Productivity Growth in the Presence of Environmental Regulations in Chinese Manufacturing Industry*

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This paper employs a relatively new method, the Malmquist-Luenberger productivity index (MLPI) based on the directional distance function, to analyze the total factor productivity (TFP) growth in Chinese manufacturing industry. The MLPI is decomposed into technical change index and efficiency change index like the general Malmquist productivity index (MPI) based on the distance functions. We investigate the TFP growth in the presence of environmental regulations, and compare it with the two results estimated by the traditional MPIs, namely , one is when ignoring pollutants, and the other is under the strong disposability of pollutants. The results show that most of provinces presented the improvement in TFP under regulations during the 1995-2002 period. Their TFP growths were mostly attributable to the innovation in technology rather than the improvement in efficiency. In addition, for most of provinces, the TFP under regulations was higher than those estimated by two traditional productivity measures. Therefore, two conclusions can be obtained: one is that the traditional productivity measures underestimated the TFP growth experienced by Chinese manufacturing industry. The other is that the environmental technology rather contributed to the economic growth in Chinese manufacturing industry during the 1995-2002 period.

1. Introduction

With an average annual GDP growth rate of about 10 percent in the past two decades (World Bank, 2003), rapid economic growth in China has attracted worldwide attention. However, accompanied by this remarkable economic growth, the sustainable growth is being threatened by serious environmental pollutions. Therefore, the environmental problems are increasingly becoming one of the fatal issues for the development of Chinese economy.

Most of the former studies on evaluating Chinese productivity growth had neglected the impacts of the environmental factors (see: Lau et al., 1990; Wu, 1995; Jefferson et al., 1996; Bai et al., 1997; Fan, 1997; Bhattacharyya et al., 1999; Xu, 1999; Wang, et al., 2002; Carter et al., 2003; Mao et al., 2003), resulting in failure to provide relatively more accurate productivity measurement in China. This study will take account of the factor of pollutants into the analysis of the productivity measurement. In details, the study will investigate the total factor productivity (TFP) growth in the presence of environmental regulations and compare it with the other two cases. One is that the pollutants were ignored, and the

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other is that the pollutants can be freely or strongly disposable under the strong disposability of pollutants.

The objective of this study is three-folded: 1) to estimate the TFP growth of Chinese manufacturing industry in the presence of environmental regulations and investigate whether the productivity growth contributes to the economic growth; 2) to identify which factors contribute to the TFP growth in Chinese manufacturing industry; 3) to observe the impacts of environmental factors on the TFP growth in Chinese manufacturing industry.

To accomplish these tasks, non-parametric data envelopment analysis (DEA) approach is used to estimate the directional distance function for the measurement of Malmquist-Luenberger productivity index (MLPI) proposed by Chung, Fare, and Grosskopf (1997). The MLPI is also decomposed into technical change index and efficiency change index, which is similar to the general Malmquist productivity index (MPI) based on the distance functions. In this paper, by comparison of the MLPI and the general MPI, especially focusing on twenty-five provinces excluding Liaoning, Jinlin, Inner Mongolia, Tibet and Hainan during the period of 1995-2002, the impact of the environmental regulations on the TFP growth in Chinese manufacturing sector has been analyzed.

This study can be outlined as follows: section 2 presents the MLPI. How to estimate the directional distance function is also shown in this section; section 3 includes a brief description of data and a discussion of empirical results; section 4 is the summary and conclusions of this study.

2. The Model

2.1 The Theoretical Model: the MLPI under the Weak Disposability of Pollutants

The MLPI is a relatively new index. It is based on the output-oriented directional distance function (Chung, Fare, Grosskopf, 1997) under the weak disposability of pollutants, which implies that the pollutants are disposed with some cost, i. e., they cannot be freely disposable. The MLPI is fundamentally different from the MPI under the strong disposability of pollutants. The MPI under the strong disposability changes the desirable and undesirable outputs proportionally; however, the MLPI considers the reduced pollutant emissions in the analysis of productivity so that more desirable outputs and less undesirable outputs can be produced. This means that the MLPI, which considers the reduction in undesirable outputs, gives a relatively complete picture of the productivity growth experienced by a producer (Fare et al. 2001).

In the analysis, the joint production of desirable and undesirable outputs is considered. The input is denoted as $x^t(x^t \geq 0)$, output as $y^t(y^t \geq 0)$, and the undesirable outputs for each period of $t=1, \ldots T.$, as $w^t (w^t \geq 0)$. Thus the production technology in terms of output set is defined as follows:

$$F^t(x^t)=\{(y^t, w^t): x^t \text{ can produce } (y^t, w^t)\} \quad (1)$$

Then the directional distance function is defined as:

$$\vec{D}_o^t(x^t, y^t, w^t; g^t)=\max\{\beta:(y^t+\beta g_y, w^t-\beta g_w) \in F^t(x^t)\} \quad (2)$$

Where g^t is the direction vector, $g^t=(y^t, -w^t)$ here. g_y and g_w are sub-vectors for y^t and w^t, respectively. β is the maximum feasible expansion of the desirable outputs and contraction of the undesirable outputs when the expansion and contraction are identically proportional to the given inputs.

Following Chung et al. (1997), the output-oriented MLPI for period t is defined as:

$$ML_o^t=\frac{[1+\vec{D}_o^t[x^t, y^t, w^t; g^t)]}{[1+\vec{D}_o^t(x^{t+1}, y^{t+1}, w^{t+1}; g^{t+1})]} \quad (3)$$

Where$g^t=(y^t, w^t)$ and $g^{t+1}=(y^{t+1}, -w^{t+1})$.

The MLPI for period $t+1$ as:

$$ML_o^{t+1}=\frac{[1+\vec{D}_o^{t+1}[x^t, y^t, w^t; g^t]}{[1+\vec{D}_o^{t+1}(x^{t+1}, y^{t+1}, w^{t+1}; g^{t+1})]} \quad (4)$$

In order to avoid adopting the arbitrary benchmark, the output-oriented MLPI is specified as the geometric means of two types of MLPIs as:

$$ML_o^{t,t+1}=(ML_o^t \times ML_o^{t+1})^{1/2}$$
$$=\left(\frac{[1+\vec{D}_o^t(x^t, y^t, w^t; g^t)]}{[1+\vec{D}_o^t(x^{t+1}, y^{t+1}, w^{t+1}; g^{t+1})]} \frac{[1+\vec{D}_o^{t+1}(x^t, y^t, w^t; g^t)]}{[1+\vec{D}_o^{t+1}(x^{t+1}, y^{t+1}, w^{t+1}; g^{t+1})]}\right)^{1/2} \quad (5)$$

This productivity index does not require any price information and it explicitly credits expansion of desirable outputs and contraction of undesirable outputs. All outputs are equally weighed because the index calculates the equal-proportional expansion of the desirable outputs and contraction of the undesirable outputs (Fare et al. 2001).

Equation (5) can also be expressed as:

$$ML_o^{t,t+1}=MLTC_o^{t,t+1} \times MLEC_o^{t,t+1} \quad (6)$$

Where $MLTC_o^{t,t+1}$ and $MLEC_o^{t,t+1}$ imply technical change index and efficiency change index, respectively, which can be shown as follows:

$$MLTC_o^{t,t+1}=\left(\frac{[1+\vec{D}_o^{t+1}(x^{t+1}, y^{t+1}, w^{t+1}; g^{t+1})]}{[1+\vec{D}_o^t(x^{t+1}, y^{t+1}, w^{t+1}; g^{t+1})} \frac{[1+\vec{D}^{t+1}(x^t, y^t, w^t; g^t)]}{[1+\vec{D}_o^t(x^t, y^t, w^t; g^t)]}\right)^{1/2} \quad (7)$$

and

$$MLEC_o^{t,t+1}=\frac{1+\vec{D}_o^t(x^t, y^t, w^t; g^t)}{1+\vec{D}_o^{t+1}(x^{t+1}, y^{t+1}, w^{t+1}; g^{t+1})} \quad (8)$$

If $ML_o^{t,t+1}>1$, it means an improvement in the productivity; on the other hand, if $ML_o^{t,t+1}<1$, it means a decrease in the productivity; and surely if $ML_o^{t,t+1}=1$, it demonstrates no changes in inputs or outputs (including desirable and undesirable outputs) between two periods. The result of $MLTC_o^{t,t+1}$ is used to measure the shift in the best-practice frontier. If $MLTC_o^{t,t+1}=1$, it implies that there is no shift in the best-practice frontier. If $MLTC_o^{t,t+1}>1$, it indicates that the shift of the frontier is in the direction of "more desirable outputs and less undesirable outputs"; however, if $MLTC_o^{t,t+1}<1$, it indicates that the shift of the frontier happens in the direction of "less desirable outputs and more undesirable outputs".

$MLEC_o^{t,t+1}$ measures the efficiency change between periods t and $t+1$, i. e., it measures the level of "catching-up" to the best-practice frontier. If $MLEC_o^{t,t+1}=1$, it indicates that an observation is the same distance from the frontier at two time periods, namely, no catching-up to the best-practice frontier between the two time periods. If $MLEC_o^{t,t+1}>1$, it implies that an observation is closer to the frontier at time period $t+1$ than that at time period t, indicating that there is the catching-up to the frontier between two periods. Finally, if $MLEC_o^{t,t+1}<1$, it means that an observation is far from the frontier at the time period $t+1$ than that at the time period t, i. e., the observation is moving towards the reverse direction of the frontier from the time period $t+1$ to the time period t.

2.2 The Empirical Model

In order to calculate the MLPI of each observation between periods t and $t+1$ under the weak disposability of pollutants, the following four directional distance functions should be calculated under the constant returns to scale (CRS). Two directional distance functions can be obtained by solving the following two linear programming (LP) problems:

$$\begin{aligned} &\vec{D}_o^t(x_k^t, y_k^t, w_k^t ; g_k^t)=\max\delta_1^k \\ &z_k^t Y^t \geq (1+\delta_1^k)y_k^t \\ &z_k^t W^t = (1-\delta_1^k)w_k^t \\ &z_k^t X^t \leqq x_k^t \\ &z_k^t \geq 0 \end{aligned} \tag{9}$$

$$\begin{aligned} &\vec{D}_o^{t+1}(x_k^{t+1}, y_k^{t+1}, w_k^{t+1} ; g_k^{t+1})=\max\delta_2^k \\ &z_k^{t+1} Y^{t+1} \geq (1+\delta_2^k)y_k^{t+1} \\ &z_k^{t+1} W^{t+1} = (1-\delta_2^k)w_k^{t+1} \\ &z_k^{t+1} X^{t+1} \leq x_k^{t+1} \\ &z_k^{t+1} \geq 0 \end{aligned} \tag{10}$$

The other two directional distance functions are two-mixed periods distance functions, which can be calculated by solving the following LP problems:

$$\begin{aligned} &\vec{D}_o^t(x_k^{t+1}, y_k^{t+1}, w_k^{t+1} ; g_k^{t+1})=\max\delta_3^k \\ &z_k^t Y^t \geq (1+\delta_3^k)y_k^{t+1} \\ &z_k^t W^t = (1-\delta_3^k)w_k^{t+1} \\ &z_k^t X^t \leq x_k^{t+1} \\ &z_k^t \geq 0 \end{aligned} \tag{11}$$

$$\begin{aligned} &\vec{D}_o^{t+1}(x_k^t, y_k^t, w_k^t ; g_k^t)=\max\delta_4^k \\ &z_k^{t+1} Y^{t+1} \geq (1+\delta_4^k)y_k^t \\ &z_k^{t+1} W^{t+1} = (1-\delta_4^k)w_k^t \\ &z_k^{t+1} X^{t+1} \leq x_k^t \\ &z_k^{t+1} \geq 0 \end{aligned} \tag{12}$$

3. Data Description and Empirical Findings

3.1 The Data Description

The data employed in this study are

provincial-level inputs, desirable and undesirable outputs of twenty-five provinces in China during the period of 1993-2002. These data are taken from the China Statistical Yearbook for the period of 1994-2003. Inputs include labor and capital stock. The number of employees multiplied by the average wage of employees is used as our proxy for labor in this paper. Desirable output is GDP. Undesirable outputs allow for wastewater and SO_2 that are the major pollutants in Chinese manufacturing industry. GDP and capital stock are transformed into real values with GDP deflator (1978=100). The "onfront" and "GAMS" computer programs were used to estimate the general and directional distance functions for each province during the period of 1995-2002.

Twenty-five provinces in China are examined, excluding Liaoning, Jilin, Inner Mongolia, Hainan and Tibet because of the availability of the data. According to the economic development levels, these twenty-five provinces are divided into three regions: the most developed eastern region, the central region and the western region. The eastern region includes nine provinces: Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong and Guangdong. The central region includes seven provinces: Shanxi, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. And the western region includes nine provinces: Guangxi, Sichuan, Guizhou, Yunnan, Shaanxi, Ganxu, Qinghai, Ningxia, and Xinjiang.

Table 1 shows the average annual growth rate of capital and labor, GDP, wastewater and SO_2 for each province from 1993 to 2002. From Table 1, it can be seen that most of the provinces showed high GDP growth. In average, a GDP growth rate of 10.85% was achieved in the entire country. The most developed eastern region even achieved 11.71%; the central region is slightly lower, but still as high as 11.27%; and the western region is lowest, which was 9.65%. These high growth rates were mainly resulted from the high introduction of inputs. For the entire country, the growth rate of capital stock was 12.63%, and that of labor force was 7.06%. For the eastern region, the growth rate of capital was 13.83%, and that of labor was 8.64%. For the central region, the growth rate of capital was 11.60%, and that of labor was 6.44%. For the western region, the growth rate of capital was 12.38%, and that of labor was 6.12%. It can be seen at the first sight that the growth rate of capital was larger than that of GDP for all of the three regions, indicating that the high growth in Chinese manufacturing industry extremely depended on capital during the period of 1993-2002.

As for the change rate of pollutants, although the central and western regions showed decrease in wastewater emission from 1993 to 2002, the eastern region showed increase by 1.13%. However, all of the three regions showed increase in SO_2 emission: the change rate of SO_2 in the

Table 1: Average Annual Growth Rate of Inputs, Desirable and Undesirable Outputs (1993-2002)

	Inputs		Desirable Output	Undesirable Outputs	
	Capital	Labor	GDP	Waste Water	SO2
National	12.63	7.06	10.82	− 1.15	2.12
Eastern	13.83	8.64	11.71	1.13	2.49
Beijing	13.63	8.25	9.25	− 8.31	− 3.99
Tianjin	11.19	3.83	11.65	1.12	3.96
Hebei	14.36	8.03	12.00	4.02	2.19
Shanghai	14.75	6.85	10.60	− 7.08	− 0.80
Jiangsu	13.01	5.44	11.38	3.71	1.86
Zhejiang	17.52	14.12	12.75	7.79	5.78
Fujian	15.08	12.53	13.08	3.84	5.84
Shandong	12.69	9.05	12.05	2.94	0.14
Guangdong	12.27	9.67	12.65	2.13	7.44
Central	11.60	6.44	11.27	− 2.74	2.00
Shanxi	8.65	12.93	10.21	− 2.34	5.32
Heilongjiang	9.50	2.73	9.20	− 4.77	− 1.00
Anhui	11.60	5.99	10.75	− 2.61	1.78
Jiangxi	12.85	5.34	13.19	− 4.28	− 4.96
Henan	12.44	10.30	10.96	2.76	7.98
Hubei	13.36	1.88	12.70	− 4.37	2.67
Hunan	12.80	5.90	11.85	− 3.57	2.18
Western	12.38	6.12	9.65	− 1.93	1.89
Guangxi	12.23	6.58	8.86	1.39	4.94
Sichuan	13.34	5.49	11.23	− 2.29	3.57
Guizhou	13.50	7.61	9.98	− 5.10	0.30
Yunnan	13.53	7.49	9.68	− 3.23	2.42
Shaanxi	11.48	5.84	9.63	− 1.51	− 1.71
Gansu	11.86	2.59	9.33	− 7.07	2.73
Qinghai	11.24	4.72	8.79	− 4.57	1.51
Ningxia	12.13	9.91	9.91	5.71	1.67
Xinjiang	12.12	4.88	9.48	− 0.69	1.62

Source: China Statistical Yearbook (1994-2003)

eastern region was 2.49%, the central region was 2.00%, and the western region was 1.89%. These data demonstrate that the eastern region had relatively more serious industrial pollutions.

In addition, it also has to be emphasized that although SO_2 emission was increased by 2.12% in the entire country, its growth rate was much less than GDP growth rate of 10.82%. And the growth rate of wastewater showed −1.15%, indicating that the environmental regulations actually did restrict pollutant emissions to some extent in China during this period.

3.2 The Empirical Findings

When the weak disposability of undesirable outputs is considered into the productivity index, infeasible LP problems in the two-mixed periods distance functions come up. In order to reduce the numbers of infeasible LP problems, multiple year "windows" of data are used as the reference technology, i. e., the reference technology for period t consists of observations from $t-2$, $t-1$ and t. Similarly, the reference technology for period $t+1$ consists of observations from $t-1$, t and $t+1$. Therefore, although the data used for calculation is from 1993 to 2002, the results can only be obtained for the period of 1995-2002.

Because the measurement of the technical efficiency is related to the basic component of the MLPI, the technical efficiencies of the twenty-five provinces are also reported under the CRS for the period of 1995-2002 in Table 2. The value of the technical efficiency is between zero and one. For the general distance function, it is known that the value of the best-practice frontier is one, however, for the directional distance function, the value of the frontier is zero (Chung et al. 1997). Therefore, the value of the efficiency equals to one implies that province is technically efficient in the corresponding year. And the value of the efficiency close to one means more efficient.

As shown in Table 2, Shanghai, Shandong and Guangdong were on the frontier each year, i. e., these provinces were technically efficient each year from 1995 to 2002 and they belong to the most developed eastern region in China. Though most of the provinces in the eastern region showed higher technical efficiency, Hebei and Beijing were relatively inefficient. Especially, Hebei was much lower than the average level of the eastern region in efficiency. In the central region, Jiangxi and Heilongjiang were close to the frontier, showing by their higher level of efficiency. Henan and Hunan were relatively inefficient. The most inefficient provinces are Guangxi, Gansu, Yunnan and Qinghai in the entire country. All of these four provinces belong to the poorest western region. Most of the inefficient provinces were centered in the western region. From Table 2, it is obvious that the technical efficiency of the eastern region was higher than those of the central and western regions. It implies that there exists relatively large gap in efficiency between the eastern regions and other two regions. At the same time, this result also shows that the central and western regions, especially the western region, have great potential to increase their TFPs through improving their technical efficiencies. It can be envisaged that enhancing research and development (R & D) or introducing foreign direct investment (FDI) from the developed countries may also help producers to improve their technical efficiencies and TFPs in the industrial production.

Furthermore, it is also interesting to

Table 2: Technical Efficiency of Each Province Based on the Directional Distance Function under CRS (1995-2002)

	1995	1996	1997	1998	1999	2000	2001	2002	Average
National	0.1870	0.1620	0.1620	0.2120	0.2020	0.2000	0.2050	0.2010	0.1910
Eastern	0.0671	0.0673	0.0815	0.0875	0.0737	0.0551	0.0484	0.0538	0.0668
Beijing	0.1909	0.2629	0.3506	0.2682	0.1803	0.0653	0.0255	0.0000	0.1680
Tianjin	0.0442	0.0153	0.0583	0.0202	0.0000	0.0000	0.0735	0.0760	0.0359
Hebei	0.2683	0.2449	0.2380	0.3413	0.3244	0.2826	0.3367	0.3827	0.3024
Shanghai	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Jiangsu	0.1006	0.0827	0.0865	0.1191	0.0761	0.0870	0.0000	0.0000	0.0690
Zhejiang	0.0000	0.0000	0.0000	0.0383	0.0554	0.0040	0.0000	0.0252	0.0154
Fujian	0.0000	0.0000	0.0000	0.0000	0.0268	0.0574	0.0000	0.0000	0.0105
Shandong	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Guangdong	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Central	0.1588	0.0663	0.1003	0.1010	0.1257	0.1057	0.1031	0.1113	0.1090
Shanxi	0.3520	0.2730	0.3367	0.1083	0.0807	0.0000	0.0000	0.0000	0.1438
Heilongjiang	0.0000	0.0000	0.0000	0.0000	0.0392	0.0000	0.0000	0.0000	0.0049
Anhui	0.0533	0.0000	0.0000	0.0127	0.0066	0.0039	0.0111	0.0146	0.0128
Jiangxi	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0226	0.0028
Henan	0.2026	0.1908	0.2344	0.2523	0.2546	0.3021	0.3083	0.3235	0.2586
Hubei	0.1232	0.0000	0.0000	0.0000	0.1466	0.0842	0.0549	0.0646	0.0592
Hunan	0.3802	0.0000	0.1309	0.3336	0.3524	0.3496	0.3477	0.3539	0.2810
Western	0.3294	0.3303	0.2910	0.4224	0.3892	0.4181	0.4399	0.4183	0.3798
Guangxi	0.0000	0.0327	0.0000	0.5188	0.5023	0.5347	0.5972	0.6214	0.3509
Sichuan	0.6963	0.6459	0.5975	0.5307	0.5118	0.6051	0.5930	0.5994	0.5975
Guizhou	0.2948	0.0000	0.0000	0.0000	0.0343	0.0000	0.2140	0.0000	0.0679
Yunnan	0.3082	0.4128	0.5111	0.5429	0.5036	0.5097	0.4905	0.5220	0.4751
Shaanxi	0.2832	0.2563	0.0000	0.2048	0.1338	0.1842	0.1573	0.2241	0.1805
Gansu	0.6076	0.6185	0.6263	0.5777	0.5490	0.4679	0.3848	0.3275	0.5199
Qinghai	0.4485	0.4333	0.5311	0.4314	0.4199	0.4787	0.5081	0.4497	0.4626
Ningxia	0.0000	0.2207	0.0000	0.5692	0.5252	0.6932	0.6784	0.6959	0.4228
Xinjiang	0.3257	0.3528	0.3528	0.4260	0.3228	0.2894	0.3358	0.3245	0.3412

Note: The zero value of technical efficiency implies that province is on the frontier.

study the changes of technical efficiency from 1995 to 2002. As in the eastern region, technical efficiency from 2000 to 2002 was higher than that from 1995 to 1999; however, in the western region, it became decrease after 1998 and reached the lowest level in 2001. This trend indicates that though the western region kept higher economic growth during the period of 1995-2002, the growth was not from the contribution of technical efficiency after 1998.

Two types of MPI and MLPI were estimated. The first MPI completely ignores pollutants, which is a traditional method used in the literatures of productivity growth. The second one recognizes the joint production of desirable and undesirable outputs but does not account for the negative impact of undesirable outputs on the production. The MLPI considers the increase of desirable outputs and the reduction of undesirable outputs simultaneously. This direction can be viewed as a compromise of the goals of the pro-growth and anti-growth environmental movements. The MLPI is used to estimate the TFP of Chinese manufacturing industry in the presence of environmental regulations, because Chinese industrial pollutions have been controlled under the regulations to some extent during the high economic growth period of 1995–2002.

Table 3 shows the average annual productivity growths under the three cases studied and their components from 1995 to 2002. Because there are infeasible LP problems for calculating the two-mixed periods directional distance function, the results were obtained only for seventeen provinces though the number of estimated provinces is twenty-five. Therefore, when calculating the average result for each region or the entire country, those provinces that had no LP solutions were excluded.

When ignoring pollutants, there are nine provinces whose MPIs are less than one, which means that their productivities decreased during the related period. The average productivity of the entire country increased by 0.53%. Under the strong disposability of pollutants, there are only three provinces whose productivities decreased during the related period. The average productivity of the entire country increased by 2.93%. In contrast to the two cases mentioned above, no province's MLPI is less than one under the weak disposability of pollutants, i.e., each province's productivity increased during the related period. In average, the productivity of the entire country increased by 4.51%. This demonstrates that the TFP contributed to the high economic growth of China by 4.51% in the presence of environmental regulations in Chinese manufacturing industry. Usually, it is indicated that Chinese high economic growth extremely depended on the introduction of capital stock or labor forces rather than the TFP growth, however, the empirical result shows that China could achieve 4.51% TFP growth in manufacturing industry under environmental regulations during the period 1995–2002, it is higher than that of American manufacturing industry (3.60%) from 1974 to 1986 (Fare et al., 2001).

From the result of each region, it can also be seen that the productivity increased under the weak disposability of pollutants compared to the other two cases. In the eastern region, the TFP increased by 4.33% under environmental regulations but it only increased by 0.93% and 2.27% when ignoring pollutants (the first case) and under the strong disposability (the second case), respectively. In the central region, the growth rate of TFP under regulations was 4.10%; however, it was 1.33% and 3.34% in the first and second cases, respectively. In the western region, the growth rate of TFP under regulations was 4.95% while it was

Table 3: Average Annual TFPs of the Three Cases and Their Compositions for Each Province under CRS (1995-2002)

	Ignore Pollutants			Strong Disposability			Weak Disposability		
	MPI (TFP)	MEC	MTC	MPI (TFP^{es})	MEC	MTC	MLPI (TFP^{ew})	MLEC	MLTC
National	1.0053	1.0031	1.0218	1.0293	0.9950	1.0127	1.0451	1.0026	1.0430
Eastern	1.0093	1.0018	1.0114	1.0227	0.9940	1.0179	1.0433	1.0029	1.0405
Beijing	1.0467	0.9689	1.0522	1.0550	0.9778	1.0789	1.0842	1.0271	1.0574
Tianjin	1.0178	1.0222	1.0122	1.0454	1.0000	1.0200	1.0553	0.9964	1.0590
Hebei	0.9733	0.9933	1.0022	1.0016	0.9911	0.9856	1.0188	0.9884	1.0304
Shanghai	1.0167	0.9900	1.0300	1.0593	0.9733	1.0489	1.0633	1.0000	1.0633
Jiangsu	1.0044	1.0233	0.9900	1.0115	1.0144	0.9922	1.0282	1.0144	1.0139
Zhejiang	0.9789	0.9944	0.9789	0.9729	0.9900	0.9878	1.0023	0.9968	1.0060
Fujian	1.0033	1.0067	1.0033	0.9985	0.9867	1.0167	n. a	1.0003	n. a
Shandong	1.0178	0.9967	1.0322	1.0176	0.9922	1.0256	1.0506	1.0000	1.0506
Guangdong	1.0189	1.0256	0.9933	1.0184	1.0133	1.0044	1.0437	1.0000	1.0437
Central	1.0133	1.0174	1.0111	1.0334	0.9985	1.0174	1.0410	0.9963	1.0446
Shanxi	1.0233	1.0233	1.0178	1.0263	1.0356	0.9889	n. a	1.0467	n. a
Heilongjiang	1.0444	1.0144	1.0589	1.1216	0.9967	1.0478	n. a	1.0002	n. a
Anhui	1.0289	1.0200	1.0167	1.0439	0.9967	1.0333	1.0587	1.0056	1.0526
Jiangxi	1.0122	1.0333	1.0078	1.0549	1.0067	1.0067	1.0566	0.9968	1.0597
Henan	0.9989	0.9989	1.0089	1.0014	0.9922	1.0122	1.0076	0.9865	1.0214
Hubei	1.0300	1.0422	1.0389	1.1245	1.0167	1.0156	n. a	1.0102	n. a
Hunan	0.9211	1.0122	1.0044	1.0214	0.9933	0.9267	n. a	1.0139	n. a
Western	0.9959	0.9976	1.0411	1.0360	0.9944	1.0033	1.0495	1.0053	1.0456
Guangxi	0.9589	0.9911	1.0522	1.0429	1.0000	0.9589	n. a	0.9422	n. a
Sichuan	0.9389	1.0067	1.0167	1.0091	0.9944	0.9422	1.0326	1.0089	1.0233
Guizhou	0.9478	0.9800	1.0078	0.9805	1.0000	0.9478	n. a	1.0477	n. a
Yunnan	1.0144	0.9967	1.0544	1.0256	0.9833	1.0356	1.0201	0.9792	1.0426
Shaanxi	1.0156	1.0044	1.0478	1.0463	1.0000	1.0144	1.0890	1.0138	1.0797
Gansu	0.9344	0.9978	1.0100	1.0200	0.9844	0.9544	1.0531	1.0280	1.0246
Qinghai	1.0433	0.9878	1.0589	1.0456	1.0011	1.0444	1.0398	1.0008	1.0396
Ningxia	0.9478	0.9556	1.0544	1.0156	1.0000	0.9478	n. a	0.9436	n. a
Xinjiang	1.0289	0.9922	1.0589	1.0697	1.0033	1.0289	1.0627	1.0009	1.0636

MEC: Efficiency change for Malmquist productivity index
MTC: Technical change for Malmquist productivity index
MPI: Malmquist productivity index (MPI = MEC × MTC)
MLEC: Efficiency change for Malmquist-Luenberger productivity index
MLTC: Technical change for Malqmuist-Luenberger productivity index
MLPI: Malmquist-Luenberger productivity index (MLPI = MLEC × MLTC)
TFP: The TFP growth when ignoring the pollutants.
TFP^{es}: The TFP growth under the strong disposability of pollutants
TFP^{ew}: The TFP growth under the environmental regulations

-1.49% and 3.60% in the first and second cases, respectively. These results, as well as the results of the entire country, show that the traditional productivity measurements without considering the environmental regulations underestimated the TFP growth in Chinese manufacturing industry. Meanwhile, it can be known that the impact of environmental factors on TFP growth is positive not only under the strong disposability of pollutants but also under the weak disposability of pollutants.

In details under environmental regulations, Shanxi achieved the highest increment of the productivity growth by 8.90%. In contrast, Zhejiang received the lowest increment of the productivity growth by only 0.23%. As for the components of productivity, the province that achieved the highest improvement in technology is Shanxi, which is opposite to Zhejiang. For the efficiency change, Guizhou achieved the highest increment in efficiency and opposite to Guangxi whose efficiency decreased by 6.78%. For the entire country, although the average efficiency improved by 0.19% during the period of 1995-2002, the productivity growth was almost attributable to the technical progress by 4.30%.

Table 4 shows the productivity changes, the technical changes and the efficiency changes in each period under the CRS. Most of the periods showed improvement in productivity except the period 1999-2000. As for the composition of productivity, only in period 1999-2000, the efficiency change was larger than the technical change. In other periods, the technical change was much greater than the efficiency change. Therefore, it can be concluded that the productivity growth in Chinese manufacturing sector was mostly attributable to the technical progress in the period of 1995-2002.

Table 4: Average Productivity Growth Change, Efficiency Change, and Technical Change for the Entire Country in Each Period under Regulations

	MLPI	MLTC	MLEC
1995-1996	1.0833	1.0546	1.0272
1996-1997	1.0807	1.0762	1.0042
1997-1998	1.0449	1.0801	0.9674
1998-1999	1.0274	1.0206	1.0067
1999-2000	0.9808	0.9750	1.0060
2000-2001	1.0095	1.0120	0.9975
2001-2002	1.0216	1.0169	1.0046

MLPI: Malmquist-Luenberger productivity index
MLEC: Efficiency change
MLTC: Technical change

Finally, it is also important to observe which province determined the production possibility frontier under the weak disposability of pollutants during the period of 1995-2002, i. e., which province shifted the frontier. In order to know which province shifted the best-practice frontier (see Fare et al., 1994), the following three conditions are required. Given a two-year period, the score of the MLTC index for a given province *k*, namely, $MLTC_o^{t,t+1}$ for *k* in Equation (7) is larger than one, and then for this province:

$$\vec{D}_o^{t}(x^{t+1}, y^{t+1}, w^{t+1}\,;\, g^{t+1})<0$$

and

$$\vec{D}_o^{t+1}(x^{t+1}, y^{t+1}, w^{t+1}\,;\, g^{t+1})=0.$$

This indicates that this province shifted the frontier in the related two-year period. The province shifting the frontier can be viewed as "innovator" the result of which is shown in Table 5. As mentioned above, seventeen provinces had solutions for LP problems during this period. Among these

Table 5: Provinces Shifting the Frontier (Innovators) under Regulations

Period	Eastern	Central	Western
1995-1996	Shanghai, Zhejiang, Fujian, Shandong, Guangdong	Heilongjiang, Anhui, Jiangxi	Guizhou
1996-1997	Shanghai, Zhejiang, Fujian, Shandong, Guangdong	Heilongjiang, Anhui, Jiangxi, Hubei	Guangxi, Shaanxi
1997-1998	Shanghai, Zhejiang, Fujian, Shandong, Guangdong	Jiangxi	
1998-1999	Tianjin, Shanghai, Shandong, Guangdong	Jiangxi	
1999-2000	Tianjin, Shanghai, Shandong, Guangdong	Heilongjiang, Jiangxi	
2000-2001	Shanghai, Jiangsu, Guangdong	Jiangxi	
2001-2002	Beijing, Shanghai, Shandong	Shanxi, Heilongjiang	

seventeen provinces, Shanghai shifted the frontier in all of two-year periods. Shandong, Guangdong and Jiangxi shifted the frontier in six of two-year periods in total of seven. Except Jiangxi, the other three provinces belong to the most developed eastern regions. In addition, fourteen different provinces shifted the frontier at least one time. In each period, the number of provinces shifting the frontier in the eastern region is much more than those in the other two regions. Therefore, it is concluded that the eastern region basically led the innovation in manufacturing sector during the period of 1995-2002.

4. Summary and Conclusions

A relatively new method, namely, the MLPI is used in this study to analyze the TFP growth in the presence of environmental regulations in Chinese manufacturing industry. Meanwhile, comparative research between the MLPI and the general MPI was also done by considering other two cases, one is ignoring pollutants and the other is under the strong disposability of pollutants. As a result, the TFP growth in Chinese manufacturing industry increased by 4.51% in the presence of environmental regulations during the period of 1995-2002, indicating that the TFP growth in Chinese manufacturing industry did contribute to the economic growth. And this TFP growth mostly resulted from the innovation in technology rather than the efficiency improvement. In addition, it was found that the TFP growth under environmental regulations was higher than the other two cases. This implies that the traditional productivity measured by the MPI underestimates the TFP growth in Chinese manufacturing sector. The major contribution of this study is to provide a relatively more accurate picture experienced by Chinese manufacturing industry during the period of 1995-2002. Meanwhile, the results of this study also provide empirical foundation to some extent for China to strengthen the environmental regulations in the current situation in order to decrease the increasingly serious industrial pollutions accompanied with the rapid economic growth.

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References

Bai Chongen, Li David D., Wang Yijiang, (1997) "Enterprise Productivity and Efficiency: When Is UP Really Down ?" *Journal of Comparative Economics*, Vol. 24, No. 3, pp. 265-280.

Bhattacharyya Arunava, Parker Elliott, (1999) "Labor Productivity and Migration in Chinese Agriculture: A Stochastic Frontier Approach", *China Economic Review*, Vol. 10, No. 1, pp. 59-74.

Carter Colin A., Chen Jing, Chu Baojin, (2003) "Agricultural Productivity Growth in China: Farm Level versus Aggregate Measurement", *China Economic Review*, Vol, No. 1, pp. 53-71

China Statistical Yearbook, 1995-2003.

Chung Y. H., Fare R., Grosskopf S, (1997) "Productivity and Undesirable Outputs: a Directional Distance Function Approach", *Journal of Environmental Management*, Vol. 51, pp. 229-240.

Fan Shenggen, (1997) "Production and Productivity Growth in Chinese Agriculture: New Measurement and Evidence", *Food Policy*, Vol. 22, No. 3, pp. 213-228.

Fare R., Grosskopf S., Pasurka C. A., (2001) "Accounting for Air Pollution Emissions in Measures of State Manufacturing Productivity Growth", *Journal of Regional Science*, Vol. 41, No. 3, pp. 381-409.

Jefferson Gary H., Rawski Thomas G., Zheng Yuxin, (1996) "Chinese Industrial Productivity: Trends, Measurement Issues, and Recent Developments", *Journal of Comparative Economics*, Vol. 23, No. 2, pp. 146-180.

Lau K. T., Brada J. C., (1990) "Technological Progress and Technical Efficiency in Chinese Industrial Growth: a Frontier Production Approach", *China Economic Review*, Vol. 1, No. 2, pp. 113-124.

Mao Wining, Koo Won W., (1997) "Productivity Growth, Technological Progress, and Efficiency Change in Chinese Agriculture after Rural Economic Reforms: A DEA Approach", *China Economic Review*, Vol. 8, No. 2, pp. 157-174.

Wang Xiaolu, Kalirajan K. P., (2002) "On Explaining China's Rural Sectors' Productivity Growth", *Economic Modeling*, Vol. 19, No. 2, pp. 261-275.

World Bank, (2003) World Development Indicators.

Wu Yanrui, (1995) "Productivity Growth, Technological Progress, and the Technical Efficiency Change in China: A Three-Sector

Analysis", *Journal of Comparative Economics*, Vol. 21, No. 2, pp. 207-229.

Xu, Yingfeng, (1999) "Agricultural Productivity in China", *China Economic Review*, Vol. 10, No. 2, pp. 108-121.

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Appendix

	MPI without Pollutants	MPI under the Strong Disposability of Pollutants
Poduction Technology	$P^t(x^t)=\{y^t : x^t \textit{ can produce } y^t\}$	$F^t(x^t)=\{(y^t, w^t): x^t \textit{ can produce } (y^t, w^t)\}$
Distance Function	$D_o^t(x^t, y^t)=\min\{\lambda : (x^t, y^t/\lambda)\in P^t\}$	$D_o^t(x^t, y^t, w^t)=\min\{\lambda : (x^t, y^t/\lambda, w^t)\in F^t\}$
MPI	$M_o^{t,t+1}=\left[\left(\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)}\right)\times\left(\frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)}\right)\right]^{1/2}$	$M_o^{t,t+1}=\left[\left(\frac{D^t(x^{t+1}, y^{t+1}, w^{t+1})}{D^t(x^t, y^t, w^t)}\right)\times\left(\frac{D^{t+1}(x^{t+1}, y^{t+1}, w^{t+1})}{D^{t+1}(x^t, y^t, w^t)}\right)\right]^{1/2}$
Estimating Distance Function	$[D_o^t(x_k^t, y_k^t)]^{-1}=\max\alpha^k$ $z_k^t Y^t\geq\alpha^k y_k^t$ $z_k^t X^t\leq x_k^t$ $z_k^t\geq 0$	$[D_o^t(x_k^t, y_k^t, w^t)]^{-1}=\max\beta^k$ $z_k^t Y^t\geq\beta^k y_k^t$ $z_k^t W^t\geq\beta^k w_k^t$ $z_k^t X^t\leqq x_k^t$ $z_k^t\geq 0$

Note: MPI is Malmquist productivity index.