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MEASURING AGRICULTURAL PRODUCTION EFFICIENCY IN VIETNAM: AN APPLICATION OF DATA ENVELOPMENT ANALYSIS (DEA)

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Abstract

This paper uses data envelopment analysis (DEA) approach to estimate technical efficiency for the agriculture production activities in sixty provinces of Vietnam in the period 1990-2005. Measurements under different technology specifications show that the average technical efficiency was not high, and thus the provinces could have a large room to improve their agricultural production efficiency. The application of rank statistics technique indicates that the studied provinces had stable relative efficiency positions over time, i.e. at least one province was consistently technically better or worse than the others. Further, under the specification of variable returns to scale (VRS), the results from a Monte Carlo simulation show that the DEA estimators of technical efficiency with and without bootstraps are not really different.

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1. Introduction

Since the Doi moi (renovation) in the late 1980s to transform the country from a centrally–planned economy into an open market economy, Vietnam has notched impressive achievements in both social and economic aspects. The economy recorded an average growth of about 7.5 percent over the past decade (CIEM, 2006). Although the agricultural sector has been reduced in terms of both share in gross domestic product (GDP) and number of labors over the past decade, it is still playing an important role in the country, as more than 70 percent of the Vietnamese population are living in rural areas, where agricultural production activities are predominant. In addition, the agricultural sector also recorded remarkable achievements in changing Vietnam from a country with a lot of people living in hunger to a country ranked as the third largest exporter of rice in the world in the mid-1990s.

However, the agricultural sector in Vietnam is also facing a number of constraints and challenges. For instance, the structure of the agricultural sector has been changed very slowly, and agricultural production has been relied substantially on labor-intensive and low-technology production process under relatively small production size (MOFA, 2007). Under such constraints and potential challenges from the accession to the World Trade Organization (WTO) in early 2007, various policy issues need to be considered for Vietnam as a whole, and the agricultural sector in particular, because competition will be fiercer in an equal playing field. Therefore, looking for appropriate development strategies for the agricultural production, including efficiency improvement, is a must. Comprehensive studies on efficiency estimates for the sector are thus necessary.

At our best knowledge, there have been no studies to measure efficiency for the agricultural production activities in Vietnam. Therefore, this paper will be the first attempt to do such important and necessary analysis. To pursue our research objectives, we will use data envelopment analysis (DEA) approach to measure technical efficiency for the agricultural production in sixty provinces in Vietnam during 1990-2005. Furthermore, we will use rank statistics technique to see whether some provinces could maintain their relative efficiency positions in comparison with other provinces in the sample. To provide more concrete estimates of technical efficiency for the agricultural production in these provinces, we will perform a Monte Carlo simulation study to bootstrap DEA estimators. The algorithm proposed by Löthgren and Tambour will be applied.

The remainder of the paper is organized as follows. Section 2 presents analytical framework for measuring technical efficiency with DEA approach, as well as the procedures to detect the DEA estimators. Descriptions of data and variables for DEA model are provided in Section 3. Section 4 presents an analysis of findings, while Section 5 provides concluding remarks for the paper.

2. Analytical Framework

T*echnical Efficiency Measurement*

In this paper, we will use DEA approach (Charnes et al., 1978) to measure technical efficiency for the agricultural production in Vietnam. As indicated in a number of existing studies, such as Coelli (1995), the main advantages of the DEA approach include that it can avoid parametric specification of technology for production, and that it does not need the distribution assumption for the inefficiency term. Also, an important strength of DEA is that, with a given set of finite samples, DEA efficiency estimates can indicate significant technical inefficiencies for the studied decision-making units—DMUs (e.g. firms, industries, or provinces of a country).

However, DEA is deterministic and it attributes all the deviations from the frontier to inefficiencies, so that a frontier estimated by DEA is likely to be sensitive to measurement errors or other issues of the data. Moreover, the DEA estimators do not offer any guidance about the statistical inference problem, in which only point estimates of efficiency are obtained from the estimators.

In this paper, we will input-oriented DEA model. We assume that each of the N provinces (or DMUs) uses k=1, 2,…, P different inputs to produce m=1, 2,…, M outputs in the agricultural production. In our data set, each observation of inputs and outputs is strictly positive. Let y_m^i be the mth output of the ith province (i=1,2,…, N; m=1,2,…, M). Let x_k^i be the kth input of the agricultural production in the ith province and λ be an N-vector of weight, in which elements of weight vectors are denoted by λz (z=1, 2,…, N).

The constant returns to scale (CRS) input-oriented technical efficiency measure for the agricultural production in the ith province is calculated as the solutions of the mathematical problem as follows.

$$\theta_c^{\,i} \min_{\theta,\lambda} \theta \qquad (1)$$

subject to:

$$y_m^i \le \sum_{z=1}^{N} y_m^z \lambda_z \qquad \text{i=1,2,…, N; m=1,…., M,} \qquad (2)$$

$$\sum_{z=1}^{N} x_k^z \lambda_z \ \le \theta x_k^i \qquad \text{i=1,2,…, N; k=1,2,…, P,} \qquad (3)$$

$$\lambda \ge 0\,, \qquad (4)$$

where $\theta_c^{\,i}$ is technical efficiency (TE) measure of the agricultural production in the ith province under CRS; and λ is an (Nx1) vector of weights attached to each of the efficient DMUs.

A separate linear programming problem is solved to obtain the TE score for each of the N provinces in the sample. If $\theta_c^i = 1$, the province is on the frontier and is technically efficient under CRS. If $\theta_c^i < 1$, the province lies below the frontier and is technically inefficient.

The non-increasing return to scale (NIRS) technical efficiency measure for the agricultural production in the ith province is computed as follows.

$$\theta_n^i = \min_{\theta_i,\lambda} \theta \qquad (5)$$

subject to:

$$y_m^i \leq \sum_{z=1}^{N} y_m^z \lambda_z \quad \text{i=1,2,…, N; m=1,2,…, M,} \tag{6}$$

$$\sum_{z=1}^{N} x_k^z \lambda_z \leq \theta x_k^i \quad \text{i=1,2,…, N; k=1,2,…, P,} \tag{7}$$

$$\sum_{z=1}^{N} \lambda_z \leq 1 \quad \text{and } \lambda \geq 0. \tag{8}$$

The variable returns to scale (VRS) technical efficiency measure for the agricultural production in the ith province is computed as follows.

$$\theta_v^i = \min_{\theta_i, \lambda} \theta \tag{9}$$

subject to:

$$y_m^i \leq \sum_{z=1}^{N} y_m^z \lambda_z \quad \text{i=1,2,…, N; m=1,2,…, M,} \tag{10}$$

$$\sum_{z=1}^{N} x_k^z \lambda_z \leq \theta x_k^i \quad \text{i=1,2,…, N ; k=1,2,…, P,} \tag{11}$$

$$\sum_{z=1}^{N} \lambda_z = 1 \quad \text{and } \lambda \geq 0.$$
(12)

Because the VRS analysis is more flexible and envelops the data in a tighter way than the CRS analysis, the VRS TE measure (θ_v) is generally equal to or greater than the CRS measure (θ_c). This relationship is used to obtain a measure of scale efficiency (SE) of the agricultural production in the ith province as follows.

$$SE_i = \frac{\theta_c^i}{\theta_v^i}, \tag{13}$$

where SE=1 indicates scale efficiency or CRS; and SE<1 indicates scale inefficiency.

Scale inefficiency is due to the presence of either increasing or decreasing returns to scale, which can be determined by solving a NIRS DEA model, which is in turn obtained by substituting the VRS constraint $\sum_{z=1}^{N} \lambda_z = 1$ with $\sum_{z=1}^{N} \lambda_z \leq 1$.

Let θ_n represent the TE measure under NIRS. If $\theta_n = \theta_c$, there are increasing returns to scale; and if $\theta_c < \theta_n$, there are decreasing returns to scale (Färe et al., 1994).

Bootstrapping DEA Estimator

One of the critical drawbacks of DEA approach is that the estimated inefficiency terms are not subject to statistical properties. Therefore, to find the confidence intervals for efficiency terms, we will use the bootstrap method. The most important step of the bootstrap is a concrete specification of the data generating process (DGP) underlying the observed data. Bootstrap method aims to approximate the sampling distributions of the estimator by using the empirical distribution of the resampled estimates obtained from a Monte Carlo resampling simulation of the estimation procedure, in which repeated resamples obtained from an estimate of DGP generate repeated estimates. In this paper, we will use the Löthgren and Tambour algorithm (Löthgren, 1998) for bootstrapping DEA estimator. Furthermore, we will also use percentile method to obtain bootstrap confidence intervals. The method is found in many existing studies, such as Efron and Tibshirani (1993).

Detecting the Stability of Efficiency Rankings

One important question in this paper is whether some provinces in the sample could maintain their relative efficiency rank positions in comparison with the others over the study period. To provide an analytical answer to such question, we will apply Kruskal-Wallis Non-parametric Analysis of Variance (ANOVA) test. For this test, there are N “populations” (or provinces in this paper) simultaneously under investigation and the null hypothesis is that all N “populations” have the same distribution of ratings.

Suppose we have r rankings for each province. To apply this statistical methodology, we first rank order the set of (N-r) scores in an ascending order and let Ri denote the sum of the ranks corresponding to the ith province. Then, we compute Kruskal-Wallis test statistic as follows.

$$H = \frac{12}{Nr(Nr+1)}\left(\frac{R_1^2}{r} + \frac{R_2^2}{r} + ... + \frac{R_N^2}{r}\right) - 3(Nr+1) \quad . \tag{14}$$

This test statistic is distributed according to a χ^2 distribution with (N–1) degree of freedom. Rejection of the null hypothesis leads to the conclusion that some provinces generally could maintain their relative efficiency positions over the study period, meaning that at least one province was consistently technically better or worse than the others. When the null hypothesis is rejected, a multiple comparison test can be performed to gain further insights into stable structure of the rankings.

3. Descriptions of Data and Variables

In this paper, we will use panel data of inputs and output for the agricultural production activities in sixty provinces of Vietnam in the period 1990-2005. The data were collected by the General Statistics Office (GSO) of Vietnam through the years.

In the DEA model, we will use gross value added (GVA) as proxy for the output of the model. The output is the sum of the value-added of production from farming, forestry, animal husbandry, fishing, and sideline activities. All the values of GVA are adjusted by the

Vietnam’s GDP deflator, in which the year 1994 is the base year. GVA is measured in billions of Vietnamese Dong (VND).

The number of labors (L) used in the model excludes labor force working for the rural industries, construction, transportation, commerce, and other miscellaneous occupations. Only labors working for farming, forestry, animal husbandry, fishery, and sideline production activities are included. L is measured in thousand persons.

Machinery (TRACTOR) is considered as capital input for the agricultural production activities in this paper, and it is measure by the number of tractors used for farming, forestry, animal husbandry, fishery, and sideline production activities, such as plowing, irrigating, draining, harvesting, farm product processing, transportation, plant protection, and stock breeding. It is measured in one unit of tractor.

Fertilizers (FERTILIZERS) refer to the sum of pure weight of nitrogen, phosphate, potash, and complex fertilizers, which were used for farming, forestry, animal husbandry, fishery, and sideline production activities during the study period. It is measured in thousand tons.

Land (LAND) is estimated by the arable land used for farming, forestry, animal husbandry, fishery, and sideline production activities. It is measured in thousand hectares.

[Table 1 about here]

Table 1 provides statistical summary for the total output and inputs of the model.

4. Analysis of Findings

Estimated Results from DEA

DEA models are estimated by using the program DEAP 2.0 (Coelli, 1996). All efficiency measures estimated from the DEA approach and their frequency distributions are summarized in Table 2.

[Table 2 about here]

The estimated mean of technical efficiency (TE) for agricultural production in the sampled provinces in the study period was 82.1% for the VRS DEA model, and 79.3% for the CRS DEA model. In terms of TE, there were only 21 and 14 out of 60 provinces in the sample were fully efficient under the VRS model and the CRS model, respectively. The results imply that most of the sampled provinces were not operating efficiently over the study period.

The scale efficiency index for the provinces varied from 74.8% to 100%, with a sample mean of 96.7%. In terms of scale efficiency, 20 out of 60 provinces exhibited CRS. Among the scale inefficient provinces, 25 provinces showed increasing returns to scale, and 15 provinces show decreasing returns to scale. This means that, in order to achieve full scale of production, these provinces should adjust their inputs for production.

Decomposition of DEA Efficiency Estimates

Since Vietnam experienced different economic fluctuations and policy changes during the period 1990-2005, we divide this period into three sub-periods, i.e. 1990-1996; 1997-1999; and 2000-2005.

In the first sub-period (1990-1996), the economy was on a high growth track with a peak in 1995. Fast growth in this phase could be attributed to the effects of several reforms. Some of the major reforms included the issuance and amendments of laws relating to government budget; state and non-state enterprises, credit and banking, encouragements of domestic and foreign investments; and expansion of trade and financial relations with the international community via negotiations and further liberalizations. In particular, Vietnam joined the Association of Southeast Asian Nations (ASEAN) and ASEAN Free Trade Area (AFTA) in 1995. In addition, since the Donor Conference within the Paris Club framework in 1993, the official development assistance (ODA) resources associated with conditionality has helped promote structural adjustments.

The second sub-period (1997-1999) was the first major challenge to Vietnam's young market economy. The Asian financial crisis, which was originated from Thailand and then expanded to other East Asian countries, led to trade and investment disruptions. The Vietnamese economy was not directly hit by this crisis due to strong capital controls. However, foreign direct investment (FDI) reduction and intensified competition in export markets brought about "real blows" to the economy. The economic growth rate declined sharply in this phase, from 8.2% in 1997 to 5.8 % and 4.8% in 1998 and 1999, respectively (CIEM, 2002).

In the third period (2000-2005), as the financial crisis was dying down, the economy resumed growth momentum in 2000. After laying out the fundamental framework in the previous sub-periods, the reform agenda was focused on structural reforms, including promotion of non-state sector and equitization of the state-owned enterprises (SOEs). The new Enterprise Law enacted in 2000 with more facilitation of business activities for private enterprises has helped promote the private sector. There was rapid growth in the number of newly established enterprises, which were mostly private ones.

[Table 3 about here]

Based on these backgrounds, we decompose DEA efficiency estimates during the study period into DEA efficiency estimates in each sub-period. The estimated results are presented in Table 3 with detailed information of the overall technical efficiency (crste), pure technical efficiency (vrste), and scale efficiency (scale).

The mean values of overall technical efficiency during the period 1990-1996; 1997-1999; and 2000-2005 were 79.3%; 79.1%; and 78.6%, respectively. The minimum values of crste, vrste, and scale during the period 2000-2005 were lowest in comparison with the other two periods.

[Table 4 about here]

The estimates of technical efficiency under the specification of CRS for three sub-periods are shown in Table 4. The mean values of technical efficiency in 1990-1996, 1997-1999, and 2000-2005 were 79.3%; 79.1%; and 78.6 %, respectively. Technical efficiency under CRS was more diverse in two last periods than the first one. One province in 1997-1999 and two provinces in 2000-2005 had technical efficiency measure of less than 40%, which is considerably low.

In addition, there were 14 provinces in 1990-1996; 12 provinces in 1997-1999; and 10 provinces in 2000-2005 that achieved full technical efficiency under CRS.

[Table 5 about here]

The estimates of technical efficiency under the specification of VRS for three sub-periods are presented in Table 5. The mean values of technical efficiency in 1990-1996, 1997-1999, and 2000-2005 were 82.1%; 83.3%; and 78.6%, respectively. Technical efficiency under VRS was also more diverse in 2000-2005 than those of two previous periods. There were two provinces in 2000-2005 that had technical efficiency measure of less than 40%.

There were 21 provinces in 1990-1996; 14 provinces in 1997-1999; and 14 provinces in 2000-2005 that had full technical efficiency measure under the assumption of VRS.

[Table 6 about here]

The estimated results for scale efficiency in the three sub-periods are shown in Table 6. The average scale efficiency measure for the period 1990-1996 (96.7%) was higher than those of 1997-1999 (94.5%) and 2000-2005 (93.1%). It can also be seen that scale efficiency in 2000-2005 was more diverse than those in two previous periods.

The number of provinces with scale efficiency of more than 90% in 1990-1996 was 55, while those of 1997-1999 and 2000-2005 were 46 and 45, respectively.

Detecting the Stability of Efficiency Rankings between Sixty Provinces

The estimated mean values of technical efficiency for some provinces were higher than those of the others in the study period. The question is whether some provinces with higher technical efficiency levels could maintain their relative positions over time in comparison with the provinces with lower technical efficiency levels, and vice versa.

To answer such question, we use rank statistics technique to evaluate efficiency performance trends. In particular, we will investigate whether we can say that, with statistical confidence, all the sampled provinces could maintain constantly their relative positions in the group over the study period. The Kruskal-Wallis non-parametric ANOVA test is applied with following hypotheses.

- ***Hypothesis test 1***: The hypothesis of equivalent distribution of efficiency ranking for the estimated overall technical efficiency (TE) from DEA for 60 provinces;
- ***Hypothesis test 2***: The hypothesis of equivalent distribution of efficiency ranking for the estimated pure technical efficiency (PURE) from DEA for 60 provinces; and
- ***Hypothesis test 3***: The hypothesis of equivalent distribution of efficiency ranking for the estimated scale efficiency (SCALE) from DEA for 60 provinces.

For these hypothesis tests, we use N=60 "populations" (or provinces) simultaneously under investigation with the null hypothesis that these 60 "populations" (each for TE; PURE; and SCALE estimated for each province) have the same distribution of ratings. We compute the Kruskal-Wallis test statistic H. The test statistic is distributed according to a χ^2 distribution with (N–1) degree of freedom. The estimated results are presented in Table 7.

[Table 7 about here]

As can be seen in Table 7, all of the null hypotheses are rejected. Rejections of these null hypotheses help to conclude that some provinces generally could maintain their relative positions of efficiency (TE, PURE, and SCALE) over time. It means that at least one province was consistently technically better or worse than the others. The estimated results (not shown) support this conclusion, as some high-income provinces, such as Hanoi, Hai Phong, Da Nang, and Ho Chi Minh City, had higher mean technical efficiency than that of the whole sample of provinces.

Bootstrapping DEA Estimators

We perform a Monte Carlo simulation to evaluate the performance of bootstrapping the DEA estimator of technical efficiency under the specification of VRS over different time periods. Since the year 1993 marked the implementation of trade liberalization policies, which had substantial impacts on the changes in the agricultural production in Vietnam, we further divide the first sub-period (1990-1996) into 1990-1992 and 1993-1996. The simulation will be conducted with five following samples:

i. the whole sample with 60 provinces during the period 1990-1992;

ii. the whole sample with 60 provinces during the period 1993-1996;

iii. the whole sample with 60 provinces during the period 1997-1999;

iv. the whole sample with 60 provinces during the period 2000- 2005; and

v. the whole sample with 60 provinces during the whole period 1990-2005;

The VRS estimator is considered with the confidence interval of 95 percent. In addition to considering VRS estimator in different periods as above, we also consider some consistency properties of the coverage accuracy of the bootstrap confidence intervals obtained from the LT algorithm.

[Table 8 about here]

The results for the VRS estimator in Table 8 indicate that, for all the sample size, technical efficiencies under VRS after 200 times bootstrap are not too different.

5. Concluding Remarks

This paper estimated technical efficiency for the agricultural production in sixty provinces in Vietnam during the period 1990-2005 by using DEA approach. The estimated results showed that overall technical efficiency, pure technical efficiency, and scale efficiency for the whole sample in the study period were 79.3%; 82.1%; and 96.7%, respectively. In addition, based on different backgrounds of economic fluctuations in Vietnam, we divided the study period into three sub-periods, including 1990-1996; 1997-1999; and 2000- 2005, to estimate technical efficiency levels for the agricultural production of the sampled provinces in these sub-periods. The mean values of technical efficiency in 1990-1996; 1997-1999; and 2000-2005 were 79.3%; 79.1%; and 78.6%, respectively, under the specification of CRS, while they were 82.1%; 83.3%; and 84%, respectively, under the specification of VRS. The estimates indicate that the studied provinces in Vietnam could have been able to improve their agricultural production efficiency.

Using rank statistics technique to detect the stability of efficiency rankings between sixty provinces, we found that some provinces could maintain their relative efficiency positions over time, meaning that at least one province was consistently technically better or worse than the others.

Also, we performed a Monte Carlo simulation to evaluate the performance of bootstrapping the DEA estimator of technical efficiency under specification of VRS over five time periods, i.e. 1990-1992; 1993-1996; 1997-2000; 2000-2005; and 1990-2005. The results show that the mean values of technical efficiency for the whole sample in different periods under DEA with and without bootstraps are not really different. In other words, the estimates of all technical efficiency indices appropriately reflect the real status of the agricultural production efficiency in Vietnam during 1990-2005.

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Table 1: Statistical Summary of Inputs and Output

Year	Obs.	*GVA* (VND Billion)	*L* (1,000 persons)	*TRACTOR* (unit)	*FERTILIZERS* (1,000 tons)	*LAND* (1,000 hectares)
1990	60	35,650	17,674	25,155	748	6,989
1991	60	36,248	18,270	35,412	1,452	6,921
1992	60	39,003	21,854	37,278	1,426	7,214
1993	60	40,499	22,647	45,026	1,449	7,257
1994	60	41,479	23,276	87,188	2,253	7,276
1995	60	43,541	23,901	95,527	2,398	7,276
1996	60	45,774	23,978	108,397	3,038	7,589
1997	60	48,272	24,601	113,117	3,180	7,743
1998	60	50,767	24,869	120,605	3,297	7,973
1999	60	53,518	25,082	143,360	3,462	8,601
2000	60	55,395	25,221	162,246	3,553	9,230
2001	60	56,147	25,426	161,492	3,513	9,391
2002	60	57,891	25,876	167,322	3,437	9,250
2003	60	62,384	26,620	179,670	3,719	9,554
2004	60	63,960	26,550	193,504	3,776	9,648
2005	60	65,928	26,714	201,490	3,791	9,715

Source: Authors' estimates using data from GSO (various years).

Table 2: Frequency distribution of the estimated efficiency measures from DEA

	crste			***vrste***			***scale***			
	Mean	***Std. Dev.***	***Obs.***	***Mean***	***Std. Dev.***	***Obs.***		***Mean***	***Std. Dev.***	***Obs.***
[0.4, 0.6)	0.523	0.057	9	0.525	0.056	8	[0.7, 0.8)	0.748	NA	1
[0.6, 0.8)	0.713	0.051	22	0.723	0.055	19	[0.8, 0.9)	0.848	0.022	4
[0.8, 1)	0.880	0.060	15	0.863	0.032	12	[0.9, 1)	0.968	0.027	36
[1, 1.2)	1.000	0.000	14	1.000	0.000	21	[1, 1.1)	1.000	0.000	19
Mean	0.793	0.167	60	0.821	0.168	60	All	0.967	0.051	60
Maximum	1.000			1.000				1.000		
Minimum	0.455			0.455				0.748		

Source: Authors' estimates using data from GSO (various years).

Table 3. General results of technical efficiencies during sub-periods (1990-1996, 1997-1999, and 2000-2005)

	1990-1996			*1997-1999*			*2000-2005*		
	crste	***vrste***	***scale***	***crste***	***vrste***	***scale***	***crste***	***vrste***	***scale***
Mean	0.793	0.821	0.967	0.791	0.833	0.945	0.786	0.840	0.931
Median	0.780	0.838	0.989	0.801	0.866	0.974	0.820	0.8715	0.958
Maximum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Minimum	0.455	0.455	0.748	0.390	0.480	0.758	0.382	0.451	0.671
Std. Dev.	0.167	0.168	0.051	0.167	0.151	0.062	0.175	0.155	0.078
Observations	60	60	60	60	60	60	60	60	60

Source: Authors' estimates using data from GSO (various years).

Table 4: Distribution of technical efficiency under CRS

	1990-1996			*1997-1999*			*2000-2005*		
Crste	***Mean***	***Std. Dev.***	***Obs.***	***Mean***	***Std. Dev.***	***Obs.***	***Mean***	***Std. Dev.***	***Obs.***
[0.2, 0.4)	0	0	0	0.390	NA	1	0.384	0.003	2
[0.4, 0.6)	0.523	0.057	9	0.542	0.054	9	0.528	0.050	9
[0.6, 0.8)	0.713	0.051	22	0.716	0.060	20	0.714	0.050	17
[0.8, 1)	0.880	0.060	15	0.881	0.059	18	0.887	0.052	22
[1, 1.2)	1.000	0.000	14	1.000	0.000	12	1.000	0.000	10
All	0.793	0.167	60	0.791	0.167	60	0.786	0.175	60

Source: Authors' estimates using data from GSO (various years).

Table 5: Distribution of technical efficiency under VRS

	1990-1996			*1997-1999*			*2000-2005*		
vrste	***Mean***	***Std. Dev.***	***Obs.***	***Mean***	***Std. Dev.***	***Obs.***	***Mean***	***Std. Dev.***	***Obs.***
[0.2, 0.4)							0.384	0.003	2
[0.4, 0.6)	0.525	0.056	8	0.541	0.042	6	0.529	0.050	9
[0.6, 0.8)	0.723	0.055	19	0.718	0.056	17	0.714	0.050	17
[0.8, 1)	0.863	0.0318	12	0.894	0.055	23	0.888	0.052	22
[1, 1.2)	1.000	0.000	21	1.000	0.000	14	1.000	0.000	10
All	0.821	0.168	60	0.833	0.151	60	0.786	0.175	60

Source: Authors' estimates using data from GSO (various years).

Table 6: Distribution of scale efficiency

	1990-1996			***1997-1999***			***2000-2005***		
scale	***Mean***	***Std. Dev.***	***Obs.***	***Mean***	***Std. Dev.***	***Obs.***	***Mean***	***Std. Dev.***	***Obs.***
[0.6, 0.7)							0.671	n.a	1
[0.7, 0.8)	0.748	n.a	1	0.775	0.024	2	0.786	0.009	5
[0.8, 0.9)	0.848	0.022	4	0.843	0.163	12	0.845	0.032	9
[0.9, 1)	0.968	0.027	36	0.940	0.015	34	0.961	0.029	34
[1, 1.1)	1.000	0.000	19	1.00	0.000	12	1.000	0.000	11
All	0.967	0.051	60	0.945	0.062	60	0.931	0.078	60

Source: Authors' estimates using data from GSO (various years).

Table 7: Hypothesis tests for overall, pure and scale efficiency measures

	H	***Critical value*** $\chi^{5}_{N-1}(0.01)$	***Decision***
TE (overall technical efficiency)	567.92	79.08	reject
PURE (pure technical efficiency)	580.23	79.08	reject
SCALE (scale efficiency)	401.11	79.08	reject

Source: Authors' estimates.

Table 8: Bootstrap results and confidence intervals

Sample	θ	***Boot 50***	***Boot 100***	***Boot 150***	***Boot 200***	θ*******	$\left(\hat{\theta}_i^{*(\alpha)}\right)$	$\left(\hat{\theta}_i^{*(1-\alpha)}\right)$	ε
1990-2005	0.793	0.876	0.822	0.808	0.817	0.837	0.835	0.840	0.0023
1990-1992	0.793	0.842	0.828	0.838	0.865	0.839	0.837	0.842	0.0024
1992-1996	0.758	0,827	0.845	0.849	0.831	0.812	0.809	0.814	0.0027
1997-1999	0.791	0.828	0.837	0.852	0.827	0.837	0.834	0.839	0.0022
2000-2005	0.786	0.842	0.837	0.848	0.856	0.830	0.828	0.833	0.0024

Note: θ is original efficiency estimate; θ^* is bootstrapped efficiency estimate; $\left(\hat{\theta}_i^{*(\alpha)}\right)$ and $\left(\hat{\theta}_i^{*(1-\alpha)}\right)$ are respectively bootstrapped efficiency estimate at α=5 percent significance level.

Source: Authors' estimates.