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Regional Differences in Measuring the Technical Efficiency of Rice Production in Vietnam: A Metafrontier Approach

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Abstract

This research study employs bootstrap data envelopment analysis and the metafrontier approach to measure and compare the technical efficiency of rice production activities across the regions of Vietnam. Using the metafrontier approach as a common production technology is more effective when wishing to compare relative technical efficiency levels across regions, those which may employ a variety of production technologies. The results of this study reflect the fact that technical efficiency levels vary more across regions when measured with respect to regional frontiers than when using the metafrontier approach. The study finds technical efficiency scores to be high when using regional frontier measurements, but lower when using the metafrontier approach. When using the metafrontier to adjust differences across regional frontiers, while the Mekong River Delta – the main rice producing region in Vietnam – has the highest efficiency, the Red River Delta – which is the second region in terms of rice production – has quite low efficiency scores when compared to some other regions in the country. One of the key findings of this study is that measuring and comparing the technical efficiency of rice production across different regions should not be carried out for individual regions alone, but for all regions.

Keywords: metafrontier, technical efficiency, data envelopment analysis, bootstrap

1. Introduction

Vietnam is one of the most important rice producers in the world, and its agricultural-based economy depends greatly on the efficiency of rice production activities, which take place throughout the country, including in the following eight regions: the Red River Delta, the northeast, northwest, north central coast, south central coast, central highlands, southeast and the Mekong River Delta. Among these regions, the Red River and Mekong River Delta areas are the two largest rice producing regions, and especially the Mekong River Delta, which contributes over 50% of domestic rice production annually and 90% of rice exports. As a result, it is commonly known as Vietnam's *rice bowl* (Tung, 2013).

In terms of measuring the technical efficiency of rice production in Vietnam, several important studies have been published to date. These studies have measured the technical efficiency of rice production activities, both in specific regions (Huy, 2009; Tung, 2013; Tuong, 2010; Thong et al., 2011) and on a nationwide scale (Minh & Long, 2008). All of these works measured technical efficiency based on either stochastic frontier analysis (SFA) or data envelopment analysis (DEA), or a mixture of the two, and produced some significant results. Among the most relevant studies, Linh (2012) assessed the technical efficiency of rice production activities across all regions. According to his results, the bias-corrected technical efficiency levels within the regions were generally quite high. The lowest average technical efficiency score was obtained in the north central coast, at 0.619, while the Mekong River Delta was the most efficient rice producing region, at 0.710. However, to carry out a comparison of technical efficiency levels across different regions in Vietnam would pose a particular challenge, because regional differences in the rice production technologies applied can lead to biased results.

Over the past decade, many scholars, including Rao et al. (2003), O'Donnell et al. (2008) and Barnes et al. (2011), among others, have argued that agricultural production is usually characterized by regional heterogeneity. Regional differences, as mentioned above, can lead to biased results when comparing technical efficiency levels across regions. Based on the metaproduction function defined by Hayami and Ruttan (1970), Rao et al. (2003)

introduced a metafrontier concept based on separate, regional frontiers, allowing the researcher to exclude regional differences in production technologies when measuring relative technical efficiency levels, and; therefore, produce more solid conclusions.

To exclude regional characteristics, this study uses the metafrontier approach to measure and compare rice production technical efficiency levels across the different regions of Vietnam. The metafrontier approach can be applied when using either SFA or DEA (Rao et al., 2003); however, to estimate the functional relationships between outputs and inputs, SFA requires an assumption to be made on the form of the production function and a distributional assumption regarding the inefficiency term (Coelli, 1995). Different regions may be characterized by varying production technologies and; therefore, SFA may require individual assumptions to be made for each. On the other hand, one of the advantages of DEA is that the method is based a non-parametric technique, so no assumptions about the form of the production technology are required, and this allows the same methodology to be used to measure technical efficiency across different regions.

However, there are also issues to deal with when using DEA, and three of the most common of these are as follows:

(1) Sample size has been identified as an important influence on the performance of various analysis methods, including DEA. Although DEA's advantage when compared to SFA is that DEA can deal with a small sample size (Coelli et al., 1998), many recent studies such as those by Alirezaee et al. (1998), Zhang and Bartels (1998), Staat (2001), and Andor and Hesse (2011), have proved that sample size variations may lead to biased technical efficiency scores. Specifically, Alirezaee et al. (1998) argued that when the number of decision-making units (DMU) is small, the number of dominant units or efficient sets will be relatively large and the average efficiency; therefore, generally high. Furthermore, two important conditions need to be in place when using DEA, and these are sample size related, as follows: (1) the number of DMU should be greater than the combined number of inputs plus outputs (Cooper et al., 2000), and (2) the sample size is only acceptable if the number of fully efficient DMUs is no greater than one-third of the total number of DMUs in the sample (Manzoni & Islam, 2009).

(2) DEA is sensitive to outliers. Outliers are observations that do not fit the pattern of the remaining data points and are not at all typical of the rest of the data set (Gunst & Mason, 1980). The frontiers in DEA are constructed using extreme points, and; therefore, this method can be sensitive to extreme observations, or outliers. Measurement errors for these observations might; therefore, cause distortions in the efficiency measures across the entire population (Wilson, 1995);

(3) Since DEA is based on a non-parametric technique, it has been criticized for lacking statistical power. Simar and Wilson (2007) showed that DEA efficiency estimates are serially correlated, especially in the two-stage DEA, and that standard approaches used for inference are; therefore, invalid. To take account of this, Simar and Wilson (2007), and other authors, have promoted using a bootstrap method to estimate bias-corrected efficiency scores.

Following the results of the literature review above, and taking into account the challenges described, the objective of this study is to assess regional differences when measuring the technical efficiency of rice production activities across different parts of Vietnam using the metafrontier approach combined with DEA.

To compare differences in technical efficiency levels based on a comparison of regional frontiers and using the metafrontier approach, the H_0 hypothesis of this study is: There is no difference in the technical efficiency levels revealed when using either the regional frontier or metafrontier approach.

Using DEA, the values obtained from the sample were bootstrapped in order to detect and remove potential outliers, as outlined above. Section 2 of this study will give a summary of the methods and data used in the study, Section 3 will describe the results, and Section 4 will provide the conclusion.

2. Methods and Data

2.1 Data Envelopment Analysis (DEA)

Farrell (1957) illustrated the concept of efficiencies using the example of a firm whose work process has two inputs (x_1, x_2) and one output (q), and based on an assumption of constant returns to scale (CRS). Figure 1 shows the technical efficiency based on an *input-oriented measure,* which measures the ability of a firm to reduce inputs without changing outputs. Technical efficiency is determined by comparing the actual production set (point P) and the fully-efficient production set (point Q), Q being a point which lies on the isoquant SS'. Then, technical efficiency (TE) is measured using the ratio TE = 0Q/0P, with the resulting TE values falling between zero and one. The distance QP represents technical inefficiencies, and inputs can be reduced without changing the outputs. The alternative approach, known as the *output-oriented measure*, measures the ability of a firm to increase outputs without changing inputs. However, only the *input-oriented measure* is described and used in this study.

To measure technical efficiency, DEA models can either assume constant returns to scale (CRS) or variable returns to scale (VRS). While with DEA, the CRS assumption is only appropriate when a firm is operating on an optimal scale, the VRS assumption allows the technical efficiency of firms operating at a sub-optimal level to be measured (Coelli et al., 1998), a scenario more common in reality.

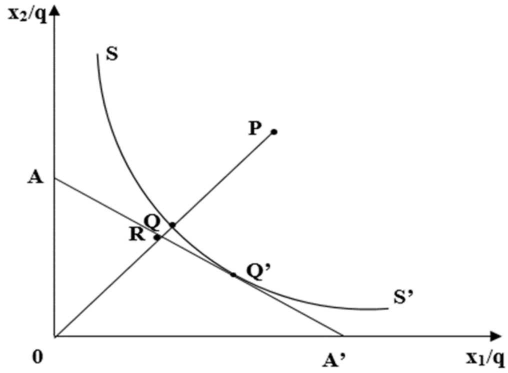

Figure 1. Technical and Allocative Efficiencies

Source: Coelli et al. (1998).

Let us assume the production set includes K inputs and M outputs in each of the I decision units (say firms). Based on this, x_i is the $K \times 1$ vector of inputs for the i-th firm, q_i is the $M \times 1$ vector of outputs from the i-th firm, X is a $K \times I$ input matrix and Q is an $M \times I$ output matrix. The envelopment forms of the input-oriented VRS DEA can be specified as:

$$\min_{\theta,\lambda} \theta,$$

$$\text{Subject to} \quad -q_i + Q\lambda \geq 0,$$

$$\theta x_i - X\lambda \geq 0,$$

$$N1'\lambda = 1,$$

$$\lambda \geq 0.$$

Where

θ is a scalar (TE), $0 \leq \theta \leq 1$ and λ is a $I \times 1$ vector of constants.

2.2 Bootstrapping DEA

To avoid bias in the results when using DEA to calculate efficiency scores, Simar and Wilson (1998), based on the work of Efron (1979), proposed using the bootstrapping strategy to analyze the sensitivity of efficiency measures to sampling variations, by providing confidence intervals and corrections for the bias inherent in the DEA procedure. Generally bootstrapping follows the following basic steps:

1) Construct an empirical probability distribution of the sample;

2) Resample the data set by a specified number of times;

3) Calculate the specific statistic from each sample;

4) Find the standard deviation of the distribution of that statistic.

2.3 Metafrontier

DEA allows a researcher to estimate the production frontier for a group of firms with similar production technology sets. Let us assume that groups are similar to regions in the country. Because of the different production environment characteristics, different regions may have different production technology sets; therefore, comparisons between regions will only be meaningful if the frontiers of different regions are similar. Based on the metaproduction function concept defined by Hayami and Ruttan (1970), Rao et al. (2003), and then

O'Donnell et al. (2008) introduced the concept of a metafrontier or metatechnology, to represent the totality of regional technologies.

To illustrate, let us say the metafrontier M in Figure 2 is determined by three regional frontiers: k1, k2 and k3. If point A is an observation for region k3, then:

The technical efficiency of A in region k3 is: $TE_A^{k3} = \frac{PB}{PA}$;

The technical efficiency of A in all regions (meta) is: $TE_A^{*} = \frac{PC}{PA}$;

The metatechnology ratio for A is: $MTR_A = \frac{TE_A^{*}}{TE_A^{k3}} = \frac{PC/PA}{PB/PA} = \frac{PC}{PB}$

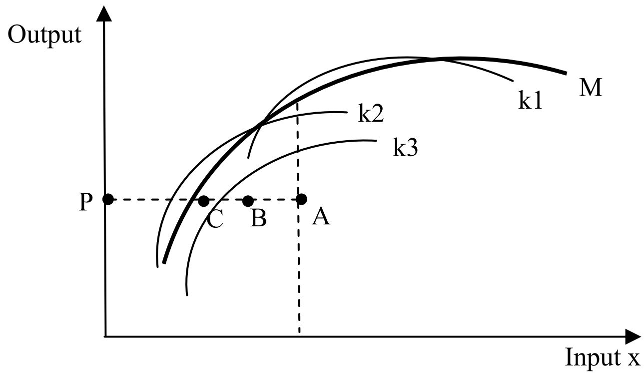

Figure 2. Regional frontiers and the metafrontier

Source: Re-illustrated from O'Donnell et al. (2008).

Differences in technical efficiency between groups (regions) can be measured using the following steps:

1) For group (region) frontiers (K), by using DEA to analyze the data sets (x, y) obtained from observations within a region: $TE^K(x, y)$

2) For metafrontier, by using DEA to analyze the data sets (x, y) obtained by pooling all the observations from all the regions: $TE^*(x, y)$

3) By calculating the metatechnology ratios (MTR) between group frontiers and metafrontiers:

$$MTR^k(x,y) = \frac{TE^*(x,y)}{TE^k(x,y)}$$

2.4 Data

To measure the technical efficiency of rice production activities across Vietnam, this study uses a data set taken from the Vietnam Household Living Standards Survey (VHLSS) for 2010. These surveys are carried out nationwide by the Vietnam General Statistics Office (GSO) every two years, and began in 2002. To prepare the data for analysis, the following steps were taken:

- Step 1: After dropping households which do not grow rice, the number of observations left included 4,367 households located in eight regions. However, the southeast region had only 132 households which satisfy all the characteristics.

- Step 2: An *ap* function was used within the FEAR package, as described in Wilson (1993) and corrected in Wilson (2010), as a tool to detect outliners for non-parametric frontier models. As a result, two suspect outliers were detected and removed in the southeast region, as per the methodology. The number of observations remaining in the southeast region was 130.

- Step 3: To avoid bias due to sample size differences when using DEA, the number of observations randomly chosen for each region was 140. These observations then had the *ap* function applied in order to remove 10 suspect outliers. Finally, each region was left with 130 observations, giving a total of 1,040 observations for the country as a whole.

For each observation there are 6 inputs (land area, family labor, seeds, fertilizers, pesticides and others) and 1 output (rice quantity) related to rice production, as described in Appendix Table 1.

To compute the Farrell bootstrapped technical efficiency of each regional frontier and metafrontier, this study employs the *boot.fear* function found in the Benchmarking package (version 0.23 by Bogetoft and Otto (2013) in R platform) to bootstrap technical efficiency values over 2,000 replications, and with an alpha value of 0.05 used to estimate the statistical size of each confidence interval.

3. Results

Firstly, paired-sample t-tests (at 95% confidence intervals) were conducted to test the H_0 hypotheses, by comparing the technical efficiency scores when measured with respect to regional frontiers and against the metafrontier, using variable returns to scale as described in the last column of Table 1. The two-tailed p-values were at the levels to reject the null hypothesis in most regions. Except for the South Central Coast region, significant differences can be seen in the technical efficiency scores for the regional frontiers and the metafrontiers. Furthermore, and as expected, the technical efficiency scores of each region are higher when measured against their regional frontier, but lower when measured against the metafrontier (Rao et al., 2003).

Table 1. Differences in the bias-corrected technical efficiency scores when using the regional frontier and metafrontier approaches with input-oriented DEA

	CRS			VRS			Two-tailed p-value
	TE*	TE^K	MTR	TE*	TE^K	MTR	
Red River Delta	0.540	0.757	0.713	0.550	0.777	0.707	0.000
Northeast	0.478	0.617	0.775	0.485	0.680	0.712	0.009
Northwest	0.383	0.529	0.724	0.384	0.584	0.658	0.000
North Central Coast	0.475	0.633	0.750	0.483	0.669	0.722	0.002
South Central Coast	0.530	0.694	0.764	0.532	0.721	0.739	0.422
Central Highlands	0.431	0.478	0.903	0.435	0.522	0.834	0.000
Southeast	0.473	0.510	0.928	0.472	0.599	0.787	0.000
Mekong River Delta	0.542	0.589	0.921	0.533	0.637	0.837	0.000

Note. CRS: Constant Returns to Scale, VRS: Variable Returns to Scale, TE^K: Regional frontier, TE^*: metafrontier, and MTR: metatechnology ratio. Two-tailed p-values were used to test the differences between TE^K and MTR values, using variable returns to scale.

The first region that should be mentioned is the Mekong River Delta – the largest rice production region in the country. In a recent article by Tung (2013), the bias-corrected-technical efficiency score produced after 1,000 observations made in this region in 2010 was 0.606. Based on the assumptions made here, in this study the value obtained when measuring the Mekong River Delta's regional frontier is 0.637 (TE^K).

The results of this study are consistent with the arguments mentioned above, that when the number of DMUs is small (130 as compared to 1,000 observations), the number of dominant units or efficient sets will be relatively large and the average efficiency generally high. However, there exists another issue. In comparison with other regions, rice production activities in the Mekong River Delta are less efficient than those in the Red River Delta, the north central coast, the south central coast and even in the mountainous regions of the northeast. These results conflict with the current thinking, that the Mekong River Delta is Vietnam's rice bowl and has an absolute advantage over other regions in terms of rice production.

These suspect results were; therefore, recalculated using the metafrontier. After measuring technical efficiency against the metafrontier and calculating the MTR values, the results are reasonable. The resulting MTR value for the Mekong River Delta is 0.837, the first-ranked among all the regions.

Similarly, other regions, excluding the Red River Delta, receive higher technical efficiency scores when measured against the metafrontiers instead of their regional frontiers. The central highlands region is a typical case; using its regional frontier and a VRS assumption, the efficiency of rice production activities here is low at 0.522, but when measured against the metafrontier, the MTR value is 0.834.

In contrast, technical efficiency in the Red River Delta, when measured against its regional frontier, is quite high at 0.777; however, its MTR value is lower when including the metafrontier, at 0.707. The technical efficiency score for this region is also quite low, being only higher than one other region - the northwest, though it is only slightly lower than its neighboring region, the northeast.

As mentioned in the introduction section, Linh (2012)'s study is among relevant studies assessed the technical efficiency of rice production activities across all regions. That study produced a bias-corrected technical efficiency score for the Mekong River Delta of 0.710, while the same region's technical efficiency score in this study is lower, at 0.637. Although in Linh (2012)'s study this region produced the highest score among all the regions, the reliability of the results may have been compromised by the first issue regarding the sample size. The proportion of farms with TE scores equal to one (fully efficient DMUs) in that study was greater than one-third, a result found in five of the eight regions (Linh, 2012, p. 18). This means that the technical efficiency scores in Linh (2012)'s study may have been biased and may have resulted in inconsistent technical efficiency scores being produced across regions.

4. Conclusion and Discussion

This study uses the concept 'metafrontier DEA' to measure the technical efficiency of rice production activities across the regions of Vietnam. Using metafrontier as a production technology measure is better suited to a comparison of relative technical efficiency levels across regions, which may vary according to the general production environment and also the use of technology. Furthermore, using the bootstrapping technique, and a sample with outliers removed, avoids bias in the results. One of the key findings of this study, is the variation in technical efficiency scores produced when calculated using the regional and metafrontier approaches, a result which reflects differences in the technical efficiencies of the regions. Another key finding is that using DEA to measure and compare rice production efficiency levels, while taking into account related government policies, should not be carried out one region at a time, but for all regions.

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Appendix

Appendix Table 1. Summary statistics for the study variables

Region	Number of observations	Mean	Standard deviation	Minimum	Maximum
Red River Delta					
Output	130	8,494	6,526	630	38,055
Area	130	16,112	11,486	1,512	66,384
Family labor	130	14,732	13,119	0	67,841
Seed	130	325	273	16	1,467
Fertilizer	130	1,355	955	96	4,900
Pesticides	130	452	443	20	2,500
Others	130	1,544	1,167	159	6,505
Northeast					
Output	130	6,876	4,609	120	21,500
Area	130	15,015	9,604	756	53,200
Family labor	130	11,623	9,532	357	50,479
Seed	130	307	219	25	995
Fertilizer	130	1,062	710	13	3,220
Pesticides	130	147	140	0	600
Others	130	781	608	0	3,150
Northwest					
Output	130	6,800	5,772	570	27,805
Area	130	21,595	19,233	1,900	118,586
Family labor	130	12,707	8,556	888	38,763
Seed	130	457	353	0	1,770
Fertilizer	130	780	727	0	3,160
Pesticides	130	147	141	0	700
Others	130	990	989	0	5,175
North Central Coast					
Output	130	11,580	10,694	500	58,300
Area	130	24,980	20,693	1,500	112,178
Family labor	130	13,907	10,713	608	50,878
Seed	130	482	379	0	1,600
Fertilizer	130	1,681	1,412	0	6,850
Pesticides	130	251	255	0	1,330
Others	130	1,695	1,698	0	7,850
South Central Coast					
Output	130	10,072	7,477	636	32,640
Area	130	19,522	12,646	2,800	60,000
Family labor	130	12,362	10,541	0	57,870
Seed	130	387	252	35	1,170
Fertilizer	130	1,418	1,077	0	4,915
Pesticides	130	242	194	0	880
Other	130	1,406	1,057	0	4,592
Central Highlands					
Output	130	9,606	7,797	600	37,600
Area	130	25,485	19,987	2,400	97,800

Family labor	130	9,261	8,579	0	49,018
Seed	130	527	447	0	2,700
Fertilizer	130	1,144	1,277	0	6,100
Pesticides	130	216	240	0	1,460
Others	130	891	1,012	0	5,380
Southeast					
Output	130	27,392	29,441	2,400	168,000
Area	130	60,876	59,115	5,000	405,000
Family labor	130	11,668	8,366	0	38,280
Seed	130	1,461	1,374	0	7,600
Fertilizer	130	4,705	4,367	188	20,700
Pesticides	130	1,395	1,590	50	7,000
Others	130	4,214	4,822	0	30,830
Mekong River Delta					
Output	130	43,818	43,147	1,000	332,400
Area	130	84,610	78,397	3,275	528,000
Family labor	130	12,533	10,269	270	57,465
Seed	130	1,676	1,683	0	8,000
Fertilizer	130	5,754	5,492	160	36,140
Pesticides	130	2,855	3,904	0	29,040
Others	130	6,166	6,378	80	46,800

Source: GSO (2010).

- *Output* (Kg) measured by the quantity of rice produced.

- *Area* (square meters) means the households' total rice growing area.

- In the VHLSS, households were asked to name each source of income, including income from rice production, other farming and non-agricultural activities. Furthermore, the VHLSS collected information on how the households divide their working hours between farming and non-farming activities. Unfortunately, there was no information available on *family labor used for rice production* in VHLSS. *Family labor used for rice production* (in hours) was; therefore, calculated based on *family labor used for farming* multiplied by *the income from rice as a proportion of total farming income*.

Seeds (1,000 VND), fertilizers (1,000 VND - including chemical and organic fertilizers bought or made on the farm), pesticides (1,000 VND) and others (1,000 VND - including equipment and tools, energy, maintenance, depreciation, rent, irrigation fees, taxes, interest and other costs for rice production) are shown per annum, taking into account the seasons.

Appendix Table 2. Technical efficiency and bias-corrected technical efficiency scores using the input-oriented DEA

Region	Technical efficiency	Bias-corrected-technical efficiency			
	Mean	Mean	Standard deviation	Minimum	Maximum
Red River Delta					
TE^{*}_{CRS}	0.579	0.540	0.100	0.222	0.773
TE^{K}_{CRS}	0.789	0.757	0.122	0.320	0.970
MTR_{CRS}	0.734	0.713			
TE^{*}_{VRS}	0.601	0.550	0.104	0.217	0.823
TE^{K}_{VRS}	0.822	0.777	0.115	0.369	0.964
MTR_{VRS}	0.731	0.707			
Northeast					
TE^{*}_{CRS}	0.505	0.478	0.106	0.049	0.886
TE^{K}_{CRS}	0.662	0.617	0.144	0.065	0.891
MTR_{CRS}	0.763	0.775			
TE^{*}_{VRS}	0.526	0.485	0.093	0.258	0.732
TE^{K}_{VRS}	0.739	0.680	0.126	0.352	0.923
MTR_{VRS}	0.711	0.712			
Northwest					
TE^{*}_{CRS}	0.403	0.383	0.155	0.100	0.758
TE^{K}_{CRS}	0.576	0.529	0.193	0.181	0.909
MTR_{CRS}	0.700	0.724			
TE^{*}_{VRS}	0.415	0.384	0.152	0.095	0.758
TE^{K}_{VRS}	0.661	0.584	0.195	0.197	0.888
MTR_{VRS}	0.628	0.658			
North Central Coast					
TE^{*}_{CRS}	0.500	0.475	0.139	0.070	0.963
TE^{K}_{CRS}	0.675	0.633	0.183	0.096	0.955
MTR_{CRS}	0.741	0.750			
TE^{*}_{VRS}	0.522	0.483	0.132	0.096	0.954
TE^{K}_{VRS}	0.734	0.669	0.175	0.181	0.922
MTR_{VRS}	0.711	0.722			
South Central Coast					
TE^{*}_{CRS}	0.560	0.530	0.147	0.080	0.900
TE^{K}_{CRS}	0.719	0.694	0.177	0.102	0.985
MTR_{CRS}	0.779	0.764			
TE^{*}_{VRS}	0.574	0.532	0.146	0.105	0.887
TE^{K}_{VRS}	0.771	0.721	0.154	0.229	0.943
MTR_{VRS}	0.744	0.739			
Central Highlands					
TE^{*}_{CRS}	0.460	0.431	0.179	0.121	0.873
TE^{K}_{CRS}	0.528	0.478	0.202	0.129	0.948
MTR_{CRS}	0.872	0.903			
TE^{*}_{VRS}	0.474	0.435	0.176	0.131	0.890
TE^{K}_{VRS}	0.608	0.522	0.190	0.137	0.881
MTR_{VRS}	0.780	0.834			

Southeast					
TE^{*}_{CRS}	0.515	0.473	0.135	0.100	0.882
TE^{K}_{CRS}	0.572	0.510	0.142	0.094	0.872
MTR_{CRS}	0.900	0.928			
TE^{*}_{VRS}	0.529	0.472	0.130	0.126	0.795
TE^{K}_{VRS}	0.675	0.599	0.146	0.237	0.908
MTR_{VRS}	0.784	0.787			
Mekong River Delta					
TE^{*}_{CRS}	0.592	0.542	0.145	0.216	0.869
TE^{K}_{CRS}	0.636	0.589	0.155	0.242	0.887
MTR_{CRS}	0.931	0.921			
TE^{*}_{VRS}	0.614	0.533	0.133	0.211	0.834
TE^{K}_{VRS}	0.707	0.637	0.139	0.268	0.911
MTR_{VRS}	0.869	0.837			