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**THE PRODUCTIVE EFFICIENCY OF CHINESE IRON AND STEEL FIRMS:
A STOCHASTIC FRONTIER ANALYSIS**

by

Yanrui Wu

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DEPARTMENT OF ECONOMICS

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Abstract

This paper applies a time-varying production frontier model to examine the productive efficiency in China's iron and steel industry. Sixty-one state and local firms are covered in this study. The objective of the paper is to estimate firm-specific technical efficiency and to analyze the impact of firm attributes on productive performance. The major issues considered include the vintage of capital, economies of scale, enterprise ownership and location. Finally, the paper draws policy implications for the Chinese iron and steel industry.

1 Introduction

China produced over 91 million tonnes of crude steel in 1994. This makes China the second largest steel producer in the world, behind only Japan. China is also an important buyer in the world steel market. Within the past years, China's imports of finished steel products totaled 6.18 million tonnes in 1992 and peaked at 30.26 million tonnes in 1993 (Editorial Board 1993, 1994). Due to such significance in production and trade, China's steel industry and market have for a long time attracted international attention. As a result, literature on steel industry in China has mushroomed. The focus of previous studies is mainly on issues related to demand and strategic development. Work on microeconomic performance is relative rare, however.

This paper attempts to extend previous work by presenting a case study of efficiency analysis using a sample of sixty-one iron and steel enterprises. The aim is to estimate firm-specific technical efficiency and to examine the sources of variation in technical efficiency among the firms.

2 Previous studies

Several studies, such as those by Jefferson (1990), Kalirajan and Cao (1993), and Wu (1995a), examined efficiency issues in the Chinese iron and steel industry. These authors all use firm-level data sets published in the Yearbook of the Iron and Steel Industry of China (Editorial Board, various issues).

Jefferson (1990) focused on productivity and its sources of variation among the firms. He estimated a trans-log production function using a data sample of 120 iron and steel enterprises. He found that the measured efficiency of the

enterprises under local government supervision was higher than that of the enterprises supervised by the central government. Jefferson also investigated the relationship between total factor productivity and firm attributes such as scale, capital vintage, investment composition, product mix and the level of supervision. He identified these factors as the main sources of efficiency variation among the enterprises.

Kalirajan and Cao (1993) attempted to look at the effect of economic reform on enterprise performance. They decomposed productive efficiency into technical, allocative and scale efficiency, and found that the Chinese iron and steel industry, on an average, achieved about 60 percent of its potential output in 1988. They also found that firms tended to economize on their use of inputs that were under their control but not on those that were provided to them by the planning authority (Feng et al. 1993).

Wu (1995a) analyzed technical efficiency and its relationship with some firm attributes such as ownership, scale and location. He applied a stochastic frontier model to a cross section data set of 87 firms. He derived the same estimate of average technical efficiency as in Kalirajan and Cao (1993). Wu also examined the impact of firm attributes on technical efficiency by incorporating these firm attributes into the production functions.

Among the above-mentioned three studies, one thing in common is that they all examined enterprise efficiency in a single time period. Nothing has been done in terms of looking at the changes in productive efficiency over time. The latter is particularly important given the fact that the Chinese firms are in the process of transformation under the economic reforms. To extend previous work, this paper introduces a production frontier model which can estimate firm-specific, time-varying efficiency.

3 Analytical framework

3.1 Definitions of efficiency

In theory, a firm may operate inefficiently in two distinct senses. It may fail to generate the maximum output from the inputs it employs, given a technology constraint imposed by the best practice, or production possibilities frontier. This type of inefficiency, operation below rather than on the production possibilities frontier, is referred to as technical inefficiency. A firm may also operate at the wrong point on its production possibilities frontier, inputs being employed in the wrong proportions given their prices and productivity at the margin. This is known as allocative inefficiency. The measurement of the latter requires information on both output and input prices. It is well known that these prices are severely distorted in China. Technical inefficiency is, however, more amenable to quantitative evaluation due to its independence of both the plan and externally determined output and input prices. For this reason the analyses in this chapter concentrate on the technical part of efficiency. In essence, technical efficiency measures the gap between the best practice and actual output. It demonstrates the extent to which the observed enterprise performance approaches its potential or the so-called 'best practice' standard (Schmidt 1986).

3.2 Measures of technical efficiency

The literature on the measurement of efficiency begins with Farrell (1957) who drew upon the work of Debreu (1951) and Koopmans (1951). Farrell's method was based on a production possibility set of the convex hull of input-output vectors. He suggested that efficiency could be measured in terms of

the deviation of observed output from an idealized frontier isoquant. After Farrell (1957), a variety of measures of technical efficiency has appeared in the literature.¹ Two primary methods are the *stochastic frontier* and *data envelopment analysis* techniques which envelop data in different ways.² The former is an econometric approach in which the inefficiency is identified with disturbances in a regression model.³ The latter involves mathematical programming techniques to the construction of production frontiers and the measurement of efficiency.³ Each method has its own advantages but neither is perfect. The econometric methods, on the one hand, have the advantage of permitting the conduct of statistical tests of hypotheses regarding the parameters and production structure. They also attempt to distinguish the effects of noise from the effects of inefficiency. On the other hand, the programming techniques are non-parametric and less prone to the effects of misspecification of function forms. Since the test of statistical hypotheses is essential in this study, an econometric approach is introduced and applied to the panel data of sixty-one iron and steel plants.

3.3 Stochastic frontier approach

The stochastic frontier model proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) is employed in this chapter. The unique characteristic of this approach is its capacity to distinguish inefficiency factors from random shocks and statistical noise. This is possible by introducing a combined error term into the conventional regression models. The original version of this model was specified for applications of cross-sectional data. This original specification has been used and extended

¹ Lovell (1993) discussed two other approaches to efficiency measurement.

² For recent surveys of econometric approaches to efficiency measurement, see Bauer (1990), Greene (1993) and Coelli (1995).

³ Detailed reviews of data envelopment analysis method are reported in Seiford and Thrall (1990), Ali and Seiford (1993) and Coelli (1995).

extensively in empirical studies since the late 1970s. One of these extensions involve the panel data models which can estimate time-varying efficiency and examine the sources of efficiency variation.

In logarithmic form, the stochastic frontier production function for panel data model can be presented as follows

$$\log(y_{it}) = \log(f(x_{it}; \beta)) + v_{it} - u_{it},$$

$$i = 1, 2, \dots, n, t = 1, 2, \dots, T \quad (1)$$

where y_{it} represents the production level of the i^{th} sample firm at period t , $f(x_{it}; \beta)$ is a suitable function of a vector, x_{it} , of inputs for the i^{th} firm at period t and a vector, β , of unknown parameters, v_{it} catches the effect of random shocks and statistical noise and is assumed to be independently distributed of u_{it} and have normal distribution with mean zero and variance σ_v^2 , u_{it} is associated with technical inefficiency factor and assumed to be the non-negative truncations of a normal distribution. The non-negative assumption of u_{it} is to ensure that firms' actual production point lies beneath the frontier. The parameters and firm-specific technical efficiency in this model can be estimated by the maximum likelihood method using FRONTIER 4.1 (Battese and Coelli 1993).

To identify some of the reasons for differences in estimated efficiencies between firms, economists have developed stochastic frontier models in which the inefficiency effects can be expressed as an explicit function of a set of firm-specific variables and a random error.

$$u_{it} = \delta z_{it} + w_{it} \quad (2)$$

where z_{it} is a vector of firm-specific variables such as firm age, ownership and time as well, δ a vector of parameters to be estimated and w_{it} defined by the truncation of the normal distribution with zero mean and variance σ_w^2 .

Thus, u_{it} is the non-negative truncations of the normal distribution with mean $z_{it}\delta$ and variance σ_u^2 .

Equation (2) is estimated together with the frontier production function (1), i.e. two equations are estimated in one step. Traditionally a two-step procedure has been used: the regressions are run in two separate steps. The first step is to estimate technical efficiency from a production function without the presence of the firm-specific variables. While this is done, the efficiency variable is further regressed in the second stage on these variables. Kumbhakar (1987) argues that the non-negative feature of the dependent variable, technical efficiency, is ignored in the estimation in the second stage. To correct these problems, Kumbhakar, Ghosh and McGuch (1991) used a one-step method that can accommodate in the likelihood function the non-negative nature of the technical efficiency. Battese and Coelli (1993) proposed the above panel data version of this model which is used in this study.

4 Estimation and results

4.1 The sample

In this section, the stochastic frontier production model proposed by Battese and Coelli (1993) is applied to the Chinese iron and steel industry using panel data of sixty-one enterprises. The data are drawn from the Yearbook of the Iron and Steel Industry of China (Editorial Board, various issues). These enterprises are situated in twenty-four Chinese provinces including two large cities, Beijing and Shanghai. Twenty-six of them are supervised directly by the central government and hence belong to the category of the key enterprises. The other thirty-five fall into the category of the local small and

medium enterprises, which are supervised by the local governments. However, they are all under the jurisdiction of the Ministry of Metallurgical Industry as well. As a whole, these sixty-one enterprises account for about 67 percent of the net value of output and over a half of employment of the iron and steel industry in 1992. They produce about 78 percent of China's pig iron, 73 percent of crude steel and 64 percent of the finished steel products in the same year. Therefore, this sample can be used as a realistic proxy for the entire industry.

Summary statistics of these firms are shown in Table 1. The local firms have an average age of 33 years, which may indicate that most of them were set up in 1958 following the Great Leap Forward (GLF). Local firms are very different from their centrally-supervised counterparts in terms of average

Table 1 Statistics of sixty-one firms 1992

Variables	Local	Key	All firms		Mean
			Max	Min	
Net value of output (m. yuan)	264	957	4196	33	559
Employment ('000)	16.6	55.1	222.3	1.95	32.1
Net value of assets (m. yuan)	397	2779	23345	44	1412
Capital-labor ratio	24.6	58	73.5	7.9	38.6
Age (years)	33	39	87	7	36
Crude steel (mts)	0.505	1.845	8.393	0.003	0.974
Pig iron (mts)	0.536	2.742	8.08	0.051	0.974
Steel products (mts)	0.359	1.319	5.437	0.036	0.698

Source:

Author's own calculation.

employment and turnover capacity. The mean employment of the key enterprises, for example, is about three times as great as that of the local

enterprises. So is the mean net value of output.⁴ In general, the key firms are more capital-intensive than the local ones. However, among the top ten firms with the highest capital-labor ratio, three of them belong to the local firm category.

4.2 Estimation and results

For the sake of simplicity, it is assumed in this study that firms employ labor and capital to produce a single output, following the Cobb-Douglas production relationship. The output, labor and capital variables represent the net value of output in 100 million yuan, total number of staff and workers in 10 thousand persons (year-end) and net value of fixed assets in 100 million yuan (year-end), respectively.⁵

In the initial model, it is assumed that changes in technology and technical efficiency may take place over time among the firms. To reflect this assumption, a time trend is included in both the main equation and the error term. This hypothesis will be tested by imposing restrictions on the coefficient of the time trend.

Firm-specific variables represent age, agglomeration, ownership, large and medium, respectively. The first two are to be defined in the following section. The ownership variable distinguishes the key firms from the local ones, taking a value of one for the former and zero for the latter. The large and medium

⁴According to the Editorial Board (1989, 48), the net value of output equals the sum of profit, tax, wage, interest, contributions to the welfare fund of staff and workers and miscellaneous fees. It is equivalent to value added, i.e. value of output less intermediate inputs. The net value of output is used as the dependent variable and differences in the product mix of output are ignored.

⁵ The content and measure of capital stock in Chinese industry are often controversial. Few studies have been undertaken to reestimate the value of fixed assets in Chinese firms (Chen et al. 1988). Due to data and technical constraints, officially published data of the net value of fixed assets are used in this paper.

variables capture the effect of scale economies among the firms. The firms are sorted according to the value of their capital stock and divided evenly into three groups, namely, large, medium and small. The large and medium groups are selected against the small one.

Following the above description, a model including all firm-specific variables is estimated (model B in Table 2). The estimation results show low t-values for the coefficients of OWNERSHIP, LARGE and MEDIUM. This may be due to the multicollinearity between OWNERSHIP and LARGE since large firms are usually in the 'key enterprise' category. However, the negative sign of the coefficients of these variables indicates that large and centrally-supervised

Table 2 Estimation results

	Final model		Optional models			
	Coefficient	t-ratio	A		B	
			Coefficient	t-ratio	Coefficient	t-ratio
<i>Inputs</i>						
Constant	-0.510	-6.653	-0.505	-6.680	-0.493	-6.197
Time	0.061	5.042	0.065	5.338	0.068	5.337
Capital	0.503	13.825	0.486	12.619	0.483	11.974
Labor	0.452	9.776	0.463	9.996	0.452	9.445
sigma-squared	0.277	8.570	0.260	7.843	0.261	7.852
gamma	0.653	10.442	0.642	10.607	0.649	12.006
<i>Firm-specific variables</i>						
Constant	2.083	6.307	2.055	5.840	2.138	6.172
Time	-0.057	-1.653	-0.046	-1.439	-0.044	-1.486
Age	-0.052	-6.155	-0.051	-5.759	-0.052	-5.050
Agglomeration	-0.001	-2.303	-0.001	-2.121	-0.001	-1.847
Ownership			-0.097	-0.729	-0.081	-0.562
Medium			0.112	0.921	0.044	0.313
Large					-0.131	-0.810
log likelihood value	-208.9		-208.0		-207.8	

Notes:

Sigma-squared is the sum of the variances of u and v.
Gamma is the ratio of the variance of u over sigma-squared.

firms might be more efficient than the small-medium and locally-supervised ones.

To correct for the multicollinearity problem, LARGE is excluded from the equation and the model is reestimated (model A in Table 2). The result still shows insignificant coefficients for OWNERSHIP and MEDIUM. Finally, both variables are dropped from the model (the final model in Table 2). The estimation result shows that the estimates of all parameters are significantly different from zero. A statistical test shows that the addition of these firm attributes is significant.⁶ The sum of the coefficients of labor and capital is 0.95, which is not significantly different from one.⁷ Since the estimated value of gamma is greater than a half, it may be concluded that a greater part of the residual variation in enterprise output is related to variation in technical efficiency than to random environmental variation.

The positive sign of the time trend in the main equation implies that substantial technological changes took place among the firms during 1984-1992, the same finding being reported in Wu (1995b) which examined the Chinese industrial sector. Furthermore, the negative sign of the time variable in the error term indicates that technical efficiency has increased over time among the firms. The mean efficiency of these enterprises is 75 percent (Table 3). This figure is greater than those estimated by Wu (1995a) and Kalirajan and Cao (1993). The difference may indicate the bias in the latter two studies due to their ignorance of the impact on efficiency of firm attributes and dynamics (time varying effects). The final estimates also show that both age and agglomeration effects are positively related to technical efficiency.

⁶ The value of the computed X-squared statistic with the degree of freedom of 4 is 97.

⁷ At the level of 5 percent.

Table 3 Technical efficiency rates of sixty-one firms 1984-1992

Codes	Names	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean
1	Shougang	0.938	0.942	0.950	0.943	0.944	0.943	0.945	0.946	0.950	0.944
2	Tanggang	0.905	0.905	0.894	0.898	0.911	0.903	0.826	0.841	0.909	0.888
3	Xuanguang	0.366	0.456	0.472	0.488	0.469	0.450	0.260	0.346	0.485	0.421
4	Taigang	0.842	0.849	0.859	0.880	0.900	0.910	0.875	0.918	0.916	0.883
5	Baotou	0.545	0.645	0.654	0.698	0.701	0.692	0.750	0.766	0.837	0.701
6	Angang	0.946	0.950	0.952	0.952	0.948	0.950	0.942	0.940	0.939	0.947
7	Liaogang	0.805	0.859	0.842	0.938	0.787	0.944	0.940	0.949	0.944	0.823
8	Bengang	0.927	0.926	0.936	0.938	0.948	0.944	0.866	0.763	0.822	0.939
9	Qigang	0.751	0.802	0.856	0.824	0.873	0.613	0.869	0.809	0.805	0.819
10	Baogang	0.235	0.148	0.315	0.389	0.433	0.805	0.790	0.798	0.835	0.491
11	Meigang			0.756	0.808	0.797	0.930	0.938	0.938	0.943	0.798
12	Magang	0.929	0.934	0.934	0.934	0.932	0.930	0.544	0.406	0.589	0.935
13	Wuyang	0.792	0.830	0.808	0.863	0.884	0.877	0.869	0.873	0.874	0.493
14	Wuhan	0.945	0.940	0.936	0.944	0.947	0.821	0.953	0.952	0.955	0.852
15	Daye	0.640	0.771	0.741	0.745	0.790	0.821	0.838	0.840	0.857	0.947
16	Xianggang	0.671	0.648	0.666	0.699	0.740	0.798	0.617	0.626	0.610	0.763
17	Panguang	0.414	0.422	0.403	0.458	0.458	0.906	0.820	0.861	0.901	0.676
18	Chonggang	0.868	0.864	0.878	0.867	0.901		0.882	0.875	0.865	0.424
19	Chenggang	0.660	0.778	0.800	0.812	0.889		0.873	0.891	0.885	0.876
20	Chenggang	0.788	0.804	0.811	0.817	0.843		0.762	0.891	0.818	0.820
21	Guiyang	0.763	0.847	0.856	0.836	0.840		0.541	0.707	0.794	0.831
22	Guizhou		0.559	0.595	0.491	0.607		0.592	0.584	0.626	0.801
23	Shaogang	0.423	0.407	0.462	0.508	0.501	0.492	0.649	0.509	0.528	0.572
24	Jiugang	0.520	0.536	0.645	0.634	0.695		0.448	0.624	0.678	0.491
25	Shuangang	0.173	0.274	0.334	0.364	0.352	0.476	0.823	0.528	0.571	0.635
26	Hangang		0.834	0.836	0.845	0.826		0.717	0.796	0.901	0.391
27	Xinggang		0.774	0.759	0.803	0.831		0.872	0.872	0.901	0.848
28	Chengde		0.675	0.621	0.593	0.618		0.588	0.803	0.803	0.783
29	Shigang		0.836	0.820	0.785	0.814		0.769	0.850	0.820	0.852
30	Shigang		0.554	0.631	0.645	0.625		0.662	0.789	0.886	0.811
31	Linfen								0.623	0.623	0.652

32	Changzhi	0.721	0.793	0.853	0.878	0.797	0.836	0.875	0.822
33	Huang	0.644		0.606	0.411	0.354	0.569	0.868	0.575
34	Xinfu	0.792	0.799	0.837	0.835		0.736	0.879	0.813
35	Beifang	0.598	0.697	0.711	0.658	0.577	0.664	0.690	0.656
36	Yingkou		0.674	0.719	0.740	0.856	0.759	0.921	0.841
37	Tonghua	0.706	0.472	0.579	0.665	0.775	0.709	0.784	0.729
38	Xigang	0.434	0.887	0.877	0.878	0.643	0.661	0.773	0.604
39	Hagang	0.828	0.786	0.737	0.782	0.578	0.729	0.897	0.811
40	Nangang	0.734		0.737	0.851	0.703	0.696	0.884	0.760
41	Nanzha		0.917	0.748	0.880	0.888	0.861	0.873	0.868
42	Sugang	0.894	0.776	0.840	0.774	0.730	0.774	0.917	0.837
43	Hanggang	0.786	0.776	0.847	0.845	0.834	0.884	0.897	0.828
44	Sangang	0.793	0.822	0.847	0.845	0.829	0.831	0.880	0.835
45	Xinyu	0.753	0.756	0.765	0.759	0.802	0.730	0.856	0.774
46	Jigang	0.768	0.758	0.819	0.781	0.799	0.814	0.849	0.798
47	Laigang	0.516	0.607	0.650	0.739	0.754	0.763	0.831	0.694
48	Zhanggang	0.782	0.758	0.806	0.820	0.810	0.778	0.807	0.784
49	Anyang	0.781	0.810	0.813	0.848	0.839	0.833	0.884	0.830
50	Echeng	0.780	0.796	0.634	0.550	0.780	0.783	0.852	0.739
51	Xialu	0.908	0.745	0.743	0.772	0.497	0.535	0.658	0.694
52	Liangang	0.810	0.852	0.833	0.806	0.854	0.814	0.895	0.838
53	Henggang	0.676	0.687	0.642	0.687	0.870	0.810	0.713	0.770
54	Lengshuijiang	0.801	0.815	0.707	0.827	0.682	0.686	0.758	0.708
55	Shaogang	0.859	0.859	0.844	0.732	0.861	0.881	0.884	0.823
56	Guanggang	0.907	0.808	0.687	0.812	0.673	0.582	0.896	0.778
57	Liugang	0.811	0.855	0.801	0.824	0.704	0.803	0.814	0.791
58	Daxian	0.833	0.845	0.850	0.872	0.675	0.776	0.802	0.792
59	Kunming	0.489	0.426	0.530	0.569	0.885	0.891	0.914	0.870
60	Lueyang	0.775	0.787	0.761	0.780	0.613	0.624	0.768	0.574
61	Xinjiang					0.817	0.813	0.898	0.804
	Mean	0.689	0.723	0.744	0.746	0.761	0.755	0.821	0.755

Note: The firm names are abbreviated names only. For more details, please refer to the Editorial Board (1993b).

First, the firm age variable, AGE, represents the age of the firm from the date of its foundation to 1992. The positive relationship between firm age and efficiency may imply that old firms gain experience in production from learning by doing and hence are more efficient than younger firms. In addition to the learning-by-doing effects, the Chinese government policy of industrial development in the last decade makes this trend possible. Recognizing the disadvantage of old machinery and equipment in the industrial sector and the high cost of building new plants, the Chinese government has made upgrading technology the central-piece of its long term industrial strategy (Tidrick 1986). It seems that this policy has contributed to the relatively better performance of the old plants.

Second, the effect of agglomeration economies on enterprise efficiency is reflected by the agglomeration variable, AGG. Two factors are important in measuring the degree of agglomeration in a region. One is the total number of the iron and steel enterprises within the region; another is the total value of net output produced by these firms. On the one hand, the total number of firms within a region reflects the degree of industrial concentration: the larger the number of firms, the higher degree of industrial concentration has the region. On the other hand, the total value of net output produced by a region may be a measure of the size of the concentration: the larger the total output value of a region, the greater size of industrial concentration has the region. The combination of these two indexes can avoid the bias due to the use of a single index. For example, a large number of small firms in one region may generate just a small value of output but few large firms in another region may have a very large value of output. In these cases, neither output nor the number of firms is a good indicator of agglomeration. Following this line, the agglomeration variable, AGG, is defined as the geometric mean of these two

variables.⁸ According to the final estimation, there are gains from the economies of agglomeration in the industry. In other words, the economies of agglomeration are positively related to enterprise performance.

5 Summary and comments

Empirical analysis using the panel data from sixty-one Chinese iron and steel enterprises illustrates that Chinese firms have achieved, on an average, about 82 percent of their potential output in 1992. This leaves scope for further improvement. According to the findings, firm age has a significantly positive effect on enterprise performance. Old firms can take advantage of their accumulated experience in production and hence are likely to be more efficient than younger firms. The findings in this study show no significant effect of economies of scale on enterprise efficiency. There is also no difference between the key or centrally-controlled enterprises and the locally-controlled firms. Hence, the hypothesis that the locally-supervised enterprises are more efficient than the centrally-supervised ones cannot be accepted, as far as the sample used in this study is concerned. Furthermore, it is found that firms exposed to certain locations may gain from the economies of agglomeration and hence perform better than the others.

The findings in this study have important policy implications. It is widely publicized that state-owned firms in China are drowning in red ink. Over 50 percent of them are actually running in the red.⁹ Due to social and political reasons, these loss-making firms are still operating. However, as China's economic reform deepens, these money-losing state firms have to be shut

⁸ As a measure of the degree of agglomeration, Jefferson (1989) used the total number of industrial enterprises, and Wu (1990) used the total value of output. Both methods are likely to be subject to bias because they fail to take 'concentration' and 'size' jointly into consideration.

⁹ See *Far Eastern Economic Review*, 23 February 1995, for a survey of China's state firms.

down sooner or later. The findings in this exercise provide important economic rationale for doing so. For example, if 10 percent of the worst performing firms were shut down and their resources transferred to other firms, China's steel output in 1992 would be 3.7 percent greater than the current output, other things being equal. Furthermore, if a quarter of the least efficient firms were closed down, then the steel output would be 7.3 percent greater than the current level. In other words, under this circumstance, China's steel output in 1992 would be about 98 million tonnes rather than 91 million tonnes. It is clear that the industry has much to gain from the shut-down of the least efficient firms.

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