Provincial Total Factor Productivity in Vietnamese Agriculture and Its Determinants

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Abstract

This paper was designed to capture the determinants of the agricultural total factor productivity (TFP) level across 60 provinces in Vietnam during the period 1990-2006. The TFP level in Tornqvist form was used to regress on 4 groups of determinants: omitted inputs of agricultural production process; quality of inputs used in agricultural production; technology factors; and output structure. The estimated results showed that: (i) Vietnam's agricultural sector became relatively more capital intensive; (ii) South provinces were more productive, while North Midlands and Central Coast tended to lag further behind; (iii) labour mobility played a very important role in resources accumulation in agriculture in Vietnam, and so in improving TFP; and (iv) agricultural TFP was significantly influenced by land quality, farm size and land fragmentation.

Keywords: Total factor productivity (TFP), Malmquist TFP index, technical efficiency (TE), technical change (TC), productivity level, Tornqvist index, Vietnamese agriculture.

1. Introduction

Vietnam's agriculture has grown remarkably during the last 20 years. Agriculture output has increased by 5.3% annually during the period 1990-2008. The value of agricultural output grew from VND 62 trillion in 1990 to VND 156 trillion in 2008, excluding inflation effect. However, the agricultural share in GDP has reduced from 34.7% in 1986 to 17.6% in 2008 (GSO, 2009). Agricultural growth came from agricultural TFP and growth of agricultural inputs such as labour, tractors, land, and draft animals. This outstanding achievement resulted from the success of the *Doi Moi* policies in agriculture, which transformed Vietnam's agriculture from a commune-based public ownership and control system to effective private property rights over land and farm assets. Markets and individuals are now active in making decisions over agricultural activities (Kompas et al., 2009).

However, there still is a lot to be done in order to develop agricultural production further. Poverty is still a big issue in Vietnamese rural areas, especially in agriculturally unproductive provinces. Industrialization transfers agricultural resources such as labour and land to the industrial sector, leaving less for agricultural production. In addition, population growth increases the demand for agricultural outputs, which requires a significant agricultural supply response to hold down prices and support economic growth. In this context, improving agricultural TFP is crucial for alleviating poverty and expanding agricultural production. Therefore, this paper aims at providing empirical evidence for suggesting policy implications to push up agricultural TFP in Vietnam.

Based on the estimated agricultural TFP growth and its decompositions, this paper presents a model to explore determinants of agricultural TFP in Vietnam using data from the three years 2002, 2004 and 2006. The model estimated the impact of four groups of variables – unmeasured inputs, quality of inputs, technology factors, and agricultural output structure – on agricultural TFP levels of 60 provinces in Vietnam.

Beside introduction, the paper consists of four sections: (i) literature reviews; (ii) theoretical framework; (iii) empirical results; and (iv) summary and conclusion.

2. Literature review

Much research has been done to explain agricultural productivity using both partial (land and labour) and TFP concepts. Most of the research has focused on capital intensity, human capital, land quality and other factors to explain the growth of productivity. An influential scholar in this area, Griliches (1963) studied United States' agriculture using a stable production function, and identified four main sources of conventionally measured productivity in U.S. agriculture in the period 1940-60: (a) improvements in labour quality as a consequence of a rise in education levels; (b) improvements in quality of machinery services; (c) underestimations of the contribution of capital and overestimation of the contribution to output growth by conventional factor share based weights; and (d) economies of scale. And another influential researcher on this topic, Hayami (1969) identified the role of education and research on labour productivity in agriculture in addition to conventional inputs like land, fertilizer, and machinery. Hayami and Ruttan (1970) classified the sources of productivity growth into three categories which are: a) resource endowments; b) technology, as embodied in fixed or working capital; and c) human capital, including education, skills, knowledge and capacity embodied in a country's population. Their analysis concluded that these three groups of factors accounted for 95% of the differences in labour productivity in agriculture between a representative group of Less Developed Countries (LDCs) and of Developed Countries (DCs).

From these key studies, more empirical research about the determinants of agricultural productivity has emerged on both the scope of cross-country and cross-province, states or regions within a country. Many cross-country researchers focused on investigating the role of education, research and infrastructure in the differences of agricultural productivity among countries. Nguyen (1979) extended Hayami and Ruttan's work (1970) to estimate the effect of general and technical education on agricultural productivity by using cross-country data in 1968-1976. Antle (1983) considered the roles of education, agricultural research and infrastructure on TFP which were estimated by a Cobb-Douglas production function. Kawagoe et al. (1985) estimated an aggregated agricultural production function of 22 less developed countries (LDC) and 21 developed countries (DC) by pooling 1960, 1970, and 1980 data. They found that LDCs were neutral with respect to farm scale, while DCs experienced increasing returns to scale, and education and research accounted for labour productivity differences among countries, especially for LDCs.

Other cross-country researchers (Craig et al., 1997; Thirtle et al., 2003; Wiebe et al., 2000, 2003; Rao et al., 2004; Alauddin et al., 2005; Headey, Alauddin and Rao, 2010) also took into account several other nonconventional determinants of agricultural productivity beside the above factors, such as input quality (labour, land, and institutional quality). In addition, determinants of agricultural TFP among households, provinces, states or regions within a country have also attracted the attention of agricultural economics researchers (Appleton and Balihuta, 1996; Teruel and Koruda, 2005; Chen et al., 2008; Fare et al., 2008; Fuglie, 2010).

To my knowledge, there has been no peer–reviewed paper exploring the determinants of agricultural productivity in Vietnam up to the current period. However, there have been several studies in capturing determinants of agricultural technical efficiency, which is a component of TFP. Rios and Shively (2005) used a Tobit regression based on the Data Envelopment Analysis (DEA), Technical Efficiency (TE) scores for coffee farms in one province in Vietnam to estimate that small farms were less efficient than large farms. Linh (2008) used both DEA Tobit regression and SFA to estimate that the TE of Vietnam's agriculture was positively influenced by education (especially primary schooling); land quality; and irrigation. Kompas et al. (2009) used a SFA to measure TE and productivity in Vietnamese rice production based on both provincial data as well as household data. They estimated several determinants of TE such as farm size, number of land plots, soil conditions, land quality, irrigation, and education beside conventional inputs.

In contrast to previous research, this paper employs agricultural TFP estimates from the non-parametric DEA method, and converts these TFP indices into agricultural TFP levels by using a transitive Tornqvist TFP index, which employs input value share information. The possible determinants of agricultural TFP levels of provinces in Vietnam were selected from the findings of the reviewed research. A model of agricultural TFP of Vietnam was constructed based on those determinants. By doing that, this research makes a significant contribution to identifying determinants of agricultural TFP in Vietnam.

3. Theoretical framework

This paper aims to measure the relationship between the agricultural TFP and its determinants. Instead of using agricultural TFP growth which is estimated by using the Malmquist indices, we use the TFP level as the dependent variable. The reason is that provinces with a faster growth rate of agricultural TFP may start with a lower level if productivity convergence appears in Vietnam's agricultural sector, so that using the growth rate does not reflect productivity gaps across provinces.

TFP level

The TFP level is measured as an index where province *i* is related to the base province *j*

$$TFP_{ij} = \frac{TFP_i}{TFP_j}$$

Using the TFP definition from and Diewert (1992), it can be written as:

$$TFP_{ij} = \frac{Output\_quantity\_index_{ij}}{Input\_quantity\_index_{ij}}$$

The output and input quantity indices could be either in Tornqvist or Fisher form. However, these indices do not satisfy the transitivity condition (Coelli et al., 2005). We applied the EKS method suggested by Elteto-Koves (1964) and Szulc (1964) (see Coelli et al., 2005) to generate transitive multilateral comparisons and we use the Tornqvist form to measure TFP levels, which does not require price information. Instead of output and input price information, we use implicit input shares based on shadow prices which can be generated from the Data Envelopment Analysis (DEA) (dual problem).

Shadow price and implicit input value share

In DEA, technical efficiency can be obtained from solving linear programming problems in the *envelopment* form (Fare et al., 1998). To obtain shadow prices, we solve dual problems of the DEA, which is also called *multiplier* form as (Nin & Yu, 2008):

$$\max_{p,w} \sum_{m=1}^{M} p_m q_{im}$$

Subject to

$$\sum_{n=1}^{N} w_n . x_{in} = 1$$

$$\sum_{m=1}^{M} p_m q_{im} - \sum_{n=1}^{N} w_n . x_{in} \leq 0$$

$$p_m, w_n \geq 0$$

where m is the number of outputs, n is the numbers of inputs, I is the number of provinces, q_m is the output m of the province, x_n is the input n of the province. p_m and w_n are the weights of output m and input n, respectively. They can be interpreted as normalized shadow prices.

From the implicit shadow prices, we employ the definition from Coelli and Rao (2001) to compute the output and input shares as:

$$\theta . p_m . q_m$$

$w_n . x_n$

where θ is TE score of the province; p and w are the implicit shadow prices of outputs and inputs; and q and x are the amounts of outputs and inputs.

Model specification for determinants of agricultural TFP

To identify determinants influencing the gap in agricultural TFP among provinces in Vietnam, we constructed a model which used the estimated agricultural TFP level as the dependent variable and determinants which are described as independent variables were selected from the literature review. All variables are at the provincial level. Based on data availability and literature review, this research categorized determinants of agricultural productivity level into 4 groups as below, which basically followed Alauddin et al. (2005):

Group 1- Omitted inputs of agricultural production process: rainfall; GDP per capita; percentage of public expenditure for development investment which is a proxy for infrastructure; and credit access.

Group 2- Quality of inputs used in agricultural production: those variables are age dependency percentage, vocational training percentage, which represents labour quality; and percentage of irrigated land in total agricultural land, which measures land quality.

Group 3- Technology factors: factors which influence the relationship between output and inputs in the agricultural production process. They are farm size, land plot size, and plot number; rural population; percentage of non-farm rural population; and trade value.

Group 4- Output structure: the output used in measuring agricultural TFP is an aggregated one. However, it is composed of many agricultural product types. The changes in the proportion of those products will impact the value of aggregated agricultural output value and so TFP. We decomposed agricultural output into cropping, livestock and farm service.

In summary, the model can be specified as:

$$TFP\_level_i = f\,(Omitted\_inputs_i\,,\ Quality\_of\_inputs_i\,,\ Techno\_factors_i\,,\ Output\_structure_i)$$

where TFP_level_i is the agricultural TFP level of province i, $Omitted\_inputs_i$ is a vector of factors in the omitted inputs group of province i, $Quality\_of\_inputs_i$ is a vector of factors in the quality of inputs group of province i, $Technology\_factor_i$ is a vector of factors in the technology factors group of province i, and $Output\_structure_i$ is a vector of factors in the output structure group of province i.

Three main sources were used for data collection in constructing those independent variables: annual statistical yearbooks of Vietnam, statistical data for Vietnam's agriculture, forestry and fishery; and VLSS. All three sources of data were established by an official statistical agent of the Vietnamese government, the General Statistics Office of Vietnam.

Variable definitions

The dependent variable of the model - level of agricultural TFP - was computed by using the Tornqvist index for the base year 1990. Agricultural TFP levels for subsequent years were generated by using the agricultural TFP index which was estimated by using the Data Envelopment Analysis (DEA) Malmquist. The DEA Malmquist indices was estimated by using agricultural aggregate output and four inputs - agricultural labor, number of tractors, land area and number of buffaloes. Appendix 1 presents the agricultural TFP levels based on the Tornqvist index with EKS adjustment for the period 1990-2006.

Group 1: Omitted inputs of agricultural production process

Rainfall level (*RAINFALL*) is the total rainfall over a year which is measured in millimetres by using a rain gauge (pluviometer). *GDP per capita (GDP)* is measured in VND million units at the relative price in the year 1994. *Infrastructure (PUPEXP)* used to estimate the impact of infrastructure on agricultural TFP is measured by the percentage of public expenditure for development investment as a proportion of provincial Gross Domestic Product. *Credit access (CREDITACC)* is defined as the percentage of agricultural households accessing credit sources compared with the total number of agricultural households.

Group 2: Quality of inputs used in agricultural production

Age-dependency (*AGE_DEP*) is defined as the percentage of agricultural people under 15 and over 60 years old in the total agricultural population in each province. *Vocational training (VOTRAIN)* is the percentage of agricultural labour who received vocational training courses in total agricultural labour. This was employed to measure the role of education in agriculture. *Irrigation (IRRIGATION)* which is a proxy for land quality is measured by the area of irrigated land as a percentage of the total area of agricultural land per agricultural household.

Group 3: Technology factors

Farm size (FARMSIZE) is included in the model to capture on-farm economies of scale in agricultural production. It is defined as the average amount of agricultural land per agricultural household. However, one agricultural household might have many separated land plots, and those plots may be far from each other. So plot size (*PLOTSIZE*) would be a better proxy to capture this impact. It was measured by land area per plot per agricultural household. Small plots are more difficult for mechanization. In relation to *FARMSIZE* and *PLOTSIZE*, plot number (*PLOTNUM*) is the average number of agricultural plots per household.

Rural population (RUPOP) captures off-farm returns to scale in agricultural production (distinguished with on-farm economies of scale which was measured by farm size, plot size and plot number). *RUPOP* was measured as the total rural population in each province. *Non-farm rural population (NONFARMPOP)* is defined as the percentage of non-farm rural population in the total rural population. The percentage of non-farm rural population is used to reflect the effect of agricultural labor mobility on agricultural TFP levels. When labour moves out of agricultural activities, resources (especially agricultural land) are accumulated for a smaller number of labourers.

Trade (TRADE): Trade is a proxy for the effect of openness on agricultural production. *TRADE* is defined as total value of export plus import.

Group 4: Output structure

The changing structure of agricultural output may change aggregate output with the same level of agricultural inputs (Balk, 2001). To take output mix effect into account, the paper categorized all types of agricultural products into three groups (cropping, livestock and farm services).

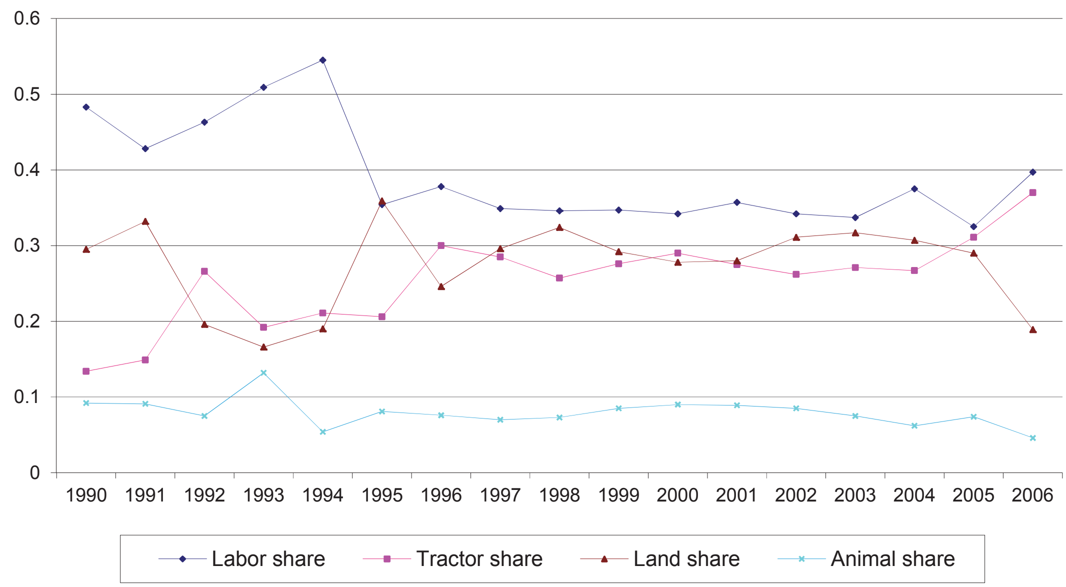
4. Empirical results

Implicit input value share

Using the techniques discussed above, we computed the implicit input value share based on the dual linear programming problems for 60 provinces for the period 1990-2006, an approach suggested by Coelli and Rao (2001). The estimated implicit input values shares show that labour was the most important factor in Vietnam's agricultural production (39% on average). Draft animals accounted for very little of agricultural production (only 8% on average). Land and number of tractors were in middle positions with 28% and 25% on average, respectively.

The implicit value shares of those four inputs during the period 1990-2006 show that there were different trends in input use in Vietnam's agriculture. Labour, land and draft animal shares went down, while the tractor share increased in that period. Of one monetary unit of agricultural output, labour input accounted for 48.3% in 1990 but only 39.7% in 2006, land was 29.5% in 1990 and 18.9% in 2006, and draft animals was 9.2% in 1990 and 4.6% in 2006. On the other hand, tractor share was raised from 13.4% in 1990 to 37.0% in 2006. This suggested that Vietnam's agricultural production changed from labour and land-intensive technology to a more capital-intensive one during the period. The agricultural modernization policy of the Vietnamese government had shown its effectiveness in this period. It had changed the input structure of Vietnam's agriculture. During the period, tractor share in agricultural output value increased 6.6% annually or 176.1% for cumulative growth. The growth

Figure 1: Implicit input value share in Vietnam's agriculture in 1990-2006



Source: Estimates from the dual linear programming problems using AIMSS 3.11.

was obtained at the expense of the shares of other inputs. Tractor use became more important in Vietnam's agricultural production and substituted for other agricultural inputs

The trend of input value shares can be decomposed into two periods. The first was from 1990 to 1996 and the second, from 1996 to 2006. In the first half, the input value shares changed dramatically. The first period modernized the agricultural sector of Vietnam with a reversal of labour and tractor shares. The reductions in labour share had been compensated by the increases in the tractor share. The land share fluctuations reflected two effects: industrialization of the country and new agricultural land development during the period. In the second half of the period, the input value shares in agriculture were becoming more stable. Agricultural production in Vietnam was still a labour-intensive industry in this half. However shares of labour, number of tractors and agricultural land were getting closer.

TFP levels

The implicit input value shares estimated above were used as the weights in the Tornqvist transitive TFP index to compute agricultural TFP level. Hanoi was selected to be the base province to other provinces in the country. The research computed the agricultural TFP level by using the Tornqvist index for the base year 1990 using EKS adjustment for transitivity. Agricultural TFP levels for subsequent years were generated by using the agricultural TFP index which was estimated by using DEA Malmquist.

Among the ten provinces that ranked highly in agricultural TFP level in 1990 (shown in bold in Appendix 1), three provinces were located in the Mekong River Delta, one in the Central Highlands, one in the Central Coast, one in the North Midlands, and four in the Red River Delta. This shows the important role of the two deltas in Vietnam's agricultural production in this year. However, those positions dramatically changed during the period 1990-2006. In 2002, 2004, and 2006 all ten highest ranked provinces were located in the Southern regions which include the Mekong River Delta, the South East, and the Central Highlands. The South became the major area for agricultural production in Vietnam, while the North, especially the North Midlands and the Central Coast, were further behind. This situation was caused by a high growth rate of agricultural TFP in the Southern regions.

Determinants of agricultural TFP in Vietnam

Plotting agricultural TFP levels against independent variables, the log-linear relations was the best form in order to estimate model. The scatter graphs of agricultural TFP levels and their determinants also show that several potential outliers needed to be considered. To obtain better estimation, we use the robust regression to estimate the model (Huber, 1964).

The estimated results are reported in Table 1. Due to high multicollinearity between trade value (*LnTRADE*) and *GDP per capita*, we omitted *LnTRADE* from the models. The shares of cropping (*LnCROPPING*) and farm service (*LnFARMSERVICE*) were also omitted due to their multicollinearity with farm size (*LnFARMSIZE*). We kept *GDP per capita* and farm size, because they were the main variables in this research.

Models 1, 2, 3, and 4 were estimated by using pooled data. Models 5, 6, 7, and 8 were in the same format but used provincial average data. Models 1 and 5 estimated the 2002-2006 dataset which did not include some variables like percentage of irrigated land in total agricultural land (*LnIRRIGATION*), agricultural land plot size (*LnPLOTSIZE*), and number of land plots (*LnPLOTNUM*). Models 2, 3, 4, 6, 7, and 8, which estimated the 2004-2006 data, included those variables. In the 2004-2006 dataset, models 3 and 4 in pooled estimations and models 7 and 8 in provincial average estimations used agricultural land plot size and number as alternatives to farm size (used in models 2 and 6) to capture different aspects of economies of scale and land fragmentation in Vietnam's agriculture.

All reported models fit the dataset quite well with fairly high R_square and significant *F* statistics. Robustness tests provided in Table 2, such as Cameron and Trivedi IM-test, Breusch-Pagan test for heteroskedasticity, variance inflation factors, linktest, and Ramsey RESET tests were obtained by trying the models by the OLS estimations. All the tests showed that there was no evidence for multicollinearity and omitted variables in those estimated models. The Breusch-Pagan test showed evidence of heteroskedasticity in models 3, 7 and 8 at 10% significance level, while the Cameron-Trivedi test failed to reject the null hypothesis of constant variances.

The signs of independent variables and number of statistically significant ones were very consistent between the two estimation methods (pooled data and provincial average data). However, between the two methods of estimation, Hausman specification tests showed that the provincial average models (models 5, 6, 7, and 8) were more consistent and efficient. Within the estimations in 2004-2006, model 7 was the best one with the smallest values of Akaike information criterion (AIC) and Schwarz information criterion (SIC) obtained by *rregfit* command.

All estimated models show that GDP per capita (*LnGDP*), percentage of agricultural household access to credit sources (*LnCREDITACC*), percentage of irrigated land in total agricultural land (*LnIRRIGATION*), size of rural population (*LnRUPOP*), percentage of non-farm population in total rural population (*LnNONFARMPOP*), farm size (*LnFARMSIZE*), and land plot size (*LnPLOTSIZE*) were statistically significant positive determinants. While land plot number (*LnPLOTNUM*) had a statistically significant negative impact on agricultural TFP level during the period 2002-2006.

Age dependency (*LnAGE_DEP*) shows the expected negative signs in all estimated models. However, it is only statistically significant in model 1 (at 10% level). The percentage of agricultural labour who received vocational training in total agricultural labour (*LnVOTRAIN*) shows a consistently positive sign in all models. However, it was only statistically significant in models 1 and 3 at 10% level. This supports the expected positive effect of education on agricultural TFP level. Provinces where more labour received vocational training courses, were more productive.

The rainfall level variable (*LnRAINFALL*) shows a consistently unexpected negative impact on agricultural TFP levels. However, it is not statistically significant in any model. Its unexpected sign may be due to worsening climate

Table 1: Estimations of determinants of Vietnam's agricultural TFP levels in the period 2002-2006

Robust Regression: Dependent Variable – LnTFPLEVEL

	Pooled estimations				***Provincial average estimations***			
	2002-2006	2004-2006			2002-2006	2004-2006		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
LnRAINFALL	-0.297	-0.161	-0.153	-0.16	-0.13	-0.133	-0.107	-0.168
	(0.197)	(0.127)	(0.124)	(0.124)	(0.137)	(0.116)	(0.113)	(0.112)
LnGDP	0.434***	0.436***	0.401***	0.423***	0.5***	0.386**	0.376**	0.4***
	(0.113)	(0.107)	(0.107)	(0.107)	(0.145)	(0.151)	(0.149)	(0.145)
LnPUBEXP	-0.001	0.02	0.007	-0.011	-0.012	0.033	-0.004	-0.022
	(0.048)	(0.04)	(0.039)	(0.04)	(0.093)	(0.082)	(0.082)	(0.08)
LnCREDITACC	-0.054	0.29**	0.306***	0.407***	0.599***	0.259*	0.321*	0.422**
	(0.047)	(0.114)	(0.111)	(0.111)	(0.164)	(0.156)	(0.168)	(0.163)
LnAGE_DEP	-0.556*	-0.452*	-0.35	-0.174	-0.777*	-0.43	-0.238	-0.003
	(0.332)	(0.276)	(0.272)	(0.272)	(0.473)	(0.425)	(0.408)	(0.396)
LnVOTRAIN	0.131	0.179*	0.088	0.167*	0.379**	0.177	0.102	0.173
	(0.084)	(0.103)	(0.103)	(0.092)	(0.158)	(0.156)	(0.152)	(0.13)
LnIRRIGATION		0.416***	0.408***	0.281***		0.472***	0.442***	0.314***
		(0.094)	(0.087)	(0.086)		(0.13)	(0.119)	(0.114)
LnRUPOP	0.328***	0.452***	0.389***	0.406***	0.558***	0.363***	0.336***	0.368***
	(0.079)	(0.083)	(0.083)	(0.082)	(0.104)	(0.103)	(0.1)	(0.095)
LnNONFARMPOP	0.728***	0.601***	0.504***	0.337**	0.688***	0.678***	0.558***	0.376**
	(0.132)	(0.143)	(0.142)	(0.143)	(0.172)	(0.191)	(0.186)	(0.188)
LnFARMSIZE	0.228***	0.243***			0.117	0.266**		
	(0.055)	(0.074)			(0.095)	(0.109)		
LnPLOTSIZE			0.202***				0.196***	
			(0.045)				(0.062)	
LnPLOTNUM				-0.417**				-0.418***
				(0.086)				(0.116)
Constant	-2.385	-8.417***	-6.633***	-4.688***	-4.05*	-4.936**	-4.655*	-4.191*
	(1.71)	(1.615)	(1.592)	(0.086)	(2.312)	(2.38)	(2.346)	(2.322)
N	180	120	120	120	60	60	60	60
F	**21.11*****	**27.39*****	**29.44**	**30.45**	**21.3*****	**17.34*****	**18.49*****	**20.38*****
R-square	**0.46**	**0.59**	**0.62**	**0.62**	**0.58**	**0.62**	**0.63**	**0.64**

*Significance level 10%: *, 5%: **, 1%: ***. R_square values were in Robust regression and computed by rregfit command in Stata.*
Source: Authors' estimation.

Table 2: Robustness tests of pooled and provincial average estimations of determinants of agricultural TFP

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Multicolinearity test								
Mean VIF	1.95	1.78	1.74	1.65	2.0	2.03	1.93	1.81
Heteroskedasticity test								
Cameron and Trivedi test (P_value)	0.255	0.145	0.258	0.25	0.569	0.439	0.439	0.439
Heteroskedasticity test								
Breusch-Pagan test (P_value)	0.122	0.13	0.051	0.044	0.151	0.124	0.071	0.03
Test for omitted variables								
Ramsey test (P_value)	0.378	0.573	0.41	0.46	0.83	0.615	0.554	0.686
Model specification test (Linktest)								
P_value for square of predict value	0.127	0.591	0.412	0.316	0.78	0.645	0.537	0.511
Akaike Information Criterion (AIC)	207.6	140.2	137.6	123.9	111.8	76.6	70.5	79.0
Schwarz Information Criterion (SIC)	240.8	175.1	172.0	160.3	136.6	108.2	102.9	109.5

during the period. The frequency of storms and floods increased in those years, damaging agricultural production in Vietnam (MARD, 2009). The dramatic increases in rainfall in those years probably delivered the negative impact on agricultural TFP level in the models.

Unlike in other studies, which found a positive effect from agricultural infrastructure, the estimated percentage of public expenditure for development investment in GDP (*LnPUBEXP*) in this research does not show any statistical evidence of its effect on agricultural TFP level. Its signs are not consistent in the estimated models. In addition, the estimated coefficients are quite small. This is probably due to the fact that collected data for this variable did not reflect the status of agricultural infrastructure appropriately. The percentage of public expenditure on development investment was for the whole province, not specifically for the agricultural sector. Unfortunately, the public expenditure for agricultural development was not available.

Overall, the proportion of non-farm rural population had the largest impact on agricultural TFP levels. This suggests that the wider rural economy provides an economic context, particularly greater competition for agricultural inputs, which encourages more productive uses of those inputs. The positive impacts of GDP per capita, access to credit and the size of rural population also supports this finding. In addition, the significant positive impact of non-farm rural population shows that labour mobility was very important to agricultural TFP improvements. Looking at the on-farm determinants of TFP levels, economies of scale in Vietnam's agriculture did exist. Farm size and plot size had significant positive impacts. Land fragmentation worsened agricultural productivity. Land quality was also an important on-farm determinant, while evidence for the impact of labour quality on agriculture was not clear.

5. Summary and conclusion

From the empirical results discussed above, there are several conclusions that can be drawn:

Firstly, the estimated implicit input value shares show that Vietnam's agricultural production still relied heavily on labour input with an average 39% share. Draft animal input played only a minor role in production with only an 8% share. Land and tractors had the middle position with 28% and 25% on average, respectively. However, there was a substitution trend between agricultural inputs over the period. The share of tractors increased over time replacing labour share in Vietnam's agricultural production. This clearly reflected the impact of the process of industrializing and modernizing agriculture in Vietnam. The first half of the period 1990-2006 experienced huge changes in shares of agricultural inputs, while the second half was more stable in those input shares. Vietnam's agricultural sector showed clear evidence of becoming relatively more capital intensive during that period.

Secondly, the estimated Tornqvist TFP levels of provinces during the period showed South provinces were more productive in agriculture compared with other regions, especially North Midlands and Central Coast, which were not only less productive and but also tended to lag further behind in agricultural TFP levels.

Thirdly, and the most important contributions in this paper, the estimated models of agricultural TFP levels showed several important determinants listed below. They included both off-farm and on-farm factors.

(i) The estimations of off-farm determinants showed that the proportion of non-farm rural population had the largest impact on the agricultural TFP levels of provinces. This finding suggests that labour mobility played a very important role in resources (especially land) accumulation in agriculture of Vietnam and so in improving its TFP. A more developed rural economy provides an economic context, for example greater competition for agricultural inputs, which encourages more productive use of those inputs. The estimates of effects of other off-farm determinants such as GDP per capita, credit access and even rural population size also supported this finding. Provinces with higher GDP per capita - which implies a higher level of economic development, higher development investment capital, better infrastructure, and probably higher education level - were more productive. A higher percentage of access to credit provided more potential to invest in agricultural production; more tractors, new technology, fertilizer, etc. were employed in agriculture; and therefore TFP was higher. The finding successfully supported the role of credit source in Vietnam's agriculture. The positive impact of rural population size on agricultural productivity suggests that Vietnam's agriculture was experiencing increasing returns to scale in the period. Besides these statistically significant off-farm determinants, the research found no statistical evidence for the effects of infrastructure on agricultural TFP levels.

(ii) The estimations of on-farm determinants showed that agricultural TFP was significantly influenced by land quality which was measured by the percentage of irrigated land; average farm size per household; average land plot size per household; and land fragmentation (average number of land plots per household). These estimates suggest that besides improving land quality, encouraging agricultural land amalgamation and consolidation, which allowed farmers to apply more advanced technology in their production thereby obtaining lower average production cost, should lead to higher agricultural TFP. On the other hand, the evidence for impacts of labour quality (which was measured by age dependency and vocational training) on the agricultural TFP was not clear, even though they still showed expected signs as in other research.

The results from the estimated models in this paper have provided useful bases for policy making and planning aimed at improving agricultural TFP. The policies should focus on several crucial issues which were drawn from the empirical results of both off-farm and on-farm determinants such as labour mobility, rural economy development, ability in investing in agricultural mechanization, land consolidation and land quality improvement.

Appendix 1: Provincial productivity levels of Vietnam's agriculture 1990-2006

(Hanoi in 1990 = 1.00)

Regions	Provinces	1990		2002		2004		2006	
		Level	Rank	Level	Rank	Level	Rank	Level	Rank
Red River Delta	Ha Noi	1.000	55	1.539	28	1.533	28	1.612	29
	Vinh Phuc	1.347	43	1.801	21	1.993	20	2.271	21
	Bac Ninh	1.769	20	1.595	26	1.676	27	1.974	25
	Quang Ninh	1.510	31	1.574	27	1.383	31	1.303	35
	Ha Tay	2.072	**9**	1.931	20	2.073	18	2.215	22
	Hai Duong	1.702	25	1.763	22	1.82	24	1.889	26
	Hai Phong	1.384	37	1.759	23	1.991	21	2.772	14
	Hung Yen	2.343	**4**	2.299	15	2.502	14	2.851	12
	Thai Binh	2.350	**3**	2.238	17	2.427	15	2.766	15
	Ha Nam	1.867	14	2.012	19	2.068	19	2.426	18
	Nam Dinh	2.079	**7**	1.73	24	1.735	26	1.871	27
	Ninh Binh	1.800	18	1.316	32	1.398	30	1.635	28
North Midlands	Ha Giang	1.341	44	0.476	58	0.516	55	0.584	57
	Cao Bang	1.026	53	0.831	49	0.701	52	0.586	56
	Bac Kan	1.473	33	0.396	60	0.399	59	0.411	60
	Tuyen Quang	1.254	48	1.403	31	1.362	32	1.454	32
	Lao Cai	1.196	49	0.6	55	0.689	54	0.768	50
	Yen Bai	1.287	47	1.125	41	1.197	38	1.284	37
	Thai Nguyen	1.725	23	1.253	36	1.086	43	1.186	40
	Lang Son	1.535	30	0.691	53	0.715	51	0.581	58
	Bac Giang	1.576	29	1.014	43	1.147	39	1.041	45
	Phu Tho	1.978	12	0.96	45	0.988	45	1.055	44
	Dien Bien	0.929	58	0.445	59	0.513	56	0.711	54
	Son La	1.147	50	0.554	56	0.496	57	0.632	55
	Hoa Binh	2.363	**2**	1.071	42	1.094	42	1.259	38
Central Coast	Thanh Hoa	1.452	34	1.13	40	1.133	41	1.211	39
	Nghe An	1.962	13	1.292	34	1.332	34	1.529	31
	Ha Tinh	1.822	16	1.223	37	1.255	37	1.287	36
	Quang Binh	0.969	57	0.683	54	0.694	53	0.749	53
	Quang Tri	1.082	52	0.696	52	0.718	50	0.831	49
	Hue	0.976	56	0.783	50	0.959	46	1.143	41
	Da Nang	2.163	**5**	1.417	30	1.326	36	1.142	42
	Quang Nam	1.740	22	0.882	47	0.898	48	0.952	48
	Quang Ngai	1.502	32	0.725	51	0.736	49	0.755	51
	Binh Dinh	1.672	26	1.198	38	1.349	33	1.392	34
	Phu Yen	1.401	36	0.971	44	1.015	44	0.995	47
	Khanh Hoa	1.634	27	1.154	39	1.136	40	1.061	43
	Ninh Thuan	1.717	24	2.246	16	2.272	16	2.423	19
	Binh Thuan	1.025	54	1.685	25	1.783	25	2.025	24
Central Highlands	Kon Tum	1.834	15	0.844	48	0.93	47	1.005	46
	Gia Lai	1.302	46	1.522	29	1.84	23	2.16	23
	Dak Lak	2.075	**8**	2.665	12	2.854	12	3.218	**9**
	Lam Dong	1.373	38	2.781	11	3.9	**5**	4.146	**6**
South East	Binh Phuoc	1.316	45	1.273	35	1.423	29	1.538	30
	Tay Ninh	1.358	40	2.052	18	2.252	17	2.599	17
	Binh Duong	1.354	42	1.306	33	1.328	35	1.444	33
	Dong Nai	1.363	39	2.945	**9**	3.465	**7**	4.5	**4**
	Ho Chi Minh	1.772	19	4.235	**2**	4.609	**2**	5.112	**2**
Mekong River Delta	Long An	1.473	33	2.526	13	2.589	13	2.657	16
	Tien Giang	2.706	**1**	3.645	**4**	3.156	**9**	3.28	**8**
	Ben Tre	2.055	11	0.934	46	0.736	49	0.752	52
	Tra Vinh	1.818	17	3.546	**5**	3.906	**4**	4.328	**5**
	Vinh Long	1.750	21	8.929	**1**	9.024	**1**	11.23	**1**
	Dong Thap	2.121	**6**	3.178	**6**	3.509	**6**	3.716	**7**
	An Giang	1.577	28	2.869	**10**	3.182	**8**	2.951	11
	Kien Giang	2.059	**10**	3.164	**7**	2.986	**10**	2.85	13
	Can Tho	1.357	41	4.232	**3**	4.135	**3**	4.585	**3**
	Soc Trang	1.429	35	3.034	**8**	2.886	11	3.049	**10**
	Bac Lieu	0.896	59	2.319	14	1.971	22	2.284	20
	Ca Mau	1.097	51	0.52	57	0.465	58	0.504	59

Source: Computation by using Tornqvist transitive index

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