able to accomplish. This may also partly resolve problems with credit availability, as would a significant extension of the 20 year lease provisions on parcels of agricultural land. The current leases on land allocated in 1993 are indeed about to expire. Without a land use certificate, or with limited remaining tenure, it is difficult if not impossible to secure a loan, much less convert and consolidate land. The original land and market reforms, as dramatic as they were, have not gone far enough to secure property rights or provide sufficient or suitable markets for land and capital.

There are at least three issues are warrant further research. First, it would be useful to have a better defined measure of land fragmentation than used here, one that includes distance and a spatial representation of non-contiguous plots. Although the number of plots in a given farm is a useful proxy, and perhaps more than sufficient for Vietnam, a more refined index would be useful. This may also further clarify any potential interaction effects between fragmentation and land size on inefficiency. Second, the estimates would benefit from additional measures of rural services. The only variable used here, access to agricultural extension services, as a simple binary variable, matters greatly to efficiency, but so too must variables like rural infrastructure (e.g., roads, water rights and quarantine and surveillance measures) and specific cultivation practices, including the use of rice hybrids. Unfortunately, there is a lack of broad rice farm survey data to provide such estimates. Finally, and perhaps most importantly, there needs to be a clear investigation into the precise nature and cause of the thin or poorly developed agricultural land and credit markets in Vietnam, and what specific policies might be best to help resolve these constraints. It is undoubtedly

the case that poorly defined property rights and inadequate land laws and practice matter greatly. Perhaps they are all that matter, but this, and the traverse from the current system to one that better serves rice farmers in Vietnam is still unclear.

APPENDIX: Data Sources and Adjustments

Data for TFP and related measures (1985-2006) and for the 1991-1991 balanced panel data set is drawn mainly from the SDAFF (Statistics Department of Agriculture, Forestry and Fisheries), 1991-2006, data sources obtained from the General Statistics Office of Vietnam (GSO), including VHLSS data, related project investigations, studies and reports by Vietnamese organizations, such as the State Planning Committee (SPC), the Ministry of Agriculture and Food Processing Industry (MAFI), the Ministry of Water Resources (MWR), the Department of Prices and Markets (DPM) (formally known as the State Department of Price (SDP)), and international organizations such as the World Bank and the Food and Agriculture Organization (FAO). The details of the structure of rice production (especially for the early data series) are extracted from the Surveys of Rice Production in the RRD and the MRD by Cantho University, funded by the International Rice Research Institute (see Nguyen Khiem (1995) and Vo (1995)).

It should be noted that from 1985-2002 there were 60 defined provinces in Vietnam based on the GSO statistics and administrative units. However, beginning in 2003, provinces were redefined into 64 provinces based on the GSO statistics and administrative units. In this study the ‘new’ provinces are aggregated into the previous provinces in the data set before 2003, for consistency. In particular, Can Tho, Dak Lak and Lai Chau refer to Can Tho and Hau Giang, Dak Lak and Dak Nong, and Lai Chau and Dien Bien provinces. Regions are as currently defined by the GSO. Primary data for 1985-1999 is obtained from Che et al. (2006) and Kompas (2004). The data set for 2000-02 is from Kompas (2004). In general, prices are measured in constant 2006 USD, and converted to Dong where appropriate. Data assembly and construction is as follows.

1. Output quantity and prices. Paddy output is drawn from SDAFF (2001, 2006) and the GSO (2008) under the category of ‘production of paddy by province’. The time series of rice prices by province is computed from a number of sources, with recent data provided by the GSO. For the period 1985-2003 price data is based on Kompas (2004) and Che et al. (2006), most of which is obtained from the Department of Prices and Markets (DPM). A rice equivalent for output is chosen rather than rice output alone since in the same rice fields farmers usually overlap production with other short-term cereal crops, such as sweet potatoes and maize. There are multiple crops per year in many areas. Specific time series data for rice output is from SDAFF (1991) and MAFI (1991) for the period 1976-90, from SDAFF (2001) for 1990-93, GSO (1995) for 1994 and the SDAFF (2001) for 1995 to 1999. All measures were verified by alternative data sets contained in the SDAFF (2001) for the years 1975-1999. Updates were obtained from SDAFF (2006).

2. Land quantity and prices. The time series for ‘planted area of paddy’ is obtained from SDAFF (1991, 1992, 2001, 2006), SPC (1995) and the

GSO (2008). The Vietnamese government divides the soil quality of land into seven levels and levies land tax depending on quality. A study by the World Bank (1994) distinguished the quality of soil into five levels in terms of cultivated area. Soil conditions and irrigation is generally much better in the RRD and MRD, compared to other regions (MWR 1994). Land-use price variables are defined as the cost of land use, or the average tax levies per one sown hectare in terms of value. The tax levies are required to be paid to government for the right of using land, which depend on land quality (by rank from type 1 to 5). Land taxes for rice land are based on the gross value of rice production (SDAFF (2006)). It is assumed that the land price indexes are coincident with the gross value of rice area (as the multiple of rice output overall crops per year and the price of rice).

3. Labour quantity and prices. Data for the quantity of labour is obtained by multiplying average man-days worked per hectare by the number of hectares in a given rice cultivation area. The rice cultivated area is obtained from SDAFF (1991, 2001, 2006) and the GSO (2008). Total labour for rice production is calculated from total rice planted (in area) and average labour used for rice production per hectare. Average man-day working requirements includes work for land preparation, transplanting, weeding and harvesting, originally based on the survey of rice production by the Cantho University (1990-1995), as detailed in Nguyen Khiem (1995) and Vo (1995). The data on the price of labour for paddy production is estimated from average labour costs by the SRP by the Cantho University, DPM (1995, 2002 and 2005) and the VHLSS (2006), for the RRD and MRD. For 2003-06, the labour price variable is estimated using 2002 as a base year and the movement in the wage index for rice production, estimated as the average annual change in labour costs for rice cropping per hectare (SDAFF 2006).

4. Material inputs and prices. Materials for paddy production are largely composed of rice seeds and preparation, fertilizer and insecticide (of these fertilizer is the largest component, representing at least 30 to 40 per cent of total costs (DPM (1995, 2002 and 2005) and the GSO (VHLSS) (2006)). For the period prior to 2002 material input quantities are partly measured in terms of a 'urea-used equivalent', or total planted paddy area multiplied by the rate of fertilizer used per hectare per rice crop. The rates of fertilizer use for paddy production per hectare per rice crop are obtained from the SRP for the RRD and MRD and SDAFF (2001, 2006). This rate is adjusted in some non-principal rice growing provinces, based on reports provided by the GSO. For the period of 2000-02, material inputs are estimated as a multiple of the growth indexes of total fertilizer consumption used by Vietnam (FAO 2007), using 1999 as a base year, and the actual current fertilizer use by provinces in 1999 (provided from Kompas (2004)).

In Kompas (2004), material inputs include the nutrition content of all fertilizers (organic and chemical), insecticides and seeds. The conversion factor used to aggregate organic and chemical fertilizers is similar to that

used by Tang (1980) and Sicular (1988). The amount of organic fertilizer for the rice industry is obtained from the total amount of organic fertilizer used for agriculture. Organic fertilizer for agriculture is assumed to be supplied from two main sources: night soil and large animal manure (buffaloes, cattle and pigs). Population-adjusted night-soil is estimated based on the size of the rural population (GSO 2008) multiplied by a rural utilization rate (0.9). The standard number of large animals equals the sum of buffaloes, cattle and pigs (GSO 2008), for which the weighted ratios are 1, 1 and 0.33 respectively. Organic fertilizer for rice production is obtained by multiplying the amount of organic fertilizer for agriculture with the weighted ratio between food grain area sown to the total sown area for cultivation. The chemical fertilizer data used for rice production is derived directly by multiplying the average amounts of chemical fertilizer used in the north (165.4 kg/ha) and the south (193 kg/ha) (drawn from the SRP) and the rice area in every province (SDAFF 2006). The data set for insecticides is constructed by multiplying the average use of insecticide per hectare in the year 1992, or 5.8 kg and 7.6 kg in the north and south, respectively, and the total rice area (SDAFF 2006). In a similar manner, the data for seeds are calculated from the average use of seeds per hectare, or 140 kg/ha and 240 kg/ha in the north and south respectively, multiplied by the total rice area (GSO 2008). The time series for chemical fertilizer is calculated from the average amounts of chemical fertilizer used per hectare multiplied by cultivated area in each year (SDAFF 2001, 2006). The time series data for insecticides and seeds are calculated from the average use of insecticide and seeds per hectare (SDAFF 2001, 2006) multiplied by rice area for each year (SDAFF 2006). To verify, an updated measure of fertilizer (in terms of quantities) for 2003-2006 is estimated from the trend of average fertilizer use in the South East Asia (FAO 2007), using the 2002 as a base year.

5. Capital quantity and prices. The capital variable for 1985-1999 is based on Kompas (2004), following a similar approach to that used by McMillan et al.(1989), and assumes that the physical capital can be represented by the capacity of tractors in combination with a buffalo equivalent measure. The conversion from the number of draught animals to the capacity of tractors is based on well-known observations in Pakistan (see Blomqvist 1986), indicating that a bullock-day (a pair of bullock working 8 hours) is approximately the same as a tractor-hour, with a typical tractor being between 15 and 25 horsepower. In the Vietnamese case, we assume that one cattle or buffalo-day is equivalent to roughly 0.6 bullock-days (or 14 hours of work by one pair of cattle or buffalo is roughly 8 hours of work by one bullock), with a typical tractor being 15 horsepower. The data sources for the capacity of tractors, number of buffaloes and cattle are provided from MAFI (1991, 1994), SDAFF (2001), and for recent series by SDAFF (2006) and the GSO (2008). The capital measure used for rice from 1985-1999 is drawn from (Kompas 2004). The capital measure used from 2000-02 is

estimated from the planted area and the average capital cost for rice from DPM (2005). The updated capital quantity variable for 2003-2006 is estimated and verified from the trend of tractors used in the South East Asia (FAO 2007), using the 2002 as a base year. Capital prices for 1985-1999 are obtained from Che et al. (2001) and Kompas (2004), with additional details for the early part of this series provided in Che et al. (2006). An updated series is drawn from district level data obtained from the GSO and GSO (2008).

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Figure 1: Paddy rice output (indexed) in Vietnam (1985-2006). Average annual growth is rate by fitted linear trend is 3.5%.

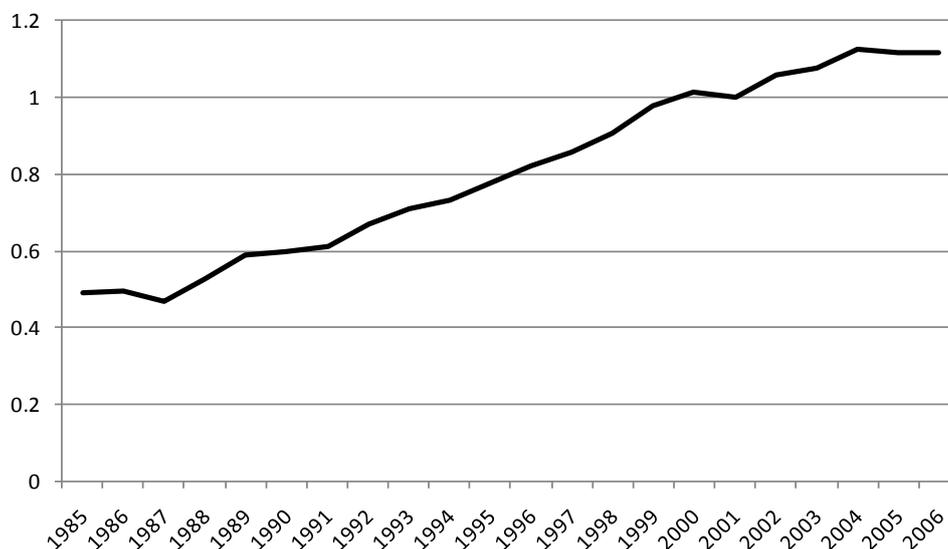


Figure 2: TFP (Total Factor Productivity) indexes for the Mekong River Delta (MRD), the Red River Delta (RRD) and all other regions (Other) for paddy rice production in Vietnam, 1985-2006. Average annual growth rate in TFP by fitted linear trend for the MRD is 4.42%, for the RRD is 2.15%, and for all other regions is 1.36%.

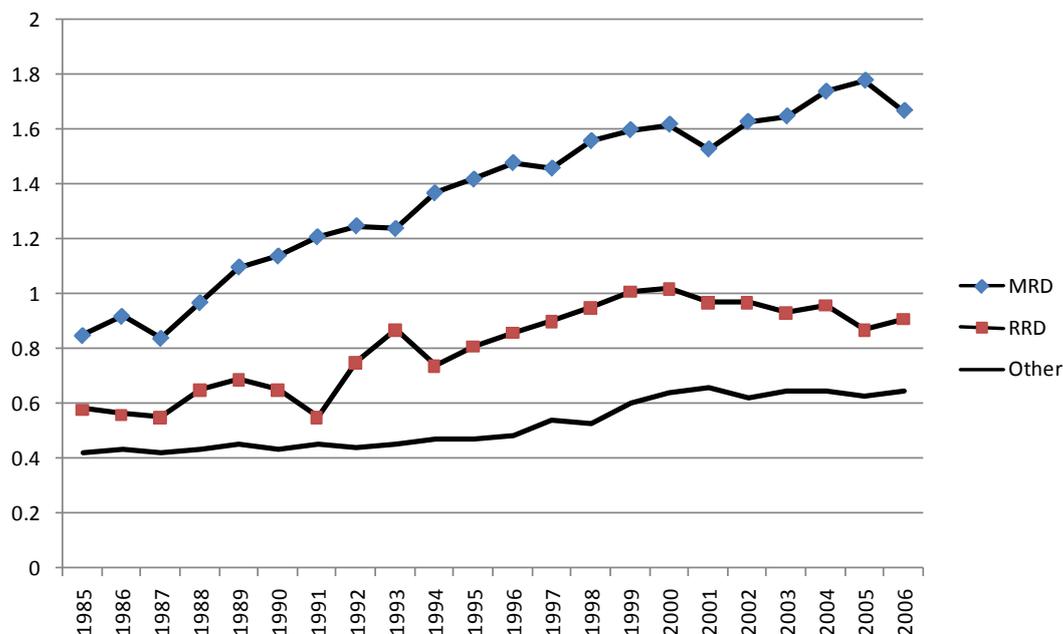


Figure 3: Paddy rice output price index for Vietnam, 1985-2006.

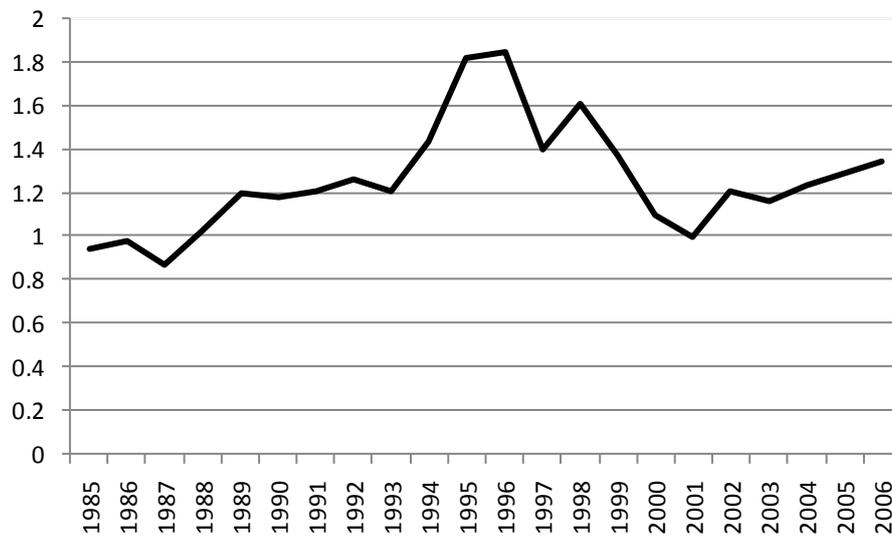


Figure 4: Paddy rice input price index for Vietnam, 1985-2006. Average annual growth rate by fitted linear trend is 2.2%.

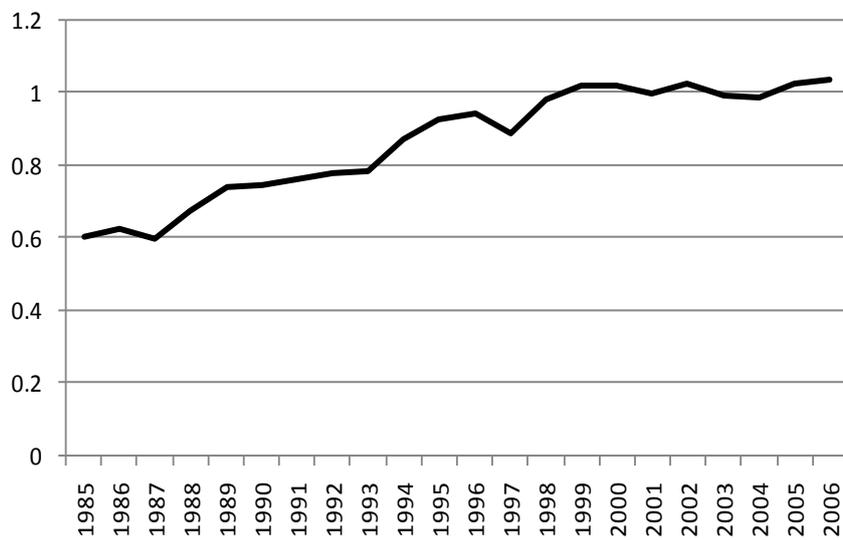


Figure 5: TOT (Terms of Trade) indexes for rice production in Vietnam, as the ratio of indexed paddy prices to the indexed value of all input prices, 1985-2006. Base year is 1985.

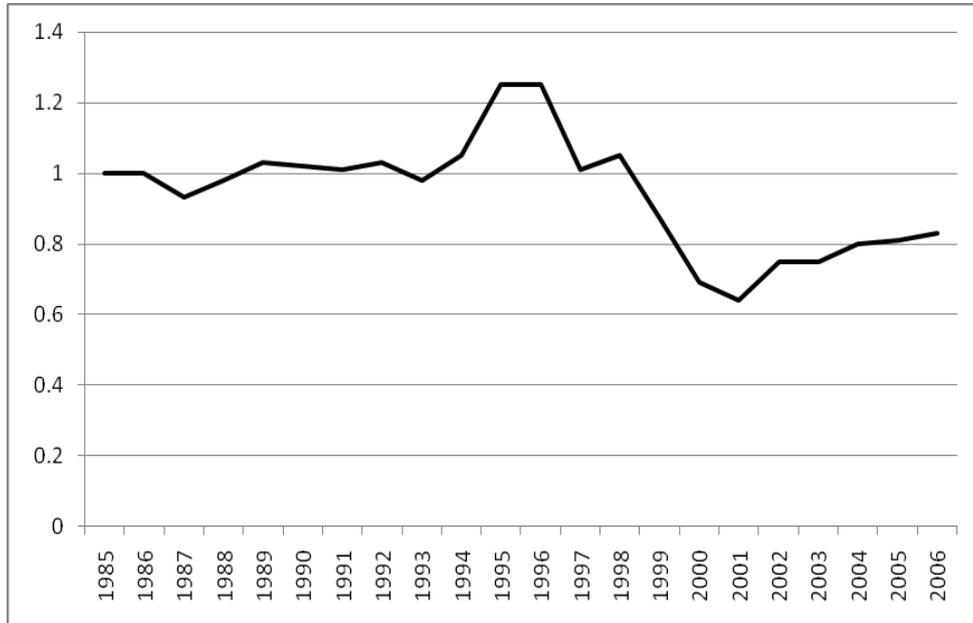


Figure 6: Net income measure or the indexed value of paddy rice output values (indexed output prices multiplied by indexed output quantities) and the indexed value of all input values (indexed input prices multiplied by indexed input quantities) in rice production in Vietnam, 1985-2006.

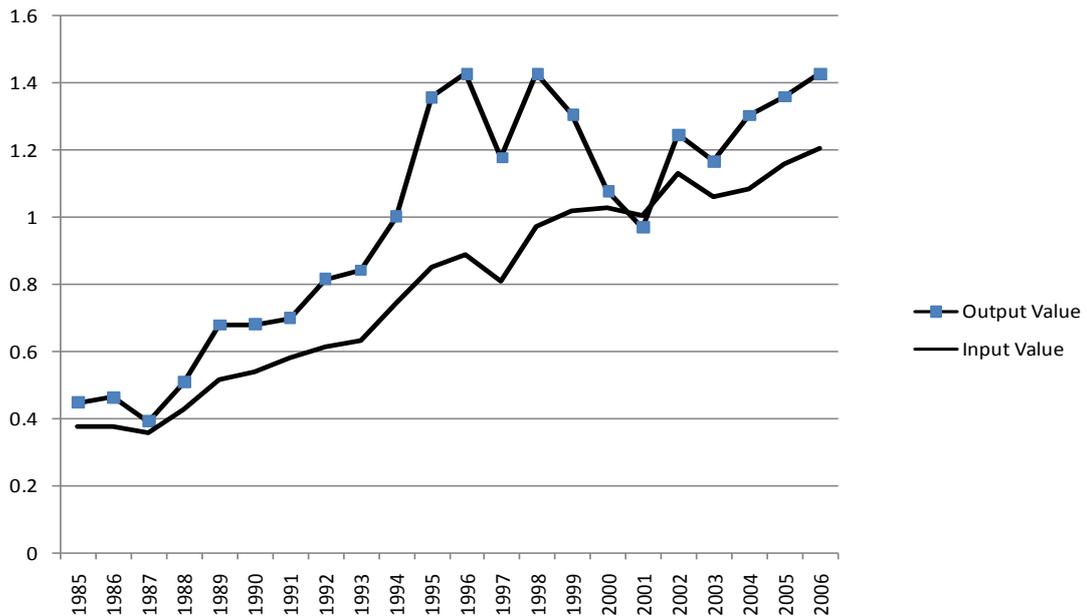


Figure 7: Net returns in Vietnam, as the indexed ratio of revenues to input costs in paddy rice production, for Mekong River Delta (MRD), Red River Delta (RRD) and all other regions (Other), 1985-2006.

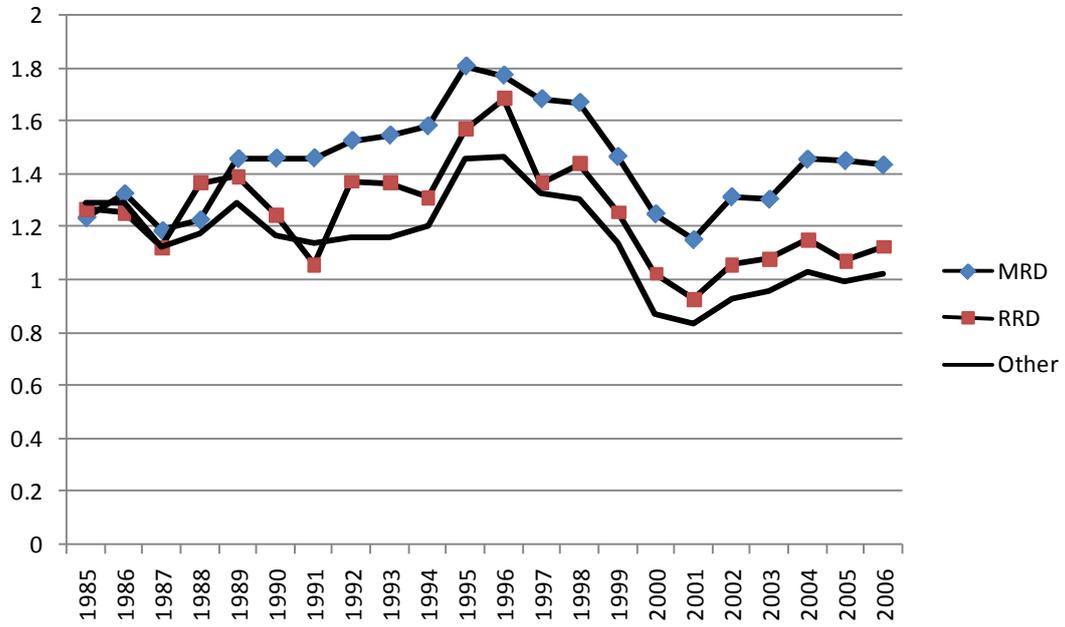


Table 1: Summary statistics for key variables in rice production for 60 provinces in Vietnam, 1991-99.

Variables	Units	Average	St dev	Min	Max
Output (Y)	'000 tons	419.4	445.6	31.2	2,100.0
Capital (K)	'0000 horse power	11,591.2	13,732.7	325.4	79,902.9
Labor (LAB)	'000 working days	17,205.8	15,173.2	978.4	114,847.2
Land (LAN)	'000 hectare	120.9	106.7	12.2	514.3
Material inputs (IN)	'000 tons	44.1	30.5	3.9	145.0
Tractor number (CA)	units	1,455.4	2,717.6	2.0	31,123.0
Farm size (SIZE)	hectare/unit	1.8	1.4	0.2	4.5
Tractor proportion (TL)	percentage	0.4	0.3	0	1.0
Threshing machines (MA)	units	2,325.2	6,419.4	0.8	69,541.0

Table 2: Generalized likelihood ratio tests, parameter restrictions for the stochastic production frontier and technical inefficiency models (equations 5.5 and 5.6)

Null hypothesis	χ^2 -statistic for Regression 1	$\chi^2_{0.99}$ -value	Decision
$\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$	151.62	19.38	reject H_0
$\gamma = 0$	23.54	8.27	reject H_0
$\delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$	411.4	17.75	reject H_0
$\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$	139.7	16.07	reject H_0

Note: The critical values for the hypotheses are obtained from Table 1 of Kodde and Palm (1986).

Table 3: Parameter estimates of the stochastic production frontier and technical inefficiency models for Vietnam, provincial data, for 540 observations, 1991-99 (equations 5.5 and 5.6).

	Coefficient	T-ratio
Stochastic production frontier model		
Constant	0.40 (0.17)	2.30
Capital (K) (ln)	0.17 (0.02)	8.78
Labor (LAB) (ln)	0.13 (0.03)	4.07
Land (LAN) (ln)	0.24 (0.04)	6.94
Material inputs (IN) (ln)	0.51 (0.03)	1.61
Time (T)	0.011 (0.002)	4.88
Technical inefficiency model		
Constant	0.63 (0.1)	6.10
Average farm size (SIZE) (ln)	-0.03 (0.01)	2.60
Tractor used proportion (TL) (ln)	-0.35 (0.08)	4.46
Natural conditions (SOIL)	-0.29 (0.04)	7.45
Threshing machine (MA) (ln)	-0.01 (0.01)	1.54
Tractor number (CA) (ln)	0.04 (0.02)	2.81
Sigma-squared	0.07	11.74
Gamma	0.94	18.84
Log-likelihood	9.87	
Mean Efficiency (per cent)	59.2	

Notes: The coefficient on material inputs is significant at the .05 level, and on threshing machines at the .10 level. All other coefficients except labour are significant at the .01 level. Numbers in parentheses are asymptotic standard errors.

Table 4: Summary statistics for key variables in paddy rice production for the farm survey data set, 2004.

Variables	Units	Mean	Std dev	Min	Max
Output (Y)	<i>kg</i>	10320.86	12483.51	690	105593
Land (LAN)	<i>ha</i>	0.915	0.9855	0.06	7.3
Labour (LAB)	<i>man days</i>	155.89	91.26	32	583.5
Capital (K)	<i>hours</i>	35.85	36.72	3.51	272.36
Fertilizer (F)	<i>kg</i>	814.08	610.05	73	5000
Pesticides (P)	<i>kg</i>	14.69	11.88	1.39	123.65
Soil Quality (SOIL)	<i>rank</i>	2.72	1.07	1	5
Irrigation (IRR)	<i>rank</i>	2.62	0.59	1	4
Farm Size (SIZE)	<i>ha</i>	0.915	0.9855	0.06	7.3
Plots (PLOTS)	<i>unit</i>	3.36	2.55	1	14
Education (ED)	<i>level</i>	2	0.639	1	4

Table 5: Parameter estimates of the stochastic production frontier and technical inefficiency models for the farm survey data, for 388 observations, 2004 (equations 5.8 and 5.9).

	Coefficient	T-ratio
Stochastic production frontier model		
Constant	7.53 (0.233)	32.34
Capital (K) (ln)	0.116 (0.028)	4.09
Labor (LAB) (ln)	0.023 (0.033)	0.69
Land (LAN) (ln)	0.668 (0.037)	17.65
Fertilizer (F) (ln)	0.182 (0.029)	6.21
Pesticide (P) (ln)	0.049 (0.015)	3.14
RRD	-0.185 (0.031)	-5.89
Technical inefficiency model		
Constant	-7.27 (0.932)	-7.80
Land Size (SIZE)	-0.665 (0.209)	3.17
Plots (PLOTS)	0.150 (0.050)	2.99
Soil (SOIL)	0.763 (0.145)	5.25
Irrigation (IRR)	0.831 (0.011)	3.55
Education (ED)	-0.689 (0.229)	-3.00
Sigma-squared	0.013	9.70
Gamma	0.98	16.9
Log-likelihood	264.3	
Mean Efficiency (per cent)	64.3	

Notes: All coefficients except labour are significant at the .01 level. Numbers in parentheses are asymptotic standard errors.

Table 6: Summary statistics for key variables in paddy rice production for the VHLSS survey data set, 2004.

Variables	Unit	Mean	Min	Max
Paddy rice output (Y)	kg	3,733	75	120,750
Land (LAN)	m2	5,447	165	100,000
Labour (LAB)	hours	2509	0	16,048
Labour hired (HLAB)	000 VND	322	0	36,000
Machines (M)	000 VND	70,998	0	3,000,000
Machines rented (MR)	000 VND	625	0	18,400
Fertilizer (F)	000 VND	1,159	0	34,000
Herbicide (H)	000 VND	375	0	19,800
Mekong and Red River Deltas (MRRD)	yes = 1	0.41	0	1
Number of plots (PLOTS)	number	4.26	1	30
Land quality (QUAL)	ratio	0.1	0	1
Land with LUC (CERT)	ratio	0.79	0	1
Household head education (ED) (1 = no school; 5 = college or university)	level	1.33	0	5
Access to extension services (EXT)	yes = 1	0.48	0	1

Table 7: Parameter estimates of the stochastic production frontier and technical inefficiency models for VHLSS data set, for 3,865 observations, 2004 (equations 5.10 and 5.11).

	Coefficient	T-ratio
Stochastic production frontier model		
Constant	1.51 (0.07)	21.55
Land (LAN) (ln)	0.507 (0.009)	58.31
Labour (LAB) (ln)	0.028 (0.007)	4.38
Hired labour (HLAB) (ln)	0.027 (0.003)	10.68
Machines (M) (ln)	0.004 (0.001)	3.55
Machines rented (MR) (ln)	0.096 0.005	18.29
Fertilizer (F) (ln)	0.161 (0.006)	26.04
Herbicide (H) (ln)	0.092 (0.005)	18.44
MRD and RRD (MRRD)	0.15 (0.014)	11.13
Technical Inefficiency Model		
Constant	-4.54 (1.045)	-4.34
Number of plots (PLOTS)	0.105 (0.018)	5.75
Household head education (ED)	-0.692 (0.118)	-5.84
Ratio of land with LUC (CERT)	-1.092 (0.181)	-6.04
Land quality (QUAL)	-1.525 (0.240)	-6.36
Access to extension services (EXT)	-0.63 (0.106)	-5.98
Gamma	0.958	119.23
Sigma-squared	1.881	5.6
Log-likelihood	-1705.5	
Mean Efficiency (per cent)	78.8	

Notes: All coefficients are significant at the .01 level. Numbers in parentheses are asymptotic standard errors.