Estimation of firm level energy efficiency in China's energy sector

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Abstract

1 Introduction

The present paper examines the energy efficiency in China's energy production sector using micro (firm) level data. The energy sector is the largest energy user in the country and its energy efficiency has a significant weight in determining the energy efficiency for the whole economy. The energy (in)efficiency is defined in the framework of stochastic production, factor demand and cost frontiers in Schmidt and Lovell (1979) (SL for short). Specifically, the energy inefficiency for a firm is measured by the excess of energy input relative to the energy demand frontier for a given level of output. A translog stochastic production frontier model is employed to characterise firm production, which enables estimation of technical inefficiency. Cost minimisation is assumed on the part of the firm, which gives rise to estimation of allocative inefficiency. In the case of a Cobb-Douglas production frontier, SL showed that both technical and allocative inefficiencies affect factor (energy) demand linearly. This enables an explicit evaluation of the effects on factor demand of the two types of inefficiency. Under the translog production technology, it is not feasible to conduct such an explicit evaluation since the factor demand frontier cannot be derived analytically. Therefore, the numerical procedure proposed by Kumbhakar and Wang (2006) (KW for short) is followed. The data used in the study are over the period 2000-2005 when the growth of total energy consumption had exceeded that of GDP (NBS, various issues of China Statistical Yearbooks). The paper also considers a scenario where under-reporting in energy use took place. The following section presents the analytical framework. Data description and empirical results are provided in Section 3 with some concluding remarks contained in Section 4.

2. Analytical framework

Energy efficiency is normally measured as the ratio of energy consumption to output (for example, Farla et al (1998), Han et al (2007), Young(2007)), which is also used to measure energy intensity. This approach to measuring energy efficiency does not facilitate modelling the effect on energy efficiency of how well the existing technology has been utilised. Following Boyd (2008), the present study takes a different approach by defining energy inefficiency as the gap between the actual and the "best" uses (observed lowest use) of energy, whereby the "best" use of energy will be determined using observed data on energy consumption. The study is different to Boyd (2008) in that the energy demand frontiers are determined by the production frontier to explicitly take into account how utilisation of production technology affects energy demand.

Specifically, the research focuses on the efficiency in the use of three types of energy, namely, coal, electricity and other fuels which are an aggregate of the heat content values of fuels other than coal and electricity. It is assumed that the production technology in China's energy sector can be represented by a translog production model as follows

$$\ln y = \beta_0 + \sum_k \beta_k \ln x_k + \sum_k 0.5\gamma_k (\ln x_k)^2 + \sum_k \sum_{k' \neq k} \delta_{kk'} \ln x_k \ln x_{k'} - u + \varepsilon \qquad k = 1,\cdots,5 \quad (1)$$

where

y : value-added output,

x_1 : total number of employees,

x_2 : net value of fixed assets,

x_3 : tons of coal,

x_4 : electricity (10,000 KWh),

x_5 : other fuels (Btus).

u : technical inefficiency (a nonnegative $N(0,\sigma_u^2)$ variable),

ε : a random disturbance from the $N(0,\sigma_\varepsilon^2)$ distribution.

Assuming cost minimisation on the part of the producer and using x_1 as the numeraire, the allocative inefficiency of x_j is (KW),

$$\xi_j = \ln S_j - \ln S_1 - \ln(w_j x_j) + \ln(w_1 x_1) \qquad (2)$$

where

$S_j = \beta_j + \gamma_j x_j + \sum_{k \neq j} \delta_{kj} x_k$, the cost share of x_j, and w_j the price of x_j.

Assume that

$$\xi = \begin{bmatrix} \xi_2 \\ \vdots \\ \xi_K \end{bmatrix} \sim MVN(0,\Sigma),$$

then the fuel inefficiency, $x_j - x_j^f$ (actual demand – the frontier), and the effects of technical and allocative inefficiencies on it, can be calculated numerically after the model is estimated by a maximum likelihood estimator (KW).

If ξ_j > (<) 0, then factor j is under (over)-used compared to labour. An increase in the technical inefficiency, u, *Ceteris Paribas*, increases the fuel inefficiency, while that in the allocative inefficiency, ξ, can be ambiguous. The ambiguity is explicit in the case of a Cobb-Douglas production function since $x_j - x_j^f = \frac{1}{r}\sum_k \beta_k \xi_k - \xi_j + \frac{1}{r}u$ (SL). This implies that pursuing allocative efficiency can be at odds with fuel efficiency. A firm may deliberately over- or under-use a particular type of fuel in order to achieve energy efficiency, which can be true in the present China where the government has set targets for firms to reduce emissions.

Statistics from China can subject to falsification (Korski, 1998). There can be a motivation for the firm to under-report its energy use to meet government stipulations. This section considers one scenario whereby energy input was under-reported. In particular, it is assumed that the reported fuel input, x_k, had been resulted from "discounting" true energy input, x_k^*, by a factor of e^{τ_k}, i.e., $x_k^* = x_k\, e^{\tau_k}$ or $\ln x_k^* = \ln x_k + \tau_k$ where the τ_k are nonnegative and fuel-specific constant, and unobservable to the econometrician. Replacing the $\ln x_k$ in (2) by $\ln x_k + \tau_k$, for $k = 3, 4, 5$, results in the reformulated model as,

$$\ln y = A_1 + \sum_k A_k \ln x_k + 0.5 \sum_k \gamma_k (\ln x_k)^2 + \sum_k \sum_{k \neq k'} \delta_{kk'} \ln x_k \ln x_{k'} \text{ - } u + \varepsilon \tag{3}$$

where

$$A_1 = \beta_0 + \sum_k \beta_k \tau_k + 0.5 \sum_k \gamma_k \tau_k^2 + \sum_k \sum_{k' \neq k} \delta_{kk'} \tau_k \tau_{k'},$$

$$A_k = \beta_k + \gamma_k \tau_k + \sum_{k'} \delta_{kk'} \tau_k \text{ ,with } \tau_1 = \tau_2 = 0$$

The first-order condition of cost minimisation becomes,

$$\xi_j + \tau_j = \ln S_j^* - \ln S_1 - \ln(w_j x_j) + \ln(w_1 x_1) \tag{4}$$

where $S_j^* = A_j + \gamma_j x_j + \sum_{k \neq j} \delta_{kj} x_k$

Since possible under-reporting in fuel consumption was independent of the production process, the way how the u affects the demand for $\ln x^*$ should be the same as that it affects the demand for $\ln x$ since $\ln x^*$ is linearly related to $\ln x$. This suggests that the u can be identified even though the τ_k are unidentifiable from (3) and (4). If the τ_k are only fuel- and firm-specific but time invariant, then changes in the observation-specific ξ_j can be estimated with panel data through first differencing.

3. Data

A sample of 150 firms in China's energy sector was selected for the study for the sample period 2000-2005. Of the 150 firms, 51 are coal mines, 44 are electricity generation plants and 55 are petro-chemical plants.

Firm output was measured by value-added output in real terms (in 2000 prices). Total employee number was used as labour input, with the price of labour being the average wage, i.e., total labour cost/total employees. Capital was measured by the annual average balance of the net value of fixed assets in real terms. The price of capital was unavailable, so the price index of fixed asset investment at the national level was used as a proxy.

The fuel prices at firm level were computed by dividing the physical amount of fuel consumption by the corresponding fuel expenditure. The shortcoming of this approach to obtaining price information is that the computed price was the average price rather than the actual tariff the firm had faced. The major fuels are coal and electricity in the sense that every sample firm consumed them, so these two fuels are treated separately in the model.

Other reported fuels include diesel, gasoline, kerosene, crude oil, liquefied petroleum gas and natural gas. These fuels were aggregated based on their heat content values for two reasons. First, they were not consumed by every sample firm and the consumption of some of them at some firms was almost negligible. Secondly, to include them separately in the model would increase the amount of code tremendously when programming the Jacobian component of the likelihood function since the fuel inputs were regarded endogenous variables.

The data are confidential and therefore more details cannot be revealed.

4. Empirical Results

Given the sample, the model to be estimated is as follows,

$$\ln y_{it} = \beta_0 + \sum_k \beta_k \ln x_{kit} + \sum_k 0.5\gamma_k (\ln x_{kit})^2 + \sum_k \sum_{k'\neq k} \delta_{kk'} \ln x_{kit} \ln x_{k'it} - u_{it} + \varepsilon_{it}$$

$$\xi_{jit} = \ln S_{jit} - \ln S_{1it} - \ln(w_{jit} x_{jit}) + \ln(w_{1it} x_{1it}) \qquad i = 1,\cdots\cdots,900; t = 2000-2005;$$

Under the assumptions regarding the distributions of the u, v, and ξ, the maximum likelihood estimator outlined in KW was used and the estimates are presented in Table 1.

Table 1
MLE estimates of the production function parameters

Variables	Coefficients	Standard error		Variables	Coefficients	Standard error
Cons	5.455	0.250				
$\ln x_1$	0.581	0.003		$\ln x_1 \ \ln x_2$	-0.018	0.000
$\ln x_2$	-0.292	0.015		$\ln x_1 \ \ln x_3$	-0.106	0.000
$\ln x_3$	-0.072	0.003		$\ln x_1 \ \ln x_4$	0.011	0.000
$\ln x_4$	-0.002	0.001		$\ln x_1 \ \ln x_5$	-0.006	0.000
$\ln x_5$	0.085	0.035		$\ln x_2 \ \ln x_3$	0.048	0.000
$\ln^2 x_1$	0.088	0.000		$\ln x_2 \ \ln x_4$	-0.012	0.000
$\ln^2 x_2$	0.046	0.003		$\ln x_2 \ \ln x_5$	0.017	0.003
$\ln^2 x_3$	0.065	0.001		$\ln x_3 \ \ln x_4$	-0.005	0.000
$\ln^2 x_4$	0.020	0.000		$\ln x_3 \ \ln x_5$	-0.007	0.000
$\ln^2 x_5$	0.004	0.002		$\ln x_4 \ \ln x_5$	-0.012	0.000
σ_u^2 = 0.2491, σ_v^2 = 0.6381 , Log likelihood = -32474.52						

Thus the system that characterises the production and factor demand is,

$$\begin{aligned}
\ln \hat{y}_{it} = {} & 5.455 + 0.581\ln x_{it1} - 0.292\ln x_{it2} - 0.072\ln x_{it3} - 0.002\ln x_{it4} + 0.085\ln x_{it5} \\
& + 0.044\ln^2 x_{it1} + 0.023\ln^2 x_{it2} + 0.033\ln^2 x_{it3} + 0.010\ln^2 x_{it4} + 0.010\ln^2 x_{it5} \\
& - 0.018\ln x_{it1}\ln x_{it2} - 0.106\ln x_{it1}\ln x_{it3} + 0.011\ln x_{it1}\ln x_{it4} - 0.006\ln x_{it1}\ln x_{it5} \\
& + 0.048\ln x_{it2}\ln x_{it3} - 0.012\ln x_{it2}\ln x_{it4} + 0.017\ln x_{it2}\ln x_{it5} - 0.005\ln x_{it3}\ln x_{it4} \\
& - 0.007\ln x_{it3}\ln x_{it5} - 0.012\ln x_{it4}\ln x_{it5} - \hat{u}_{it} + \hat{v}_{it}
\end{aligned} \tag{5}$$

$$e^{\hat{\xi}_{it2}} = \frac{-0.292 + 0.046\ln x_{it2} - 0.018\ln x_{it1} + 0.048\ln x_{it3} - 0.012\ln x_{it4} + 0.017\ln x_{it5}}{0.581 + 0.088\ln x_{it1} - 0.018\ln x_{it2} - 0.106\ln x_{it3} + 0.011\ln x_{it4} - 0.006\ln x_{it5}} * \frac{w_{it1}x_{it1}}{w_{it2}x_{it2}} \tag{6}$$

$$e^{\hat{\xi}_{it3}} = \frac{-0.072 + 0.066\ln x_{it3} - 0.106\ln x_{it1} + 0.048\ln x_{it2} - 0.005\ln x_{it4} - 0.007\ln x_{it5}}{0.581 + 0.088\ln x_{it1} - 0.018\ln x_{it2} - 0.106\ln x_{it3} + 0.011\ln x_{it4} - 0.006\ln x_{it5}} * \frac{w_{it1}x_{it1}}{w_{it3}x_{it3}} \tag{7}$$

$$e^{\hat{\xi}_{it4}} = \frac{-0.002 + 0.020\ln x_{it4} + 0.011\ln x_{it1} - 0.012\ln x_{it2} - 0.005\ln x_{it3} - 0.012\ln x_{it5}}{0.581 + 0.088\ln x_{it1} - 0.018\ln x_{it2} - 0.106\ln x_{it3} + 0.011\ln x_{it4} - 0.006\ln x_{it5}} * \frac{w_{it1}x_{it1}}{w_{it4}x_{it4}} \tag{8}$$

$$e^{\hat{\xi}_{it5}} = \frac{0.085 + 0.020\ln x_{it5} - 0.006\ln x_{it1} + 0.017\ln x_{it2} - 0.007\ln x_{it3} - 0.012\ln x_{it4}}{0.581 + 0.088\ln x_{it1} - 0.018\ln x_{it2} - 0.106\ln x_{it3} + 0.011\ln x_{it4} - 0.006\ln x_{it5}} * \frac{w_{it1}x_{it1}}{w_{it5}x_{it5}} \tag{9}$$,

where the observation-specific technical inefficiency, $\hat{u}_{it}$, are computed from the Jondrow et al (1982) formula, and the observation-specific allocative inefficiencies, $\hat{\xi}_{itk}$, are computed using (6)-(9). A summary on the estimated technical and allocative inefficiencies are presented in Table 2. The technical inefficiency estimates, $e^{-\hat{u}}$, show the percentage that the observed production was below the production frontier. Since in most of the years the same factor was over-used in some firms and under-used in the other firms, both cases were reported.

Technical inefficiency increased over the period 2000-2005 for all three types of firm, with the electricity generators recording the biggest increase. As discussed in Section 2, these are still consistent estimates of technical inefficiency even when the fuel consumption was under-reported in the way described. Over-use of capital was diminishing over time, whereas under-use of it experienced ups and downs. For the three fuels, the extent to which over-use took place exceeded that for under-use except for some electricity generators that experienced an increasing under-use of electricity. Over-use of coal was absent for 2003 and 2002-2003 for the refineries and electricity generators, respectively. Also absent was over-use of other fuels for the coal mines and the electricity generators for 2003-2003 and 2003-2005, respectively.

The five factor demand frontiers are solved from the system of (5)-(9) by setting the $\hat{u}_{it}$ and $\hat{\xi}_{itk}$ to zero, hence it is assumed that inefficiencies in factor use were only affected by technical and allocative inefficiencies.

Table 2
Estimated technical and allocative inefficiencies (sample means)

Year	$e^{-\hat{u}}$	$\hat{\xi}_2<0$	$\hat{\xi}_2>0$	$\hat{\xi}_3<0$	$\hat{\xi}_3>0$	$\hat{\xi}_4<0$	$\hat{\xi}_4>0$	$\hat{\xi}_5<0$	$\hat{\xi}_5>0$
Coal mines									
2000	0.787	-1.664	0.665	-0.677	1.817	-1.350	3.284	-0.363	4.941
2001	0.802	-1.402	0.897	-0.396	1.869	-1.763	3.173	-0.199	4.944
2002	0.807	-1.226	1.269	-0.225	1.918	-1.211	3.433	-	4.992
2003	0.816	-1.205	0.591	-0.892	2.092	-1.359	3.044	-	5.112
2004	0.811	-1.230	2.995	-0.766	1.770	-1.891	2.738	-0.171	3.329
2005	0.761	-1.128	1.808	-0.928	1.410	-1.723	2.867	-0.164	2.911
Refineries									
2000	0.812	-2.002	1.376	-2.638	3.184	-2.267	3.336	-1.818	3.989
2001	0.818	-1.751	0.295	-1.734	2.921	-1.300	3.285	-1.396	3.832
2002	0.752	-1.703	1.013	-1.077	3.097	-0.843	3.207	-1.382	3.896
2003	0.716	-1.580	1.498	-	2.909	-0.843	3.431	-0.989	3.897
2004	0.640	-1.635	1.101	-0.763	1.876	-1.774	2.868	-2.552	2.448
2005	0.581	-1.546	0.846	-0.666	1.619	-2.070	2.680	-2.608	2.466
Electricity generators									
2000	0.799	-2.508	1.163	-1.092	4.283	-1.673	2.097	-0.010	5.158
2001	0.837	-2.367	2.175	-0.164	4.449	-1.255	2.242	-0.008	5.435
2002	0.831	-2.195	2.031	-	4.388	-0.916	2.327	-0.208	5.406
2003	0.803	-2.129	1.019	-	4.265	-1.152	1.776	-	5.139
2004	0.802	-2.020	1.027	-0.887	3.580	-2.349	2.445	-	3.504
2005	0.409	-2.214	0.774	-0.816	3.014	-2.576	2.908	-	3.256

It is worthwhile to point out that the system of (5)-(9) may not be solved exactly because of the nonlinearity in the variables. Therefore, the Generalized Reduced Gradient method[1] was used to compute the factor demand frontiers, $\ln x|_{\xi=0,\,u=0}$, the observations as the initial values for the variables. The factor demand in the presence of the two types of inefficiency was computed similarly, which allows evaluation of their effects on factor use inefficiency. Specifically, the difference, $\ln x|_{\xi=\hat{\xi},\,u=\hat{u}}$ - $\ln x|_{\xi=0,\,u=0}$, measures the amount of excess (inefficiency) in using the particular factor when the both types of inefficiency existed. Similarly, the difference, $\ln x|_{\xi=0,\,u=\hat{u}}$ - $\ln x|_{\xi=0,\,u=0}$ ($\ln x|_{\xi=\hat{\xi},\,u=0}$ - $\ln x|_{\xi=0,\,u=0}$), measures the amount of excess in using the particular factor when only the technical (allocative) inefficiency existed. The results are contained in Tables 3-5.

Under the presence of allocative inefficiency and absence of technical inefficiency, electricity and other fuels tended to be more efficiently used than otherwise since most of the estimates in the last columns in Table 3 are negative. However, the same cannot be said about coal consumption for the coal mines.

When only technical inefficiency existed, the evidence is generally mixed – for some of the years it caused more inefficiency in the fuel consumption while for the other years the opposite was true. This is disturbing and might be attributable the lack of an exact solution to the system (5)-(9). In the case of electricity consumption, however, the results suggest that

[1] The method was implemented in MS Excel.

the electricity generators would improve the fuel efficiency if their technical inefficiency could be reduced.

Table 3
Estimated inefficiencies in factor use in the presence of allocative inefficiencies only (sample means)

Year	labour	capital	coal	electricity	Other fuels
Coal mines					
2000	0.354	0.126	0.359	-1.270	-0.380
2001	0.370	-0.702	0.937	-1.303	-0.215
2002	0.545	0.661	0.412	0.201	-0.480
2003	0.301	-0.509	0.485	-0.452	-1.729
2004	0.206	0.290	0.147	0.120	0.545
2005	1.027	0.671	1.205	-0.154	0.309
Refineries					
2000	-0.303	-0.562	-0.129	-1.121	-0.755
2001	0.445	-0.383	1.208	-2.001	-0.212
2002	-0.898	-1.151	-1.525	-5.355	-6.278
2003	-0.129	-0.214	0.115	-0.323	-1.352
2004	0.826	0.447	1.635	1.198	2.987
2005	0.297	-0.154	0.542	-0.453	-0.025
Electricity generators					
2000	-0.739	-0.575	-0.950	-0.568	3.546
2001	-0.545	-0.771	-0.142	-1.169	1.511
2002	-2.825	-2.194	-2.558	-2.810	-3.097
2003	-1.272	-1.294	-0.590	-2.873	-3.620
2004	-0.770	-0.788	-0.727	-3.364	-3.501
2005	-0.426	-0.403	-0.330	-1.559	-1.365

In the case of the presence of both types of inefficiency, there was strong evidence that the inefficiency in coal use was high throughout the years. For the electricity generators, both the efficiencies in electricity and other fuels were improving over the period.

Tables 6 to 8 contain similar estimates to those in Tables 3 to 5. The difference is that they were obtained under the assumption that under-report in fuel use followed the way described in Section 2, namely, fuel- and firm-specific but time invariant. Through first-differencing (6)-(9), the nuisance parameters, τ_{ik}, were swept out from the system and the numerical procedure used earlier was re-applied.

Table 4
Estimated inefficiencies in factor use in the presence of technical inefficiencies only (sample means)

Year	labour	capital	coal	electricity	Other fuels
Coal mines					
2000	-0.040	0.081	-0.119	0.018	0.051
2001	-0.045	-0.108	0.004	-0.132	-0.033
2002	0.399	0.586	0.339	0.564	0.489
2003	-0.341	-0.544	-0.220	-0.574	-0.631
2004	-0.298	0.149	-0.603	0.299	0.105
2005	-0.276	-0.261	-0.328	-0.424	-0.312
Refineries					
2000	-0.518	-0.726	-0.372	-0.693	-0.309
2001	-0.031	-0.107	-0.009	-0.010	-0.097
2002	-0.308	-0.082	-0.428	0.457	0.530
2003	-0.202	-0.277	-0.174	-0.413	-0.280
2004	0.094	0.035	0.237	0.307	0.294
2005	0.440	0.236	0.588	0.100	0.310
Electricity generators					
2000	-0.002	0.144	-0.143	0.075	-0.047
2001	0.231	0.248	0.128	0.146	-0.089
2002	0.178	0.160	0.219	0.229	0.176
2003	0.123	0.215	0.081	0.268	0.238
2004	-0.149	-0.041	-0.075	0.004	-0.083
2005	-0.128	-0.334	-0.061	-0.460	-0.144

Table 5
Estimated inefficiencies in factor use in the presence of technical and allocative inefficiencies (sample means)

Year	labour	capital	coal	electricity	Other fuels
Coal mines					
2000	3.000	-1.660	5.549	-0.857	-0.812
2001	0.809	-2.962	4.086	-1.891	-1.893
2002	0.503	-3.475	2.700	-3.323	-2.571
2003	1.743	-2.558	5.198	-0.441	0.034
2004	4.147	-0.253	7.277	0.842	3.121
2005	3.600	-0.290	7.174	0.020	2.727
Refineries					
2000	8.728	-1.176	14.765	9.401	6.094
2001	3.094	-2.365	5.749	-5.763	-4.854
2002	3.515	-3.083	5.526	-3.089	-4.661
2003	3.400	-1.891	7.538	1.897	0.608
2004	2.748	-0.090	7.191	1.763	1.936
2005	4.896	1.342	8.410	2.364	3.463
Electricity generators					
2000	1.555	-1.028	4.275	-0.913	1.966
2001	1.039	-1.314	4.450	-3.204	0.111
2002	-1.452	-2.434	1.088	-4.119	-1.052
2003	0.899	-2.184	3.817	-2.176	-1.620
2004	0.866	0.264	3.652	-5.901	-4.437
2005	2.238	0.214	5.451	-6.691	-4.516

Table 6
Estimated inefficiencies in factor use in the presence of allocative inefficiencies and under-report in fuel consumption
(sample means)

Year	labour	capital	coal	electricity	Other fuels
Coal mines					
2000	0.051	-0.432	1.126	-1.884	-1.855
2001	-0.560	-0.265	-0.285	-0.651	-1.263
2002	-0.278	-0.771	-0.375	-1.585	-3.564
2003	-0.900	-0.453	-1.110	-0.048	-0.850
2004	-0.017	-0.057	-0.051	-0.018	-0.573
2005	-0.199	-0.247	-0.263	-0.031	-1.159
Refineries					
2000	1.115	0.836	0.787	-3.577	-5.600
2001	-0.233	-0.560	0.726	-0.999	0.716
2002	-0.334	-0.524	-1.016	-2.364	-3.791
2003	-1.107	-1.201	-0.531	1.320	2.241
2004	0.557	0.391	0.102	1.312	-0.024
2005	0.088	-0.023	0.142	-0.128	-0.073
Electricity generators					
2000	-1.544	0.968	-0.374	-2.460	-0.555
2001	-0.392	-0.790	-0.160	-0.176	0.234
2002	-1.276	-1.099	0.167	-0.667	-1.727
2003	-1.058	-0.680	-1.052	-3.408	-3.684
2004	-0.994	-0.640	-0.666	-4.536	-5.240
2005	0.491	0.308	0.311	-3.325	-2.827

Table 7
Estimated inefficiencies in factor use in the presence of technical inefficiencies and under-report in fuel consumption
(sample means)

Year	labour	capital	coal	electricity	Other fuels
Coal mines					
2000	-0.116	0.663	-0.151	-0.470	-0.867
2001	-0.791	-0.670	-0.716	-0.660	-1.044
2002	0.045	-0.094	0.227	0.132	0.059
2003	0.231	0.485	0.121	0.547	0.587
2004	-0.401	0.115	-0.719	0.716	-0.356
2005	-0.587	-0.417	-0.780	-0.666	-0.640
Refineries					
2000	0.870	0.832	0.397	-2.088	-3.436
2001	-0.007	0.180	-0.036	0.392	0.627
2002	-0.692	-0.403	-0.841	0.468	0.416
2003	-0.277	-0.682	-0.077	0.144	-0.039
2004	0.620	0.259	0.189	-0.600	-2.286
2005	0.408	0.297	0.491	-0.009	0.297
Electricity generators					
2000	-1.310	4.985	1.393	17.991	22.497
2001	1.017	0.569	0.824	0.876	1.917
2002	-0.986	0.023	-0.075	0.322	0.551
2003	-0.797	-0.326	-1.211	-1.571	-2.310
2004	0.191	0.107	0.236	-2.946	-2.933
2005	1.188	0.932	1.327	-0.211	0.271

Table 8
Estimated inefficiencies in factor use in the presence of technical and allocative inefficiencies and under-report in fuel consumption
(sample means)

Year	labour	capital	coal	electricity	Other fuels
Coal mines					
2000	0.141	-0.393	1.542	-1.445	-1.532
2001	-0.302	-0.064	0.044	-0.176	-0.777
2002	-0.458	-0.801	-0.480	-0.274	-1.962
2003	-0.048	0.255	-0.238	0.505	0.005
2004	0.575	0.623	0.532	0.422	0.036
2005	-0.518	-0.448	-0.709	-0.580	-0.881
Refineries					
2000	0.945	0.925	0.529	-3.826	-6.749
2001	-0.605	-0.460	0.293	-0.576	1.946
2002	0.005	-0.318	-0.607	-2.817	-3.955
2003	-0.077	-0.329	0.230	0.188	-0.350
2004	0.970	0.332	1.095	2.083	1.239
2005	0.000	-0.261	0.066	-0.637	-0.733
Electricity generators					
2000	-1.289	0.869	-0.138	-2.071	-0.455
2001	-0.428	-0.750	-0.281	-0.054	0.211
2002	-1.272	-0.948	-1.063	-3.506	-4.909
2003	-1.396	-0.964	-1.336	-3.231	-3.726
2004	-1.191	-0.555	-0.860	-3.880	-5.043
2005	0.742	0.054	0.375	-1.846	-0.475

For the coal mines, the existence of allocative inefficiency helped increase fuel consumption efficiency, however, the level of efficiency was decreasing. The evidence for the refineries and electricity generators is mixed. Fuel consumption efficiencies deteriorated when only technical inefficiency existed, compared to the situation where only allocative inefficiency existed. When both allocative and technical inefficiencies took place, the efficiency in coal use improved whereas those for electricity and other fuels decreased for the coal mines and refineries. For the electricity generators, the evidence is mixed.

5. Concluding remarks

This paper has considered estimation of energy efficiency in China's energy sector when firm-level data are available. The energy efficiency was studied by measuring efficiency in firms' uses of three fuels, namely, coal, electricity and other fuels including crude oil, diesel, etc... The sample firms were made up of coal mines, refineries and electricity generators over the period 2000-2005. The analysis began by describing the production process with a translog production function, which is considered flexible in reflecting the underlying technology. The cost of pursuing such flexibility is that the efficiency in the fuel consumption cannot be evaluated analytically. Therefore, the numerical procedures were followed. It was found that, in the presence of both technical and allocative inefficiencies, the efficiency in coal use decreased over the period. However, if the fuel consumption data were under-reported in the way described in the paper, coal was actually used increasingly efficiently. The efficiencies in using electricity and other fuels were decreasing in the coal-mining and refinery firms, whereas the electricity generators experienced an increasing in the efficiency of using the two fuels. This was true even when the described under-report was in place.

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7. References

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