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Industries TFP and Environmental Regulation Cost Analysis Using Malmquist–Luenberger

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Abstract

Environmental problem is a worldwide focus, so as the effect of environmental regulation on economic. In this paper, we constructed a model including energy consumption and integrated pollutant emissions of "Three wastes" as "bad" output. This paper used Malmquist–Luenberger based on directional distance function to measure TFP and environmental regulation cost of Chinese 36 industries from 2001 to 2010. The result was that: From the overall analysis, the TFP was lower after considering the environmental regulation. Technological progress was the main driver of productivity growth. Environmental regulation brought about a certain cost; from the industry analysis, there were some differences between industries on TFP growth and the cost of environmental regulation. The monopoly and heavy industrieswere the focus in the industry; from the annual analysis, TFP increased during "Eleventh Five-Year Plan" period, mainly drived by technological progress.

Keywords: *environmental regulation, directional distance function, TFP, technical progress*

1. Introduction

Environmental issues have always been a whole world problem, whether developed or not developed countries, whether poor or rich countries must face. Environmental issues but also with economic issues rised to a globalization problems. Nowadays, environmental issues and economic issues both must be taken into account. Furthermore, it is a pair of contradictory relationship need to balance. Does Environmental Regulation as a measure to protect the environment, what have impact on the economy, promote or hinder economic growth? TFP is one of the important indicators to measure economic performance. The traditional TFP just take labor, manpower and other inputs of production factors into account, not the resource and environmental factors into consideration, which to some extent distorted changes in the social welfare and economic performance evaluation, but also further misguided policy recommendations [1].

Due to absence of the price information of resource and environmental factors, the traditional measure of TFP (such as the Tornqvist index and Fischer index) will not be able to account for the productivity with resource and environmental constraints. Traditional distances function although can measure TFP without both pricing information, cannot calculated the productivity including undesirable outputs ("bad output", such as wastewater discharges). Pittman first attempted to take "bad" output as an input to measure the productivity, but this is contrary to the "mass balance" (Materials Balanced Approach) [2]. Chung et al. [3] proposed Malmquist-Luenberger (ML) while introduced a new function - Directional Distance Function; it can measure TFP existing "bad" output, and does not require price information of resources and environmental factors. ML index has played a certain role on measuring TFP existing "good" output and "bad" outputs, the productivity growth can be further decomposed into efficiency change and technological progress.

In recent years, a large number of scholars have conducted empirical research on TFP. Tommy et al. [4] studied the Swedish CO2 emission taxes and the EU ETS for the paper industry in terms of productivity effects. Wang et al. [5] using ML measured the APEC 17 countries and regions, including CO2 emissions from 1980 to 2004, TFP growth and its components. They draw that after consideration of environmental regulation, APEC's TFP growth raise, technological progress is a source of its growth. Wang et al. used ML to measure regional TFP of China 1998-2007 with environmental constraints. The study found after

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considering environmental considerations, the Chinese regional industrial TFP index decreased, mainly promoted by technical progress. Ye et al. used ML index measure TFP under four different environmental regulation policies in all regions china 1999-2008, draw that environmental regulations will increase TFP. Shen et al. [8] considering SO2 emissions as a “bad” output, used the ML to calculate high energy-consuming industries TFP, and on the basis of studying industry and inter-provincial differences of high energy-consuming industries , they empirical analysis influencing TFP factors. Wang et al. used of the directional distance function and the ML to estimate TFP of 36 industrial China 2001-2008 with CO2 emissions constraints, the TFP levels were increased in different degrees. Chai [10] taking SO2 and COD emissions as "bad output", calculated the traditional TFP without considering environmental constraints and consideration of environmental constraints environment TFP 36 industries in China 2001-2009.

However, few people discuss theTFP in our industry perspective; few people do research with energy as an input; meanwhile, in selecting the "bad" output indicators, most take the single indicator, but we know pollutants including waste water, waste gas and solid waste. A single pollutant as "bad" output will cause some errors, and thus may mislead policy recommendations. Therefore, this article took 36 industries as the research object and the energy as an input, while selecting comprehensive pollutant emissions as "bad" output for TFP and environgment regulation cost studies.

2. Research Method

2.1. Environmental Technology

In order to integrate environmental considerations into the framework of efficiency analysis, you first need to construct a possibility set containing "good" output and "bad" output of the production. Fare [11] contained the structural relationship between the "bad" output, including output and factor resources into as environmental technology. First define $x = (x^1, x^2, \dots, x^N) \in R_+^N$ as a set of input vectors, $y = (y^1, y^2 \dots, y^M) \in R_+^M$ is a production of "good" output vector, $b = (b^1, b^2, \dots, b^J) \in R_+^J$ as the "bad" output vector (such as waste water, waste gas, solid waste). Simulating environment technology through the output set of p (x).

$$p(x) = \{(y, b): x \text{ can produce } (y, b)\} \quad x \in R_+^N \tag{1}$$

$p(x)$ provides a description of all technologically feasible relationships between inputs and outputs. p (x) need to meet three assumptions: (1) "Bad" outputs joint weak disposability, if $(y, b) \in p(x)$ and $0 \le \theta \le 1$, then $(\theta y, \theta b) \in p(x)$. This feature is considered "bad" products reduce the need to invest resources and facilities to control pollution, resulting in reduction of normal output because of a reduction in investment in production. This shows that there is a cost reduction of pollution, and thus the idea of environmental regulation included in the analysis framework. (2) Input and "good" output strong disposability, if $x_1 \ge x_2$, then $p(x_1) \supseteq p(x_2)$; If $(y_1, b) \in p(x)$ and$y_1 \ge y_2$, then$(y_2, b) \in p(x)$. This feature is that "good" outputs are freely disposable, and "bad" outputs remain unchanged. (3) "Good" output and "bad" outputs null-joint. If $(y, b) \in p(x)$ and $b = 0$, then$y = 0$. That is to say if there are no "bad" products, there would be no "good" products.

2.2. Directional Distance Function

The structure of environmental technology is conducive to the interpretation of the concept, but not contributing to the calculation, so a new function came out. DDF was first proposed by Chambers (1996) [12] as promotion of Luenberger (1992) profit function. Fare, etc. (2001) [13] according to Luenberger shortage function ideological construct DDF:

$$\vec{D}_0^t(y^t, x^t, b^t; g) = \sup\{\beta: (y^t, b^t) + \beta g \in p^t(x^t)\} \tag{2}$$

In the expression (2), $g = (g_y, g_b)$ expresses the direction of expansion of output vector, the choice of g is not unique, according to the different choice of the g, we can consider different case of environmental control. $g = (-x, y, -b)$, says y is proportional to the increase, inputs and b is proportional to the decrease. β is maximum feasible reduction in number of x, y, b.

In production process, we seek maximum profit. But at the same time, we have to take input into account; the producers cannot be infinitely large investment of resources in order to maximize the "good" output, so this paper uses DDF for the input have a certain constraints.

Suppose t = 1, ⋯, T periods, $k = 1, \cdots, K$producers using a vector of n = 1,. . .,N inputs to obtain a vector of m = 1,. . .,M desirable outputs and a vector of j = 1,. . .,J undesirables. Linear programming problem of producer $k'\left(x^{t,k'}, y^{t,k'}, b^{t,k'}\right)$ under no environmental regulation and strict environmental regulation are as followed:

No environmental regulation

$$\vec{D}_{s0}^{t}\left(y^{t,k'}, x^{t,k'}, b^{t,k'}; -x^{t,k'}, y^{t,k'}, -b^{t,k'}\right) = \mathrm{Max}\beta_s$$

$$\text{s.t.}\begin{cases} \sum_{k=1}^{K} z_k^t y_{km}^t \geq (1+\beta_s) y_{k'm}^t, m = 1, \dots, M \\ \sum_{k=1}^{K} z_k^t x_{kn}^t \leq (1-\beta_s) x_{k'n}^t, \quad n = 1, \dots, N \\ z_k^t \geq 0, \qquad k = 1, \dots, K \end{cases} \tag{3}$$

Strict environmental regulation

$$\vec{D}_{w0}^{t}\left(y^{t,k'}, x^{t,k'}, b^{t,k'}; -x^{t,k'}, y^{t,k'}, -b^{t,k'}\right) = \mathrm{Max}\beta_w$$

$$\text{s.t.}\begin{cases} \sum_{k=1}^{K} z_k^t y_{km}^t \geq (1+\beta_w) y_{k'm}^t, m = 1, \dots, M \\ \sum_{k=1}^{K} z_k^t b_{kj}^t = (1-\beta_w) b_{k'j}^t, j = 1, \dots, J \\ \sum_{k=1}^{K} z_k^t x_{kn}^t \leq (1-\beta_w) x_{k'n}^t, \quad n = 1, \dots, N \\ z_k^t \geq 0, \qquad k = 1, \dots, K \end{cases} \tag{4}$$

2.3. Environmental Regulation Cost

Under environmental regulation, the producers need to put some resources to control the environmental pollution, which is bound to reduce the output in the economy, reducing economic output is the cost of environmental regulation. Its value can get through model (3) and model (4) using the index that Domazlicky and Weber (2004) [14] construct.

$$\mathrm{Cost}_t = \frac{1+\vec{D}_{s0}^{t}\left(y^{t,k'}, x^{t,k'}, b^{t,k'}; -x^{t,k'}, y^{t,k'}, -b^{t,k'}\right)}{1+\vec{D}_{w0}^{t}\left(y^{t,k'}, x^{t,k'}, b^{t,k'}; -x^{t,k'}, y^{t,k'}, -b^{t,k'}\right)} - 1 \tag{5}$$

2.4 Malmquist-Luenberger Productivity Index

Based on the DDF and modeled M Index, Chung et al.（1997）made the following definitions for Malmquist-Luenberger (ML) index based on period t and t +1:

$$ML_t^{t+1} = \left[\frac{1+\vec{D}_0^{t}(x^t, y^t, b^t; g^t)}{1+\vec{D}_0^{t}(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})} \times \frac{1+\vec{D}_0^{t+1}(x^t, y^t, b^t; g^t)}{1+\vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})}\right]^{1/2} \tag{6}$$

ML index can be decomposed into two parts, one for measuring efficiency changes (MLEFFCH), the other for measuring technical progress (MLTECH), decomposed expression is as follows:

$$ML_t^{t+1} = MLEFFCH_t^{t+1} \times MLTECH_t^{t+1} \tag{7}$$

$$MLEFFCH_t^{t+1} = \frac{1+\vec{D}_0^{t}(x^t, y^t, b^t; g^t)}{1+\vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})} \tag{8}$$

$$MLTECH_t^{t+1} = \left[\frac{\{1+\vec{D}_0^{t+1}(x^t, y^t, b^t; g^t)\}\{1+\vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})\}}{\{1+\vec{D}_0^{t}(x^t, y^t, b^t; g^t)\}\{1+\vec{D}_0^{t}(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})\}}\right]^{\frac{1}{2}} \tag{9}$$

$ML_t^{t+1} MLEFFCH_t^{t+1}$和$MLTECH_t^{t+1}$ greater than (less than) 1 represent productivity growth (decline), efficiency improvement (deterioration) and cutting-edge technical progress (regress).

3. Empirical Research

This paper took 36 Chinese industries in 2001-2010 as the research object from "China Statistical Yearbook". However, some data of “Mining of Other Ores”, “Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work”, and “Manufacture of Artwork and Other Manufacturing Recycling and Disposal of Waste” are missing, in order to maintain the industry classification consistency and continuity in the “energy index, environmental indicators and economic indicators”, the sample data to be removed, eventually identified 36 industries. In this paper, the industrial were the enterprises above designated size, industry data were from the "China Statistical Yearbook "and "Environment Statistical Yearbook".

3.1. Data and Variables

(1) Capital input: choose the annual average balance of net fixed assets as the capital input. For price deflator, we used price index for investment in fixed assets and chose base period is 2001. (2) Labor input: labor input is generally measured by the labor time or labor number. Due to the labor time is difficult to obtain and no corresponding index data in "China Statistical Yearbook", so we chose the above-scale industries Annual Average the number of labor as labor input. (3) Energy input: industrial enterprises, economic activities cannot do without certain energy. The paper chose industry's total energy consumption as a resource input of each industry. (4)"Good" output: The choice of "good" output indicators have always been of great controversy, and some scholars chose the total industrial output value, some chose the industrial added value, but most scholars tend to chose the industrial added value. However, industrial added value in 2009-2010, cannot obtain in "China Statistical Yearbook", so it took total industrial output value to calculate the good output. (5) "Bad" output: The choice of "bad" output indicators is more numerous than the "good" output indicators. For a more comprehensive and more integrated assessment of the economic performance under environmental regulation, choose comprehensive environmental indicators. The total discharge of industrial wastewater, industrial sulfur dioxide emissions and emissions of industrial solid waste was "Bad" output.

3.2. Empirical Results and Analysis

According to the research methods and data processing above, estimated economic and environmental indicators results under environmental regulation and without environmental regulation through Matlab 7.0 software programming.

Based on the environmental technical efficiency (ETE), the industries are divided into three types: highly coordinated industry, more coordinated and uncoordinated industry sectors. 36 industries data results are summarized in Table 1 below v according to these three types:

Table 1. The Average Annual ML Index, Composition Decomposition and Environmental Regulation Cost

Type	Under environmental regulation				Without environmental regulation				COST
	ML	MLEFCH	MLTECH	ETE	M	MEFCH	MTECH	TE	
Highly coordinated industry	1.065	1.016	1.071	0.902	1.332	1.010	1.367	0.819	0.119
More coordinated industry	1.072	1.016	1.062	0.733	1.201	1.009	1.213	0.704	0.042
Uncoordinated industry	1.062	1.014	1.044	0.635	1.128	1.010	1.138	0.623	0.017
Total	1.067	1.015	1.060	0.757	1.221	1.009	1.239	0.717	0.059

(1) Overall, after considering the undesirable output "bad" products, that is, considering environmental regulation, the TFP decreased, which can show that the traditional measurement methods overestimate TFP. It also shows, without considering the environmental regulation, companies don't need to put part of resources (labor and capital) into environmental regulation input as to reduce environmental pollution. Instead, companies can invest these part resources in the production process, resulting in more "good" output.

(2) In the case of environmental regulation, the overall average TFP index was 1.067, indicating that the various sectors of the average annual TFP growth rate was 6.7%. From an average sense, this productivity growth of 6.7%, 1.5% of which technical efficiency promote, 6.0% of which technological progress promote. This shows that our industry efficiency improves and technology progress is the main driver of productivity growth. This paper further analyzed from the time point of view, shown in Figure 1. TFP change was mainly due to comprehensive technical efficiency change and technological progress the joint action. In the production process, the constraints of environmental regulation, companies strive to improve economic development and try to find a balance.

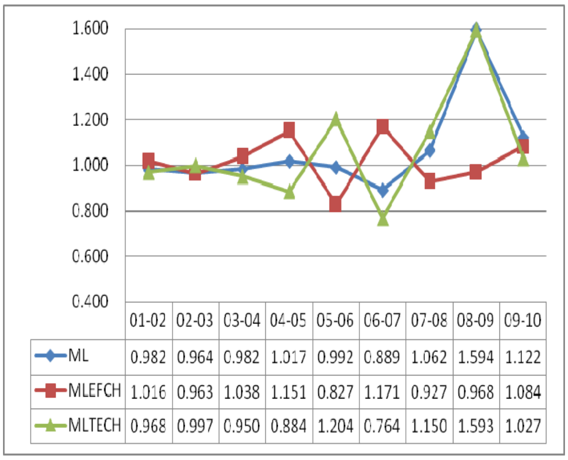

Figure 1. Industry Average TFP and Component Decomposition of ML in 2001-2010

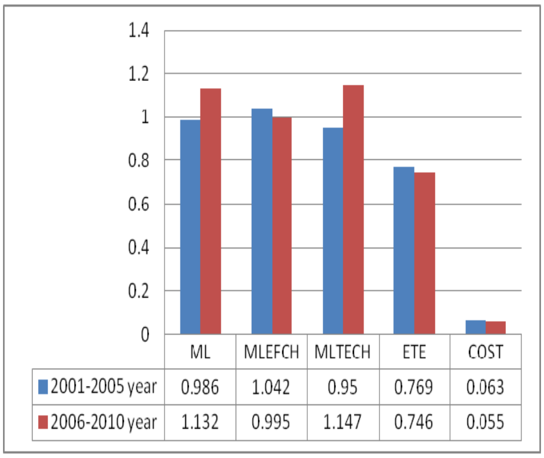

Figure 2. Comparison Sample changes in Period Two Stages

(3) From the industry perspective, after considering the environmental regulation, ML didn't descend as the performance of industry coordination. On the contrary, ML of more coordination industry is the largest. This phenomenon shows and no necessary connection between TFP and the industry coordination. Meanwhile, the paper also found that TFP are quite different between Chinese industrial sectors. Of which 10 industries showed a decrease in productivity. In these 10 industries, including two highly coordinated industries, four more coordinated industries and four uncoordinated coordination industries. Three industries showed "efficiency change" and "technical progress" "double low" of the 10 industries, respectively, “Manufacture of Textile”, “Manufacture of Paper and Paper Products” and “Manufacture of Non-metallic Mineral Products” for all these three industries in order to improve factor productivity, need to introduce appropriate technology or perform certain technological innovation, thus promote technological progress. Meanwhile, they must in an appropriate way to use these technologies to improve technical efficiency. The remaining seven industries all showed regression techniques, and a number of them are monopoly industries and traditional industries, such as “Mining and Washing of Coal”, “Mining and Processing of Ferrous Metal Ores” and “Production and Supply of Electric Power and Heat Power”. These industries will face some difficulties on technological innovation. Meanwhile, they have been for our environmental regulation difficult and focus (See appendix Table 1).

(4) This study sample time spans China two important periods - "Fifteen- Year Plan" and "Eleventh Five-Year Plan", so this paper was divided into two period’s interval: 2001-2005 and 2006-2010, the results shown in Figure 2. From the figure we can see that in the "Eleventh Five-Year Plan" period, TFP had improved, technological progress has improved, and however, technical efficiency was presented as worse. In the "Eleventh Five-Year Plan" period, TFP growth can be considered mainly driven by technological progress. In the background of "Eleventh Five-Year Plan", facing environmental regulation, the industries introduced a series of advanced technology and equipment and conducted a series of technological innovation activities. However, in the process of economic development introduced advanced technology

cannot meet the conditions of their economic development, resulting in reduced matching technical skills, also led to the deterioration of technical efficiency. From the industry perspective, the industries of TFP had increased were about 77.8% of the industry in the period 2006-2010. TFP of five industries among the above-mentioned ten industries in the "Eleventh Five-Year Plan" period, had been improved, namely “Manufacture of Textile”, “Manufacture of Paper and Paper Products”, “Manufacture of Non-metallic Mineral Products”, “Production and Supply of Electric Power and Heat Power”. Although these industries TFP is low, but in the "Eleventh Five-Year Plan" period, has a certain degree of improvement.

(5) From environmental regulation cost analysis, environmental regulation can cause some loss of productivity seen from Table 1, i.e., environmental regulation has a cost to some extent. Environmental regulation cost have some differences between the industries, the top five industries (at the cost of regulation descending order) were: “Mining and Processing of Non-Ferrous Metal Ores”,” Mining and Processing of Ferrous Metal Ores”, “Extraction of Petroleum and Natural Gas” and “Extraction of Petroleum and Natural Gas”. The environmental regulation cost of “Manufacture of Paper and Paper Products” as a one of the most concerns industries ranked sixth. Thus industries with much environmental regulations cost found are also those monopolies and heavy industries. This will be an important and difficult for our environmental regulation. From Figure 2, we find that in the "Eleventh Five-Year Plan" period, the environmental regulation cost has a certain degree of reduction, which means environmental regulation is effective.

4. Conclusion

This paper used Malmquist-Luenberger index which based on directional distance function to estimate the total factor productivity and environmental regulation cost of Chinese 36 industrial. In this model we took energy consumption as an input and comprehensive "three wastes" emissions as the "bad" output, making the input and output more in line with actual production process.

Research showed that the overall average TFP index was 1.067, the average annual TFP in various industries was 6.7%, driven by 1.5% technical efficiency, 6.0% technological progress, technological progress as the productivity growth main driving force. Also found that after consideration environmental regulation, TFP reduced and there was a certain cost. Classified by the environmental technology efficiency, we found there is no necessary connection between TFP and the industry coordination; the exponential growth of total factor productivity was quite different between Chinese industrial. 10 industries showed a decrease in productivity, the environmental regulation focus “Mining and Washing of Coal”, “Mining and Processing of Ferrous Metal Ores”, “Production and Supply of Electric Power and Heat Power” and “other monopolistic strong and heavy industries”. In the "Eleventh Five-Year Plan" period, total factor productivity index had improved, so as the technological progress, and however, technical efficiency was presented as worse. The main reason was the introduction of advanced technology or equipment was incompatible with business development at the economic level.

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Appendix

Table 1. National 36 industry average ML index, composition decomposition and environmental regulation costs

	ML	ML-EFCH	ML-TECH	ETE	M	M-EFCH	M-TECH	TE	COST
Mining and Washing of Coal	0.966	1.022	0.959	0.636	1.117	1.016	1.120	0.613	0.037
Extraction of Petroleum and Natural Gas	1.099	1.020	1.092	0.822	1.114	1.003	1.196	0.726	0.139
Mining and Processing of Ferrous Metal Ores	0.899	1.012	0.926	0.855	1.066	1.015	1.072	0.632	0.353
Mining and Processing of Non-Ferrous Metal Ores	1.065	1.017	1.073	0.963	1.101	1.007	1.117	0.649	0.495
Mining and Processing of Nonmetal Ores	0.996	1.017	0.989	0.587	1.033	1.014	1.028	0.579	0.014
Processing of Food from Agricultural Products	0.946	1.014	0.968	0.746	1.260	1.013	1.291	0.732	0.020
Manufacture of Foods	1.044	1.015	1.051	0.703	1.240	1.014	1.249	0.696	0.010
Manufacture of Beverages	0.901	1.005	0.919	0.696	1.281	1.004	1.309	0.687	0.013
Manufacture of Tobacco	1.127	1.015	1.111	0.982	1.708	1.016	1.692	0.982	0.000
Manufacture of Textile	0.932	0.976	0.971	0.745	1.071	0.974	1.116	0.738	0.010
Manufacture of Textile Wearing Apparel,Footware, and Caps	1.162	1.025	1.154	0.734	1.374	1.022	1.367	0.728	0.008
Manufacture of Leather, Fur, Feather and Related Products	1.085	1.034	1.070	0.810	1.416	1.033	1.407	0.801	0.012
Processing of Timber,Manufacture of Wood,Bamboo,Rattan,Palm,	1.160	1.014	1.106	0.613	1.113	1.014	1.116	0.612	0.002
Manufacture of Furniture	1.159	1.063	1.093	0.740	1.470	1.029	1.445	0.685	0.084
Manufacture of Paper and Paper Products	0.939	0.982	0.954	0.739	1.060	0.987	1.091	0.659	0.113
Printing,Reproduction of Recording Media	1.164	1.026	1.150	0.725	1.282	1.017	1.241	0.641	0.138
Manufacture of Articles For Culture, Education and Sport Activity	1.157	1.045	1.154	0.775	1.307	1.019	1.324	0.711	0.088
Processing of Petroleum, Coking, Processing of	1.070	1.022	1.065	0.978	1.021	1.008	1.076	0.971	0.007

Nuclear Fuel									
Manufacture of Raw Chemical Materials and Chemical Products	1.048	0.979	1.076	0.711	0.995	0.982	1.029	0.695	0.022
Manufacture of Medicines	1.083	1.002	1.095	0.695	1.291	1.002	1.307	0.689	0.009
Manufacture of Chemical Fibers	0.964	1.022	0.963	0.726	1.127	1.021	1.130	0.710	0.022
Manufacture of Rubber	1.179	1.010	1.055	0.700	1.144	1.011	1.156	0.698	0.003
Manufacture of Plastics	1.179	1.018	1.069	0.682	1.149	1.004	1.163	0.642	0.060
Manufacture of Non-metallic Mineral Products	0.982	0.998	0.992	0.617	1.004	0.998	1.015	0.606	0.018
Smelting and Pressing of Ferrous Metals	1.062	1.018	1.054	0.783	1.021	1.013	1.031	0.744	0.052
Smelting and Pressing of Non-ferrous Metals	1.009	1.014	1.013	0.734	1.062	1.014	1.072	0.718	0.024
Manufacture of Metal Products	1.156	1.028	1.137	0.679	1.127	1.017	1.142	0.677	0.004
Manufacture of General Purpose Machinery	1.161	1.020	1.147	0.722	1.269	1.004	1.295	0.705	0.025
Manufacture of Special Purpose Machinery	1.149	1.028	1.124	0.714	1.333	1.009	1.351	0.703	0.015
Manufacture of Transport Equipment	1.072	1.022	1.059	0.842	1.570	1.007	1.564	0.824	0.022
Manufacture of Electrical Machinery and Equipment	1.112	1.014	1.128	0.918	1.502	1.013	1.545	0.829	0.108
Manufacture of Communication Equipment,Computers and Other	1.179	1.000	1.188	0.984	1.616	0.993	1.640	0.970	0.015
Manufacture of Measuring Instruments and Machinery for Cultural	1.170	1.021	1.152	0.831	1.465	1.006	1.511	0.803	0.035
Production and Distribution of Electric Power and Heat Power	0.839	1.002	0.915	0.933	1.076	1.005	1.218	0.826	0.129
Production and Distribution of Gas	1.141	1.029	1.117	0.598	1.116	1.027	1.121	0.591	0.011
Production and Distribution of Water	1.057	1.005	1.058	0.542	1.053	1.002	1.059	0.538	0.007
Total	1.067	1.015	1.060	0.757	1.221	1.009	1.239	0.717	0.059