A stochastic frontier approach to measuring regional technical efficiency in China

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Abstract

This paper applied a stochastic translog production function to examine the underlying causes of technical inefficiency for 28 provinces in the mainland China over the period 1970-2004. We found that inefficiency was present in production and several relevant explanatory variables contributed to it. Specifically we found that the provinces with higher level of human capital, higher engagement in international trade, and further relaxation of the household registration system (*hukou* system) and a smaller government size tended to lie closer to the national frontier. In addition, we found that public infrastructure was not productive and we found no evidence to support the general view that state-owned enterprises (SOEs) were operating relatively inefficiently as compared to the non-SOEs.

Key words: Stochastic production frontier Hypothesis testing Panel data
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1. INTRODUCTION

Since the start of its economic reform and open-door policy in 1978, China has achieved stunning economic growth. The growth, however, has not been distributed evenly across the landscape. The unevenness of growth is due, largely, to the rising disparities in production efficiency (Hu, 1996). There were several factors including government policies that have affected production efficiency. These policies, among others, include: the economic reforms in the late 1970s aimed to attract investments from abroad, the reform of state-owned enterprises launched in 1997 purporting to reduce state intervention in production and to increase production efficiency, the reforms of the household registration (*hukou*) system implemented in the late 1990s in order to allow free migration between cities and countryside, and the Western China Development Program started in 2000 to promote economic development of the least efficient western regions in China.

Lovell (1993) defines productivity of a production unit as the ratio of its output to its inputs. According to him, productivity differences are due to three different resources: difference in production technology, difference in the efficiency of the production process, and difference in the environment in which production occurs. Among these sources this study focuses on the contribution of the technical efficiency to provincial productivity using 28 Chinese provinces as units of production in the period 1970-2004.

The efficiency of a production unit is the ratio between the actual and the maximum feasible output from given inputs. This paper assumes that there exists an idealized national production frontier ("best practice" frontier) and any departures from the frontier are considered to be due to either a realization of inefficiency or a random shock. Observations staying on the frontier hence means that the economy agents most efficiently allocated existing resources to produce its goods and services, while observations staying off the frontier indicates that the economy agents wasted some of available resources in production.

Econometrically, several approaches can be applied to measure technical efficiency, which include the nonparametric data envelopment analysis (DEA) and the parametric stochastic frontier approach (SFA). This paper utilizes the parametric SFA which allows for decomposing the error term into two components: the inefficiency term and the random error terms. The DEA approach suffers from two major criticisms (Lovell, 1993; Coelli et al., 1998). First, the DEA approach assumes away measurement error, which implies that all deviations from the frontier are solely due to the inefficiency. Therefore, by making such assumption, the DEA approach leads to an upward bias in estimation of the inefficiency. Second, as a nonparametric technique, it is difficult to conduct statistical hypotheses tests regarding the existence of inefficiency and the structure of the production technology (Coelli et al., 1998). In light of these two limitations of the DEA approach, this study uses the SFA to model for the cross sectional and time series data in this study.

The first objective of this paper, thus, is to employ the SFA to examine the technical efficiency performance for the 28 provinces (including three municipalities, Beijing, Tianjin, and Shanghai) in the mainland China from 1970-2004. To the best of the author's knowledge, this paper is the first provincial level study of China to estimate production inefficiency using the Battese and Coelli's (1995) model, which allows technical inefficiency to vary over time, and allows for inefficiency to depend on set of covariates. The second objective of this paper is to explore the effects of several reform-related policy variables on production.

The remainder of this paper is structured as follows. Section 2 presents the theoretical stochastic frontier model for efficiency analysis. Section 3 specifies the empirical model and discusses several hypothetical factors that may explain differences in productive efficiency across provinces. Section 4 provides a description of the data. Section 5 presents results. The final section summarizes the key findings and attempts to draw a number of implications for public policy.

2. THEORETICAL MODEL

Following the pioneering work developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) where the stochastic frontier models are designed for cross-sectional data, Battese and Coelli (1995) extended their model by incorporating inefficiency effects into the stochastic production frontier for panel data. This paper adopts the extended model of BATTESE and COELLI, 1995, where the inefficiency effects are specified as an explicit function of a set of explanatory variables[1]. Specifically the panel specification of the stochastic frontier production function is modeled as:

$$Y_{it} = f(X_{it};\beta)\exp(\varepsilon_{it}) = f(X_{it};\beta)\exp(V_{it} - U_{it}),\ i = 1, 2, \ldots, N \quad t = 1, 2, \ldots, T \tag{1}$$

where Y_{it} is the gross output for province i at time t; X_{it} is a vector of inputs for province i at time t; β is a vector of unknown parameters to be estimated; ε_{it} is the error term which consists of two mutually independent components, V_{it}s and U_{it} and both are independent of X_{it}. V_{it}s are further assumed to be independently and identically distributed (*i.i.d*) random variables with V_{it}s $\sim N(0, \sigma_v^2)$, while $U_{it}s$ are nonnegative random variables that account for technical inefficiencies in production. i.e., U_{it}s are assumed to be independently normally distributed with $U_{it} \sim N^+(z_{it}\delta, \sigma_u^2)$ that are truncated at zero.

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[1] Wu (2000) applied a stochastic production frontier model to examine productivity growth for 27 provinces in China during 1981–1995. He uses smaller sets of inputs in his translog production function than us, and does not consider characteristics that correlate with inefficiency as we do

The technical inefficiencies (U_{it}) in equation (1) can be specified as:

$$U_{it} = z_{it}\delta + W_{it} \qquad (2)$$

where z_{it} are explanatory variables that explain the level of technical inefficiency of production, δ is vector of parameters to be estimated, W_{it} is defined by the truncation of the normal distribution with mean zero and variance σ_u^2, such that the point of truncation is z_{it}.

A number of studies (Page, 1981; Pitt and Lee, 1981; Kalirajan, 1981; Kalirajan and Shand, 1985; Jaforullah, 1999) have estimated the production frontier (equation (1)) and the determinants of technical inefficiency (equation (2)) separately. According to their two-stage procedure, the production frontier is first estimated and then the technical inefficiencies are derived. These predicted inefficiencies are subsequently regressed upon a set of firm (or industry, or farm) specific variables (z_{it}) in an attempt to determine reasons for differing efficiencies. Apparently their two-stage estimation procedure suffers from a fundamental contradiction as the inefficiency effects (or scores) are derived under the assumption that they are *i.i.d* in the first stage, while in the second stage the predicted inefficiency scores are assumed to be a function of several firm (or industry) specific factors, which implies that they are not identically distributed unless all the coefficients of the factors are simultaneously equal to zero (Coelli et al. 1998). In addition, using Ordinary Least Squares (OLS) in the second stage regression fails to capture the fact that the dependent variable (U_{it}) is restricted to be nonnegative. The two-stage procedure is unlikely to provide estimates which are as efficient as those that are obtained from the one-step estimation procedure (Coelli, 1996). For these reasons, the Battese and Coelli (1995) model is, therefore, applied in this study and allows for a simultaneous estimation of the parameters of the stochastic frontier and the inefficiency model using the single-stage, maximum-likelihood estimation (MLE) method. The likelihood function is expressed in terms of the variance parameter σ^2 and γ, where $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$. Namely, σ^2 measures the total variance of the composed error term (ε_{it} or V_{it} - U_{it}) and γ denotes the relative importance of the two errors.

The technical inefficiency for the province *i* at time *t* is:

$$TE_{it} = \frac{Y_{it}}{Y_{it}^*} = \frac{F(X_{it};\beta)\exp(V_{it} - U_{it})}{F(X_{it};\beta)\exp(V_{it})} = \exp(-U_{it}) = \exp(-z_{it}\delta - W_{it}) \tag{3}$$

where Y_{it} is the observed output and Y_{it}^* is the frontier output. The prediction of technical inefficiency is based upon the conditional expectation: $E(TE_{it}) = E(exp(-U_{it})|\varepsilon_{it})$. The details on the derivation of the MLE function and inefficiency predictions for each province at given period can be found in Battese and Coelli (1993). The econometric computation was performed using software package FRONTIER 4.1 (Coelli, 1996).

3. EMPIRICAL MODEL

This paper considers equation (1) as the translog production function and tests it against the restricted Cobb-Douglas functional form. Such flexible functional form provides a second order approximation to an unknown production function (Christensen et al., 1973). Specifically the translog production function has the following form:

$$\begin{aligned} \ln(PGDP_{it}) = \beta_0 + \beta_1 \ln(K_{it}) + \beta_2 \ln(L_{it}) + \beta_3 \ln(H_{it}) + \beta_4 T + \beta_5 \ln(K_{it})^2 + \beta_6 \ln(L_{it})^2 \\ + \beta_7 \ln(H_{it})^2 + \beta_8 T^2 + \beta_9 \ln(L_{it})\ln(K_{it}) + \beta_{10} \ln(L_{it})\ln(H_{it}) + \beta_{11} \ln(L_{it})T \\ + \beta_{12} \ln(K_{it})\ln(H_{it}) + \beta_{13} \ln(K_{it})T + \beta_{14} \ln(H_{it})T + (V_{it} - U_{it}) \end{aligned} \tag{4}$$

where **PGDP** represents provincial GDP, **K** and **L** measure physical capital and labor, respectively, **H** denotes human capital, **T** is time trend which is included as an additional input to capture the technological change over time.

Both the test for Cobb-Douglas specification versus the translog production model and the test for the presence of time trend are conducted using the generalized likelihood-ratio (LR) test, which is defined as:

$$LR = -2[L_R - L_U]$$

where L_R and L_U are the log-likelihood functions of the restricted model and the unrestricted model, respectively. The LR test statistic follows a chi-squared distribution with degree of freedom equal to the number of restrictions.

We conjecture that inefficiencies (U_{it}) from equation (4) are linked with such key factors as human capital (**H**) (Huffman, 1977; Benhabib and Spiegel, 1994; Adkins et al., 2002), road density variables as measured by route length of highways (**HIGHWAY**) and railways (**RAILWAY**), and degree of openness measured by foreign direct investment (**FDI**) (Yao and Zhang, 2001; Fleisher and Chen, 1997). In addition, the following factors are considered to be important to explain deviations of provincial output from its national frontier.

Hukou System (**URBAN**): The household registration system (*hukou* system) was implemented in the 1950s to prevent labor and capital migrating from the countryside to the cities. The *hukou* system created distortions that deterred the development of labor market, consequently leading to inefficient allocation of labor (Cai et al., 2002; Au and Henderson, 2004). As a result of imbalanced labor allocation between rural and urban areas, China had the highest proportion of agricultural labor with lowest labor productivity in agriculture compared to its benchmark countries (Cai et al., 2002). Meanwhile, restriction on labor migration by the *hukou* system leads to non-optimal city sizes as well (Au and Henderson, 2004), which potentially limits the strength of Jacobs externalities (Jacobs, 1969), a major source of agglomeration externalities contributing to regional economic growth. To capture the efficiency effect of *hukou* system on production, the variable **URBAN,** measured as the percentage of population who were classified as urban residents, is used and expected to increase efficiency (i.e., the sign on **URBAN** is expected to be negative in the technical inefficiency equation).

Size of State-owned Enterprises (**SOE**)**:** The performance of state-owned enterprises (SOEs) has been a hot debate topic since China's enterprise reform initiated in the earlier 1980s. Some studies find evidence that there were substantial improvements in productive efficiency in China's SOEs during the 1980s (Chen et al., 1988; Jefferson and Rawski, 1994), whereas Chen and Feng (2000) find the opposite. Empirical studies by Raiser (1997), Bouin (1998) and Diwan and Chen (1999) find that SOEs performed poorly in the 1990s. The general consensus appears to be that the SOEs are operating inefficiently as compared to the non-SOEs due to the separation of ownership and control, the soft-budget constraint and other problems (Lin and Tan, 1999). Therefore, the variable **SOE**, the share of state owned enterprises in the total provincial GDP, is applied to be a proxy variable for size of SOEs and is expected to have a positive sign, as **SOE** is expected to increase inefficiency in the inefficiency model.

Government Size (**GOVT**): Government expenditure share (**GOVT**), measured as a share of provincial governmental consumption expenditure to provincial GDP, is used as a proxy variable for government size. In theory, the relationship between government expenditures and economic output is ambiguous. In empirical studies, Ram (1986), Holmes and Hutton (1990), Aschauer (1989) and Devarajan et al. (1996), find positive relationship between government expenditures and growth. On the contrary, Grier and Tullock (1989), and Barro (1990) find the opposite. Hence, the sign on **GOVT** in the technical inefficiency model is not predicted.

Region-Specific Effects (**COASTAL, NORTHEAST, CENTRAL, and WESTERN**): The explanatory variables as proposed in the inefficiency equation may be quite limited. Hence, it is necessary to include three dummy variables (**COASTAL**, **CENTRAL**, and **WESTERN**) to control for unobserved regional heterogeneity because region-specific characteristics not captured by the aforementioned explanatory variables may affect the efficiency of a province categorized in that region. Previous empirical studies find evidence that coastal regions operate relatively more efficiently than western regions and central regions (Tong, 1997; Shiu, 2002; Yang, 2002).

With all the variables defined, the technical inefficiency model (equation (2)) then can be estimated by:

$$U_{it} = \delta_0 + \delta_1 URBAN_{it} + \delta_2 HIGHWAY_{it} + \delta_3 RAILWAY_{it} + \delta_4 H_{it} + \delta_5 FDI_{it} + \delta_6 SOE_{it}$$
$$+ \delta_7 GOVT_{it} + \delta_8 COASTAL_{it} + \delta_9 CENTRAL_{it} + \delta_{10} WESTERN_{it} + \delta_{11} T \tag{5}$$

Three tests are constructed under such specification. The first tests the null hypothesis H_0: $\gamma = \delta_0 = \delta_1 = ... = \delta_{11} = 0$. In other words, it tests whether inefficiency effects are absent from the model. The second test is to identify whether the inefficiency effects are a linear function of the explanatory variables by testing the null hypothesis H_0: $\delta_0 = \delta_1 = ... = \delta_7 = 0$. The third test is performed to test the null hypothesis (H_0: $\delta_8 = \delta_9 = \delta_{10} = 0$) that there are no region-specific efficiency effects.

4 DATA AND VARIABLES

The data set for this empirical analysis consists of a panel of 28 provinces (including three municipalities, Beijing, Tianjin, and Shanghai) covering the period 1970-2004 in mainland China. Hainan and Tibet are excluded from the sample due to the data availability. The dependent variable in the production function is provincial output (**PGDP**), measured by real provincial gross domestic product (using 1978 as the basis year). Production involves using three factor inputs, which are labor employment (**L**), per capita physical capital (**K**), and human capital (**H**). In the technical inefficiency model, **URBAN** is defined as the percentage of provincial population who were classified as urban residents. **HIGHWAY** (**RAILWAY**) is measured by the mileages of highway (railway) per squared kilometer. **FDI** is the ratio of provincial foreign direct investment to **PGDP**. **GOVT** is the percentage of provincial governmental consumption expenditure to **PGDP**. Data for **PGDP**, **K**, **L**, and the determinants that explain technical efficiency (**URBAN**, **HIGHWAY**, **RAILROAD**, **FDI**, **GOVT**) are taken from the China Center for Economic Research (CCER) database[2]. The CCER database covers a panel of data until year 1999 and was compiled mainly from several Chinese official publications by National Statistical Bureau such as *Statistical Yearbook of China*, *Population Yearbook of China*, *Comprehensive Statistical Data and Materials on 50 Years of New China*, and *Compilation of 50 Years Statistics Data of China Industry, Traffic and Energy (1949-1999)*. We expanded the database to include five additional years of data using more recent publications such as *Statistical Yearbook of China (2000-2005)* and *Comprehensive Statistical Data and Materials on 55 Years of New China (1949-2004).* Table 1 presents the summary statistics for the variables included in the analysis.

Among the variables included in the technical inefficiency equation are **H** and **SOE**. **H** is measured as the average number of student enrollments in primary, secondary and higher education, which is used as a proxy variable for human capital stock.[3] **SOE** is the share of output from state owned enterprises to **PGDP**. Both variables are computed based upon the data obtained from *Comprehensive Statistical Data and Materials on 55 Years of New China (1949-2004)* published by National Statistical Bureau.

[2] The CCER data on real provincial GDP across provinces are not adjusted for purchasing power, which can bias the estimates of inefficiency up for the rural provinces as provincial GDP would look smaller in relatively rural provinces if the prices are higher in urban provinces (cities).

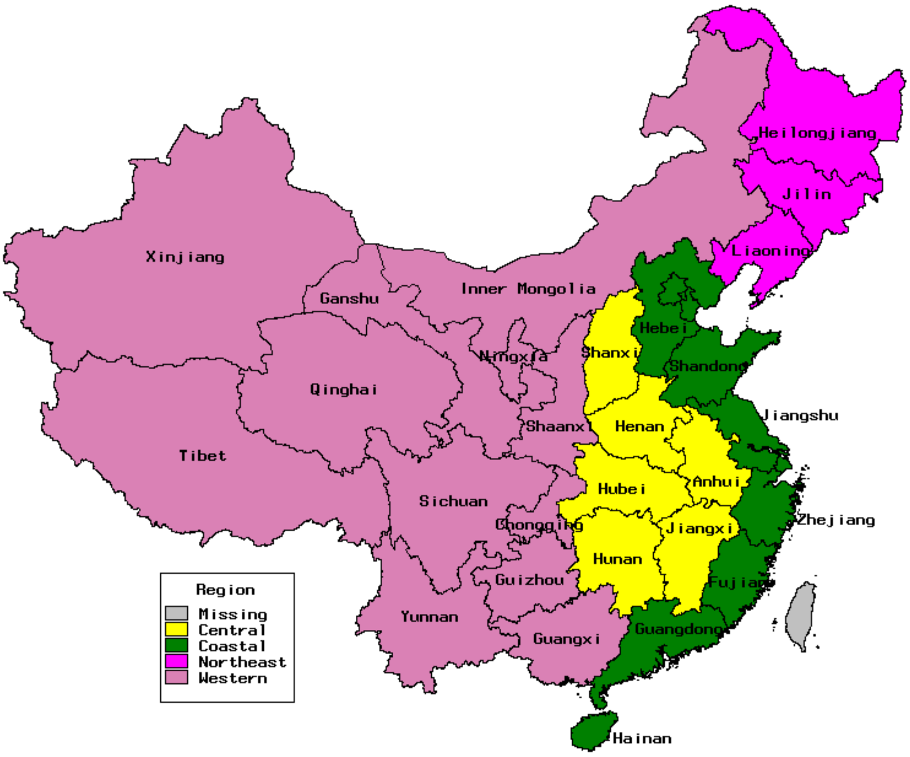
Table 1. Descriptive Statistics of Variables in the Stochastic Frontier Model

Variable	N	Mean	Standard Deviation	Minimum	Maximum
ln(PGDP)	950	5.6508	1.4537	1.8752	9.0439
ln(L)	950	15.5615	1.0639	12.7543	18.6044
ln(K)	950	7.1483	0.8477	4.7238	9.0454
ln(H)	950	5.2572	1.1407	2.2083	10.2142
URBAN	950	0.2441	0.1492	0.0734	0.7475
HIGHWAY	950	0.2036	0.1299	0.0021	0.7984
RAILWAY	950	0.0235	0.056	0.0002	0.3856
FDI	950	28.7968	102.3543	0.0000	994.056
SOE	950	0.6636	0.2109	0.0487	0.979
GOVT	950	0.1028	0.0464	0.0000	0.2856
COASTAL	950	0.3182	0.4668	0.0000	1.0000
CENTRAL	950	0.2149	0.4209	0.0000	1.0000
WESTERN	950	0.3552	0.485	0.0000	1.0000

Notes: N = 950 as some data on *H*, *HIGHWAY*, and *RAILWAY* in the earlier 1970s are missing. *PGDP* (100 million RMB yuan); *K* (RMB yuan per capita); *L* (10,000 persons); *HIGHWAY* & *RAILWAY* (kilometers per squared kilometers, km/ km^2)

In addition, three regional dummies (**COASTAL**, **CENTRAL**, and **WESTERN**) are included in the technical inefficiency equation to account for unobserved regional heterogeneity that is not captured by the proposed explanatory variables. Figure 1 maps four economic regions of mainland China suggested by central government, which are divided into coastal, northeastern, central, and western areas. The wealthy east coast covers 9 provinces, including 3 municipalities (Beijing, Fujian, Guangdong, Hebei, Jiangshu, Shandong, Shanghai, Tianjin, and Zhejiang). The Northeast area, also known as the old industrial bases in China, includes 3 provinces (Heilongjiang, Jilin, and Liaoning). Central regions cover 6 provinces (Anhui, Henan, Hubei, Hunan, Jiangxi, and Shanxi). Less developed western regions cover 9 provinces including 3 autonomous regions (Gansu, Guangxi, Guizhou, Qinghai, Inner Mongolia, Ningxia, Shaanxi, Sichuan, and Yunan).

Fig. 1. Economic Regions in Mainland China



5 EMPIRICAL RESULTS

The analysis was conducted using FRONTIER 4.1 program developed by Coelli (1996) which applies the MLE method to simultaneously estimate the stochastic production frontier and technical inefficiency model. A series of statistical tests were conducted to examine the appropriate specification of the production function, the existences of inefficiency effects, and the technological change effect. The generalized LR test results are presented in Table 2.

The first test reveals that the null hypothesis of Cobb-Douglas functional form against the translog functional form is rejected at the 5% level. By adding a time trend in the production

Table 2.
LR Tests of Hypothesis for Parameters of the Stochastic Frontier and Technical Inefficiency Models

Test	Null Hypothesis (L_R)	Log-likelihood	$\chi^2_{0.95}$	Test statistic
1	$\beta_5 = \beta_6 = \ldots = \beta_{14} = 0$	72.81	17.67	610.56*
2	$\beta_4 = \beta_8 = \beta_{11} = \beta_{13} = \beta_{14} = 0$	-154.94	10.37	1072.83*
3	$\gamma = \delta_0 = \delta_1 = \ldots = \delta_{11} = 0$	-278.82	21.74	1287.46*
4	$\delta_0 = \delta_1 = \ldots = \delta_7 = 0$	-80.37	17.67	923.71*
5	$\delta_8 = \delta_9 = \delta_{10} = 0$	268.46	7.05	202.42*

Notes: The test statistic involving a zero restriction on the parameter γ follows a mixed chi-squared distribution. Critical values for the testing of the hypothesis are given in Kodde and Palm (1986). The asterisk (*) indicates significance at the 5% level

function, test 2 rejects the null hypothesis that there is no technological change in the provincial production over time. Test 3 shows the null hypothesis of no technical inefficiency effect is rejected, suggesting that the stochastic production frontier approach is proper and the inefficiency was present in the production. Test 4 rejects the null hypothesis that the proposed explanatory variables are not capable of explaining the inefficiency. To account for the unobserved regional heterogeneity which is not captured by the proposed explanatory variables, Test 5 is conducted to test the null hypothesis that region-specific effects are jointly equal to zero. Again, the null hypothesis is rejected, indicating the region-specific effects should be included in the technical inefficiency model.

The results of these five tests suggest that a proper model of specification is the translog stochastic production frontier (equation (4)) that includes a time trend along with the technical inefficiency model (equation (5)) which includes ten exogenous variables. The parameter estimates are reported in Table 3. The parameter γ, which is defined as $\sigma_u^2/(\sigma_u^2 + \sigma_v^2)$, is significant at the 5% level and is estimated to be 0.7761, implying that 77.61 percent of the total

Table 3.
Maximum-Likelihood Estimation of the Production Frontier
and Determinants of Technical Inefficiency Function

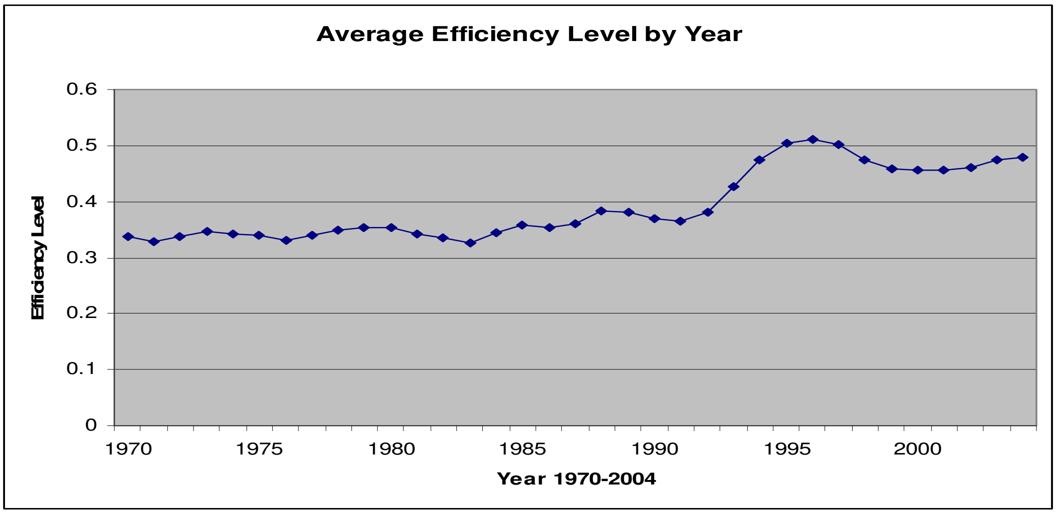
Production Function			*Inefficiency Function*		
Variable	Coefficient	*t-ratio*	Variable	Coefficient	*t-ratio*
Constant	-10.2461	-4.98*	Constant	4.2581	28.48*
ln(L)	2.2349	6.48*	URBAN	-2.5609	-29.64*
ln(K)	1.2678	-4.87*	HIGHWAY	0.2350	2.72*
ln(H)	1.0347	2.96*	RAILWAY	0.8207	5.12*
T	0.0021	0.05	H	-0.4420	-27.20*
$[\ln(K)]^2$	0.0865	-5.41*	FDI	-0.0013	-21.65*
$[\ln(L)]^2$	0.0724	2.51*	SOE	-0.0162	-0.37
$[\ln(H)]^2$	0.0259	3.41*	GOVT	0.5789	2.89*
T^2	0.0028	14.77*	COASTAL	-0.2358	-6.78*
ln(L)ln(K)	0.1578	5.81*	CENTRAL	0.0017	0.09
ln(L)ln(H)	-0.0065	-0.78	WESTERN	0.1315	5.26*
ln(L)T	-0.0056	-2.49*	T	-1.3871	7.25*
ln(K)ln(H)	0.0473	-3.57*	σ^2	0.0298	17.08*
ln(K)T	0.0538	-2.21*	γ	0.7761	16.49*
ln(H)T	0.0137	5.65*			

Notes: Significance levels: *5%; **1%. The coefficients in the inefficiency function are inefficiency effects and therefore a positive coefficient implies a negative effect on performance

variance is explained by the inefficiency effects. The high value of parameter γ highlights the importance of inefficiency effects in explaining the total variance in the model.

In general, the signs of these determinants that account for inefficiencies are expected. The negative and statistically significant coefficients for variable **H**, **URBAN**, **FDI** support the hypothesis that human capital, the degree of urbanization (or relaxation of the *hukou* system), and the depth of openness are important factors to increase production efficiency. The positive sign of **GOVT** implies that current government size reached over its optimal level and further increasing government size reduces provincial production efficiency, which might be consistent with the hypothesis that fiscal decentralization increases economic efficiency (Qian and Roland, 1998; Lin and Liu, 2000). The coefficient on **SOE** is negative but statistically insignificant. Surprisingly, the coefficients on transportation density variables (**HIGHWAY** and **RAILWAY**) are found to be positive in this empirical work, suggesting that highway and railway infrastructure are unproductive at the level of provinces. One explanation of this empirical result could be that, according to Boarnet (1995), "[i]t is possible that public capital is productive at a geographic scale that is smaller than states. Public capital might boost private sector productivity or output largely by moving economic activity from one location to another nearby location. . . Public capital would appear productive at small geographic scales (e.g. metropolitan areas or cities), but would appear unproductive at larger geographic scales (e.g. states). . . The primary effect of public capital is to give one local area an advantage over other local areas in the same state. The hypothesized local advantage is largely zero-sum at a state level." Figure 2 shows that overall technical efficiency score of the sample, in terms of the average value, improved slightly

Fig. 2. Mean Efficiency by Year 1970-2004



over time. The average efficiency remained more or less stable between 1970 and 1990 and increased to the highest level in the mid 1990s, declining slightly thereafter. The mean efficiency level is estimated at 38.72%, implying that during the time analyzed the provinces averagely produced only 38.72 percent of maximum attainable output given current input usage[3].

To compare the efficiency scores across provinces at a given time and examine efficiency variations over time for each province, Table 4 shows that the efficiency level differed noticeably from period to period for some provinces such as Shanghai, Jiangsu, Guangdong, Shanxi, and Shandong. In addition, the average efficiency score at each year varied dramatically across provinces as well. For instance, the largest efficiency value is found for Shanghai or Shanxi in 1970, 1980, 1990, and 2000 (0.951, 0.973, 0.975, and 0.977, respectively) and the smallest value is found for Ningxia or Qinghai (0.078, 0.113, 0.170, and 0.121, respectively) during these years.

In addition, Table 4 lists the ranking of provinces generated by ordering the provinces according to the average efficiency levels of the period 1970-2004. The estimated average efficiency score for each province are mapped in Figure 3. On the whole, the map shows the coastal provinces are more efficient than the central and western provinces, which is consistent with findings by TONG, 1997, YANG, 2002, and SHIU, 2002. Efficiency scores for western provinces such as Qinghai, Ningxia, Guizhou, and Gansu are ranked at the bottom of the 28 provinces. Sichuan is an exception, ranked fourteen in the nation. Central provinces generally performed worse than the east coastal provinces. Shanxi province is an exception, which is found to be the second most efficient province in production, only behind the coastal city Shanghai.

[3] Strictly speaking this is not accurate, as the stochastic frontier methodology determines the location of the frontier only by the observations given. If all observations are well below the "true frontier", then these relative efficiencies would not be relative measures of attainable output. Therefore, conceivably if the most efficient Chinese provinces are still highly inefficient (which is true in our case), then production would be even lower than 38.72% maximum attainable output given current input usage.

Table 4.
Provincial Rankings by Average Efficiency Scores, and Minimum and Maximum Efficiency Score by Province and by Year, Respectively

By Province					By Year		
Province	Minimum	Maximum	Average	Rank	Year	Minimum	Maximum
Coastal					1970	0.078	0.951
Shanghai	0.544	0.988	0.917	1	1971	0.087	0.928
Guangdong	0.381	0.973	0.636	3	1972	0.086	0.929
Jiangshu	0.487	0.942	0.551	6	1973	0.093	0.925
Shandong	0.323	0.824	0.510	7	1974	0.106	0.867
Tianjin	0.310	0.812	0.452	8	1975	0.117	0.873
Beijing	0.321	0.621	0.443	9	1976	0.110	0.796
Fujian	0.287	0.684	0.411	11	1977	0.113	0.872
Hebei	0.314	0.584	0.410	12	1978	0.112	0.954
Zhejiang	0.321	0.675	0.397	13	1979	0.109	0.974
Northeast					1980	0.113	0.973
Liaoning	0.471	0.698	0.573	4	1981	0.107	0.975
Heilongjiang	0.489	0.708	0.559	5	1982	0.109	0.976
Jilin	0.321	0.432	0.373	15	1983	0.112	0.970
Central					1984	0.120	0.987
Shanxi	0.325	0.950	0.796	2	1985	0.131	0.986
Hubei	0.295	0.565	0.416	10	1986	0.135	0.981
Henan	0.301	0.456	0.348	16	1987	0.138	0.977
Hunan	0.302	0.428	0.346	17	1988	0.146	0.978
Anhui	0.280	0.389	0.325	18	1989	0.141	0.977
Jiangxi	0.261	0.330	0.272	21	1990	0.170	0.975
Western					1991	0.129	0.960
Sichuan	0.221	0.520	0.376	14	1992	0.131	0.965
Inner Mongolia	0.259	0.326	0.282	19	1993	0.134	0.986
Xinjiang	0.171	0.412	0.276	20	1994	0.144	0.984
Guangxi	0.177	0.376	0.251	22	1995	0.143	0.988
Shaanxi	0.311	0.301	0.245	23	1996	0.135	0.987
Yunnan	0.142	0.296	0.217	24	1997	0.128	0.985
Ganshu	0.117	0.213	0.169	25	1998	0.120	0.983
Guizhou	0.099	0.209	0.168	26	1999	0.120	0.979
Ningxia	0.078	0.173	0.128	27	2000	0.121	0.977
Qinghai	0.081	0.158	0.119	28	2001	0.123	0.981
					2002	0.134	0.983
					2003	0.136	0.980
					2004	0.133	0.984

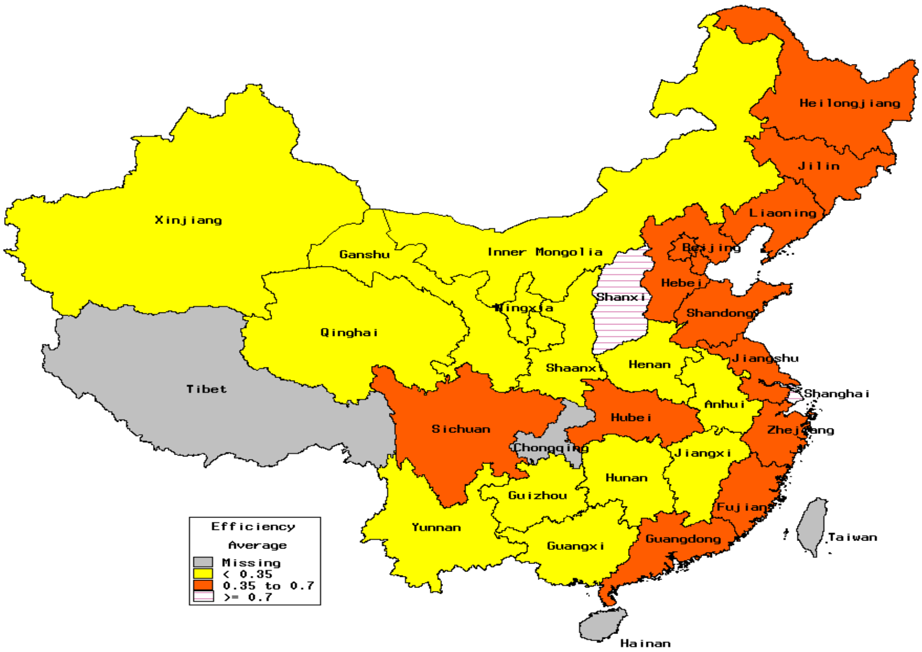
6. CONCLUSION

This paper applies a stochastic translog production function to examine the underlying causes of technical inefficiency for 28 provinces in mainland China over the period 1970-2004. The results indicate that inefficiency was present in production and several relevant explanatory variables contribute to it.

A few tentative conclusions and policy implications may be drawn from this econometric analysis. First, human capital was modeled as a productive input and as a variable that affects efficiency, as one benefit of investment in human capital is improved allocative ability in the economy (Adkins et al., 2002). This research found that the investment in human capital is positively associated with productive efficiency in China. Local and central government should place emphasis on the dual role of human capital on production efficiency.

Second, smaller government tends to increase efficiency, supporting Tiebout's (1956)

Fig. 3. Regional Average Efficiency Disparities



hypothesis that local (smaller) governments are more efficient than the higher level (larger) governments in resource allocation and in provision of local public goods and services that meets local needs.

Third, the state-owned enterprises in a number of empirical studies were found to operate inefficiently as compared to the non-state ones. This study found no evidence to support this general view. Meanwhile, highway and railway infrastructure were found to be unproductive, which coincides with the findings of empirical studies on U.S. States by Holtz-Eakin (1994) and Kelejian and Robinson (1994). One explanation, according to Boarnet (1995), is that it can be due to the possibility that infrastructure influences economic activity largely by shifting that activity from one location to another, hence infrastructure is productive at small geographic scales (e.g. cities, counties) but not productive over large geographic scales (e.g. provinces).

Fourth, even though labors are freed from agricultural production due to the rural reform adopted in the 1980s, there are still large barriers for labor mobility and labor markets are still segmented. The inefficient labor and capital allocation caused by the household registration system (*hukou* system) suggests that further reforms of *hukou* system are desirable in promote economic efficiency.

Fifth, provinces should promote more foreign trade. When domestic markets become more liberalized, international trade theory suggests that international competition will force domestic firms to adopt more efficient production techniques to reduce production costs.

Finally, coastal provinces were found to be more efficient in production than central and western provinces. To narrow regional efficiency imbalance, the least efficient western regions in China call for more education and more openness.

In summary, this study provides some useful information on how to reduce provincial production inefficiency. This study found that the provinces with higher level of human capital, higher engagement in international trade, and further relaxation of the *hukou* system tend to lie closer to the national frontier. However, the inefficiency estimates, which may suffer from omitted variable and measurement error bias in regression with the stochastic frontier approach, should be interpreted with caution, further exploration is desirable.

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