

# **Provincial Productivity in China: Accounting for Environmental Factors (1999-2005)**

**JINGHAI ZHENG**

Department of Economics  
Gothenburg University, Sweden

**YUNING GAO**

Department of Land Economy  
University of Cambridge, United Kingdom

**NING ZHANG**

Department of Economics  
Chinese University of Hong Kong, China

**Abstract:** One of the most serious consequences of China's rapid economic development has been increased pollution and degradation of natural resources. The purpose of this study is among the first attempts to measure and analyze the impact of environment pollution on production in China by means of applied productivity analysis. We investigate technical progress and technical efficiency differences across Chinese regional economies using Malmquist-Luenberger productivity indexes and re-evaluate productivity performance at provincial level taking environmental factors into account. We expect that our findings will help provide theoretically well-founded estimates of green national accounts, determine the nature of China's productivity growth, and contribute to the knowledge of sustainable economic growth and environment-friendly development in a broad sense.

**Key words:** *Productivity, Data Envelopment Analysis, Undesirable Output, Malmquist-Luenberger Index, Environment*

## 1. Introduction

Environmental pollution and degradation of natural resources have been the most serious problems along with China's rapid industrial development. In terms of air quality, the World Bank recently examined 20 of the most severely polluted cities in the world, 16 of these cities are located in China. As water use increases, particularly in industrial and urban sectors, wastewater discharges are also rapidly rising. The most ubiquitous pollutant is readily degradable organic material from domestic and industrial sources. China generates the largest total emissions of organic water pollutants in the world—the equivalent to the emissions of the United States, Japan, and India combined (Wolf, *et al.*, 2003).

China's increasingly polluted environment is largely a result of its rapid development and consequently a large increase in primary energy consumption, which is almost entirely produced by burning coal. China has pursued a development model, which promotes export-oriented growth, by expediting increases in manufacturing capacity, largely in the absence of any significant ecological or pollution controls to reduce polluting emissions from the nation's rapidly industrializing economy.

The Chinese government has been working on criteria and indexes of a green GDP, which deducts the cost of environmental damage and resources consumption from the traditional gross domestic product. Preliminary results in the recently issued Green GDP Accounting Study Report 2004 suggests that economic losses due to environmental pollution reach 512 billion Yuan, corresponding to 3.05% of GDP in 2004, while imputed treatment cost is 287 billion Yuan, corresponding to 1.80% of GDP. Although the concept of and measurement for green GDP are rather controversial, the report may serve as a wakeup call to the government's strategy of growth at all costs.

A closely related concept to green GDP is total factor productivity (TFP) growth when environmental factors are taken into account, i.e., 'green TFP'. It turns out that the concept of green TFP can be studied under the standard framework of applied productivity analysis, which is based on well-founded economic theory of production. The purpose of this research project is to measure and analyze the impact of industrial production on environment in China by means of applied productivity analysis. The main empirical methodology to be used is the distance function approach (Färe *et al.*, 1993, and Chung, Färe, and Grosskopf, 1997). This method has been employed in the estimation of total factor productivity with undesirable outputs for the Swedish pulp and paper industry (Chung, Färe and Grosskopf, 1997), the

calculation of shadow prices for industrial wastes in Spanish firms (Reig-Martinez *et al.*, 2001), and the investigation of the role of environmental factors in growth accounting for OECD and Asian economies (Jeon and Sickles, 2004). However, this approach have not been applied to the Chinese case with only a few exceptions,

During the many years of our productivity studies on China (e.g., Zheng, Liu, and Arne Bigsten, 1998, 2003), we have accumulated a wide range of data sets, especially industrial panel data at provincial level and survey data from industrial firms. In this project, we intend to investigate technical efficiency differences across Chinese regional economies, re-evaluate industrial productivity performance at provincial level when environmental factors are taken into account, and estimate the cost of pollution when marketable goods are produced at firm level. We expect that our findings will help provide theoretically well-founded estimates of green national accounts, determine the nature of China's productivity growth, and contribute to the knowledge of sustainable economic growth and environment-friendly development in a broad sense.

## 2. Literature Review

Most Chinese studies on green GDP have been done within the framework provided by the World Bank (1997). This approach has been advanced in the early 1990s (Mäler, 1991) and has attracted the interest of governments around the world. Hu (2005) cited half a dozen such studies written in Chinese, which often appear to be direct calculation of green GDP by subtracting various imputed environmental costs from ordinary GDP figures. The concept of green GDP has been controversial since there is no consensus on how 'green GDP' can be calculated and, in fact, still less consensus on whether it should be attempted at all (United Nations, 2003).

Another line of research, which is related to the concept of green GDP but maybe less controversial, is the study of total factor productivity (TFP) when environmental factors are taken into account. One may as well term the concept of TFP in this context as 'green TFP'. The advantage of green TFP is that it can be studied under the standard framework of applied productivity analysis. For example, the distance function approach and especially the directional distance function approach provide theoretically well-founded empirical methodologies to economic analysis of production involving environmental factors.

The distance function approach can be implemented with various frontier production function estimation techniques such as Data Envelopment Analysis and stochastic frontier production function estimation. Three aspects of this approach are particularly interesting to productivity analysis with environmental factors.

First, many production activities generate undesirable byproducts in conjunction with the desirable outputs they produce. Pittman (1983) showed how to adjust productivity calculations, and Färe et al. (1989) showed how to adjust efficiency measures, in the presence of undesirable outputs. But in Färe et al. (1993), it was pointed out that to estimate output distance functions as frontiers in order to generate shadow values of the undesirable output, both types of adjustment are required.

Second, Chung, Färe, and Grosskopf (1997) introduced a directional distance function, and use it as a component in a new productivity index that readily models joint production of goods and bads, credits firms for reductions in bads and increases in goods, and does not require shadow prices of bad outputs.

Third, the directional distance function approach also provides natural extension for decomposing productivity growth into technical progress and efficiency improvement components. For example, Jeon and Sickles (2004) decompose productivity growth into changes in technical efficiency over time and shifts in technology. These allow them to identify the major factors in each country's growth process. They do not observe the true production frontier but construct it from their sample, and they provide a statistical interpretation of the productivity indices via recently developed bootstrap methods introduced by Simar and Wilson (1998, 1999, 2000a, b).

There have been quite a few applications of directional distance function approach to environmental issues in productivity analysis in the literature, but studies on China have been lacking. For example, one of the most popular studies in recent years concerns regional economic and productivity growth due to the easy access to official statistics of provincial panel data (e.g., Zheng and Hu, 2006, and Zheng, Wang, and Shi, 2006, 2007), but only a very small number of the studies considered the environmental factors. Exceptions are Kaneko and Managi (2006 and 2004), and Managi and Kaneko (2004), but the methodologies used in these studies on China are limited to translog distance functions and stochastic frontier function

estimations. These studies are primitive in the sense that they have yet to be published in the major economic journals.

### **3. The Environmental Data**

Productivity studies accounting for environmental factors at firm level are often discouraged due to lack of access to data. But we have access to a wide range of Chinese data sets, especially industrial panel data at provincial level and survey data from industrial firms. For the provincial panels, we have used them for traditional productivity studies (Zheng and Hu, 2006, Zheng, Wang, and Shi, 2007). These data will be updated to include environmental variables from the Environmental Statistics and Materials of China (1987-2006), and China Statistical Yearbook of various years. At the preliminary stage the main environmental variables we consider to include are:

Since the later 1970s, China has achieved miracle economic development. At the same time, the environmental problems, which occurred in different industrialization phases of developed countries, appear at a time in China. The conflict between environment and development become sharper and sharper. Relative shortage of resources, frailty of ecology and environment, and shortage of environmental capacity are becoming significant issues in

China's development. Although Chinese government has been always employing positive measures to environment management, the situation of Chinese environment is still very difficult (Zhou, 2000; The State Council Information Office, 2006; Sustainable Development Research Team of CAS, 2006). Because the effects of environmental factors on efficiency measurement are mainly considered as those of environmental pollution on efficiency measurement, we choose 5 major indicators of environmental pollution as measurements which can improve the shortcoming of aggregate economy growth accounting mentioned in section 1. They are volume of waste water discharged (including industrial waste water and living waste water), volume of industrial solid wastes discharged, discharge amount of COD in waste water (including industrial waste water and living waste water), volume of SO<sub>2</sub> emission (including industrial waste gas and living waste gas), and volume of CO<sub>2</sub> emission which are highly correlated with energy consumption.

#### (1) Waste Water

Since 1989, the volume of waste water discharged has been growing (Wang, 1993; Liu and Hong, 2003), but the growth rate varies among provinces. Generally, the growth rate of provinces in east region are faster than those of

provinces in middle and west regions in which even those of some provinces became decreasing. The five provinces with highest annual growth rate are Guangdong, Jiangsu, Zhejiang, Shandong and Fujian which are also the provinces with highest economic growth rate since Reform and Opening. The annual average volume of waste water discharged of Guangdong is as large as 246.78 million ton, and those of Jiangsu, Zhejiang, Shandong, and Fujian are 147.54, 103.35, 89.27 and 69.47 million ton. By contrast, the annual average volume of waste water discharged of some provinces decreased recently, such as Heilongjiang (decrease 21.23 million ton annually), Sichuan (decrease 18.66 million ton annually), Hubei (decrease 7.51 million ton annually), Liaoning (decrease 4.39 million ton annually), and Gansu (decrease 0.57 million ton annually). However, compared with the volume increased, the volume decreased is so smaller as not to turn back the increase trend of national waste water discharged. The volume of national waste water discharged is continuing increasing, especially in Ninth Five-year Plan and Tenth Five-year Plan. (see table 1)

**Table 1      Provinces with largest 5 increase and provinces with largest 5 decrease of volume of waste water discharged**

Largest increase	Annual increase (million ton)	Largest decrease	Annual decrease (million ton)
Guangdong	246.78	Heilongjiang	21.23
Jiangsu	147.54	Sichuan	18.66
Zhejiang	103.35	Hubei	7.51
Shandong	89.27	Liaoning	4.39
Fujian	69.47	Gansu	0.57

## (2) Industrial Solid Waste

Because the statistics of living and agriculture solid waste discharged is fairly difficult, only the statistical data of industrial solid waste discharged are available. Our paper also only analyzes the industrial sector data. At national level, the volume of industrial solid waste discharged shows a decreasing trend. Some provinces, such as Tianjin, Jiangsu, Hainan, Heilongjiang, Anhui, Shandong and Shanghai, succeed to comprehensively utilize or re-treat the industrial solid waste, and the volume discharged nearly reaches 0. Up to 2005, the volumes discharged of Shanxi, Chongqing, Guizhou, Sichuan and Guangxi are still fairly large. Their volumes discharged are 6.05, 1.85, 1.31, 1.15 and 1.11 million ton in 2005. During the Tenth Five-year Plan, the volumes discharged of most provinces have decreased a lot, but there are also some provinces where the volumes have increased, such as Xinjiang, Shanxi, Chongqing and so on. The increase of volume discharged of Xinjiang is largest among provinces. Compared with 2000, the volume discharged in 2005 have increased 4.69 million ton. (see Table 2)

**Table 2 Changes of Volume of Industrial Solid Waste Discharged during 10<sup>th</sup> Five-year Plan**

Provinces with largest volume discharged in 2005	Volume (million ton)	Provinces with largest decrease of volume discharged	Decrease of Volume (million ton) from 2000 to 2005
Shanxi	6.05	Xinjiang	0.47
Chongqing	1.85	Shanxi	0.22
Guizhou	1.31	Chongqing	0.16
Sichuan	1.16	Guangxi	0.05
Guangxi	1.10	Hubei	0.04

### (3) Chemical Organic Demand

COD is the typical pollution in waste water. During the 10<sup>th</sup> Five-year Plan (2000-2005), the national amount of COD discharged shows an increasing trend (Peng, and et al., 2006), but those of some provinces increased. The provinces with largest 10 discharge amount are Guangdong, Guangxi, Jiangsu, Hunan, Sichuan, Shandong, Henan, Hebei, Liaoning, and Hubei. From the beginning to the end of 10<sup>th</sup> Five-year Plan, the provinces with largest increase of discharge amount are Jiangsu, Hunan, Guangdong, Xinjiang, Fujian, Shanxi, Jiangxi, Gansu and Inner Mongolia. The provinces with discharge amount decrease are Shandong, Sichuan, Henan, Hubei, Jilin, Beijing, Liaoning, Hebei, Tianjin, and Ningxia. (see Table 3)

**Table 3** Changes of discharge amount of COD during 10<sup>th</sup> Five-year Plan

Provinces with largest 10 discharge amount of COD in 2005	Discharge amount (million ton)	Provinces with larges discharge amount increase	Amount (million ton)	Provinces with larges discharge amount decrease	Amount (million ton)
Guangdong	1.06	Jiangsu	0.312	Shandong	0.229
Guangxi	1.07	Hunan	0.221	Sichuan	0.193
Jiangsu	0.97	Guangdong	0.107	Henan	0.099
Hunan	0.90	Xinjiang	0.074	Hubei	0.086
Sichuan	0.78	Fujian	0.072	Jilin	0.069
Shandong	0.77	Shanxi	0.07	Beijing	0.063
Henan	0.72	Jiangxi	0.067	Liaoning	0.057
Hebei	0.66	Guangxi	0.044	Hebei	0.046
Liaoning	0.64	Gansu	0.044	Tianjin	0.04
Hubei	0.61	Inner Mongolia	0.041	Ningxia	0.032

#### (4) SO<sub>2</sub>

For most provinces, the volume of SO<sub>2</sub> emission experienced a period of increase (1989-1998) – decrease (1998-2003) – increase (2003-2005). After 2003, there was a new increase peak (Sustainable Development Research Team of CAS, 2006; Peng and Bao, 2006). Table 7 shows that, the volumes of SO<sub>2</sub> emission of Shandong, Henan, Shanxi, Hebei, Inner Mongolia, Jiangsu, Guizhou and Sichuan are ranked top of the country, while the provinces with highest growth rates of emission volume are Qinghai, Fujian, Xinjiang, Ningxia, Guangdong, Inner Mongolia, Henan, Yunnan and Hainan. Especially some provinces in east region, such as Qinghai, Xinjiang, Ningxia,

Inner Mongolia, Guizhou and Yunnan, have extremely high growth rates.

(see Table 4)

**Table 4 Provinces with largest 10 volumes and Provinces with highest 10 growth rate of volumes of SO<sub>2</sub> emission**

Provinces with largest 10 2005	with volume in (million ton)	Provinces with highest growth rate of volume	with 10 rate (%)
Shandong	2.00	Qinghai	313.3
Henan	1.63	Fujian	254.6
Shanxi	1.52	Xinjiang	246.0
Hebei	1.50	Ningxia	211.8
Inner Mongolia	1.46	Guangdong	208.1
Jiangsu	1.37	Inner Mongolia	197.1
Guizhou	1.36	Guizhou	151.5
Sichuan	1.30	Henan	139.0
Guangdong	1.29	Yunnan	127.0
Liaoning	1.20	Hainan	120.0

(5) CO<sub>2</sub>

Because there are no CO<sub>2</sub> statistical data in Environmental Statistics and Materials of China (1987-2006), and China Statistical Yearbook of various years, but CO<sub>2</sub> emission is of importance and highly correlated with energy consumption, we estimate the volume of provincial CO<sub>2</sub> emission by ourselves. The estimation of CO<sub>2</sub> emission based on energy consumption is according to the following formula (Journal of Energy Conservation and Environmental Protection, 2006):

$$\text{CO}_2 \text{ Emission} = \text{Consumption of Fossil Fuel}^1 \times \text{Carbon Emission Factor} \times \text{Fraction of Carbon Oxidized}$$

Fraction of Carbon Oxidized refers to the ratio of the quality of the CO<sub>2</sub> that carbon completely gasified and quality of itself, which is a standard ratio 3.67 (44:12). The most important coefficient here is the Carbon Emission Factor, which refers to the equivalent carbon emission in the consumption of fossil fuel. The most common used factors are the following three: the one from the Energy Research Institute of China's National Development and Reform Committee, which is 0.67; the one from the Carbon Dioxide Information Analysis Center of US's Department of Energy, which is 0.68; the one from the Institute of Energy Economy of Japan, which is 0.69. We use the first one.

In this paper, data of Energy Consumption Structure and aggregate volume of energy consumption of 1990-1994 are from Comprehensive Statistical Data and Materials on 55 Years of New China (National Bureau of Statistics, 2006), data of provincial aggregate energy consumption of 1995-2004 are from China Energy Statistical Yearbook (National Bureau of Statistics, 2000;

---

<sup>1</sup> More accurate calculation should exclude the carbon stored. We here use the approximate amount because of the limit of data.

2003; 2004; 2005). Because the data of Energy Consumption Structure of Shanxi and Shanghai are terminal energy consumption data, they can't be used directly. We use "Energy Production Structure" as alternative of Energy Consumption Structure, and some missing values are replaced and estimated using linear interpolation method. (see Table 5)

**Table 5 Provinces with largest 10 volumes and Provinces with highest 10 growth rate of volumes of CO<sub>2</sub> emission**

Provinces with largest 10 2004	Volume in (million ton)	Provinces with highest 10 average growth rate of 1999-2004	Growth rate (%)
Shandong	482.05	Ningxia	23.96
Hebei	387.32	Shandong	16.70
Jiangsu	333.71	Inner Mongolia	14.90
Liaoning	320.22	Zhejiang	14.28
Guangdong	298.93	Guangxi	12.82
Shanxi	275.87	Shannxi	12.58
Zhejiang	255.03	Hainan	12.47
Hubei	211.95	Hunan	12.12
Sichuan	187.70	Jiangxi	11.67
Inner Mongolia	186.90	Shanxi	11.60

#### 4. Models and Literature of Method

The production possibility set including pollution emission can be written as

$$F^t = \left\{ (x^t, y^t, b^t) \mid x^t \text{ can produce } (y^t, b^t) \right\}$$

Here  $b$  represents pollution emission, one of the outputs. We impose weak disposability of outputs

$$(x^t, y^t, b^t) \in F^t \text{ and } 0 \leq \theta \leq 1 \text{ imply } (x^t, \theta y^t, \theta b^t) \in F^t$$

The assumption of joint production for output and pollution emission

$$\text{If } (x^t, y^t, b^t) \in F^t \text{ and } b^t = 0 \text{ then } y^t = 0$$

The standard output distance function is written as

$$D_o^t(x^t, y^t, b^t) = \inf \left\{ \theta \mid (x^t, y^t / \theta, b^t / \theta) \in F^t \right\} = \left( \sup \left\{ \theta \mid (x^t, \theta y^t, \theta b^t) \in F^t \right\} \right)^{-1}$$

To construct the Malmquist productivity index one first needs to specify the distance function with respect to the two adjacent time periods wherein the technology is in place and the resource allocation decisions are made:

$$D_o^t(x^{t+1}, y^{t+1}, b^{t+1}) = \inf \{ \theta \mid (x^{t+1}, y^{t+1} / \theta, b^{t+1} / \theta) \in F^t \}$$

The output-based Malmquist productivity change index (Malmquist, 1953) is defined as:

$$M_0^{t,t+1} = \left[ \left( \frac{D_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, b^{t+1})}{D_o^t(\mathbf{x}^t, \mathbf{y}^t, b^t)} \right) \left( \frac{D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, b^{t+1})}{D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t, b^t)} \right) \right]^{1/2}$$

The index can be factorized to the product of two parts

$$\text{Efficiency Change} = \frac{D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, b^{t+1})}{D_o^t(\mathbf{x}^t, \mathbf{y}^t, b^t)} \text{ and}$$

$$\text{Technology Change} = \left( \frac{D_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, b^{t+1})}{D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, b^{t+1})} \frac{D_o^t(\mathbf{x}^t, \mathbf{y}^t, b^t)}{D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t, b^t)} \right)^{1/2}$$

The distance function at  $t$  will be constructed by the linear program:

$$\left( \hat{D}_0^t \left( x^t(k^*), y^t(k^*), b^t(k^*) \right) \right)^{-1} = \max \theta(k^*)$$

$$s.t. \theta(k^*) y_m^t(k^*) \leq \sum_{k=1}^K \lambda^t(k) y_m^t(k), m=1, \dots, M$$

$$\sum_{k=1}^K \lambda^t(k) x_l^t(k) \leq x_l^t(k^*), l=1, \dots, L$$

$$\lambda^t(k) \geq 0, k=1, \dots, K$$

The output set including pollution emission can be written as

$$P(x^t) = \left\{ (y^t, b^t) \mid (x^t, y^t, b^t) \in F^t \right\}$$

When the directional vector is  $g$ , the directional distance function can be defined as:

$$\hat{D}_0^t(x^t, y^t, b^t; g) = \sup \left\{ \beta \mid (y^t + \beta g_y, b^t - \beta g_b) \in P(x^t) \right\}$$

When the directional vector is  $(y, b)$ , the relationship between Shephard's distance function and the directional distance function is:

$$\begin{aligned} \bar{D}_0^t(x^t, y^t, b^t; y, b) &= \sup \left\{ \beta \mid (y^t + \beta g_y, b^t + \beta g_b) \in P(x^t) \right\} \\ &= \sup \left\{ \beta \mid (y^t(1+\beta), b^t(1+\beta)) \in P(x^t) \right\} \\ &= \sup \left\{ -1 + (1+\beta) \mid (y^t(1+\beta), b^t(1+\beta)) \in P(x^t) \right\} \\ &= -1 + \sup \left\{ (1+\beta) \mid (y^t(1+\beta), b^t(1+\beta)) \in P(x^t) \right\} \\ &= -1 + \frac{1}{D_0^t(x^t, y^t, b^t)} \end{aligned}$$

The directional distance function can be constructed by a linear program similar to the standard DEA model

$$\hat{D}_0^t(x^t(k^*), y^t(k^*), b^t(k^*); y^t(k^*), -b^t(k^*)) = \max \beta$$

$$s.t. (1 + \beta) y_m^t(k^*) \leq \sum_{k=1}^K \lambda^t(k) y_m^t(k), m = 1, \dots, M$$

$$\sum_{k=1}^K \lambda^t(k) b_n^t(k) = (1 - \beta) b_n^t(k^*), n = 1, \dots, N$$

$$\sum_{k=1}^K \lambda^t(k) x_l^t(k) \leq x_l^t(k^*), l = 1, \dots, L$$

$$\lambda^t(k) \geq 0, k = 1, \dots, K$$

Chung *et al.* (1997) define the output-oriented Malmquist–Luenberger productivity index between period  $t$  and  $t + 1$  as:

$$ML_0^{t,t+1} = \left[ \left( \frac{1 + \vec{D}_0^t(\mathbf{x}^t, \mathbf{y}^t, b^t; y^t, -b^t)}{1 + \vec{D}_0^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \right) \left( \frac{1 + \vec{D}_0^{t+1}(\mathbf{x}^t, \mathbf{y}^t, b^t; y^t, -b^t)}{1 + \vec{D}_0^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \right) \right]$$

It can also be factorized to the product of two parts

$$ML \text{ Efficiency Change} = \frac{1 + \vec{D}_0^t(\mathbf{x}^t, \mathbf{y}^t, b^t; y^t, -b^t)}{1 + \vec{D}_0^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}$$

ML Technology Change =

$$\left[ \left( \frac{1 + \vec{D}_0^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}{1 + \vec{D}_0^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \right) \left( \frac{1 + \vec{D}_0^{t+1}(\mathbf{x}^t, \mathbf{y}^t, b^t; y^t, -b^t)}{1 + \vec{D}_0^t(\mathbf{x}^t, \mathbf{y}^t, b^t; y^t, -b^t)} \right) \right]^{1/2}$$

## **5. Analysis of Empirical Results**

The main results of the empirical study are presented in Table 6 through 9. We compared the Malmquist productivity index and its components of different regions under the influence of the 5 different environmental factors from 1999 to 2005. The regional capital stock we used here is based on the estimation of Zhang et. al.(2004) .

### **a. Trend and Pattern in TFP growth**

The TFP growth under traditional estimations shows a stable trend of both the mean and the Standard Deviation of the Malmquist Index during the period from 1999 to 2005, where the lowest is 4.64 per cent from 2004 to 2005 and the highest is 5.63 percent from 2000 to 2001. The gap is only 1 per cent. Although the Efficiency Change in the period of 2001/2002 and 2002/2003 is comparatively lower than others, the higher Technology Change (both more than 6 per cent) makes them still keep their level of productivity growth. (See Table 6) The less change in Efficiency Change of regional growth has been observed in other studies (Zheng and Hu, 2006), especially from later 1990s, as a basic characteristic.

**Table 6 China's TFP Growth through Periods**

	Malmquist Index		Efficiency Change		Technology Change	
	Mean	SD	Mean	SD	Mean	SD
<b>Without Environmental Factor</b>						
1999/2000	1.0491	0.0293	0.9947	0.0166	1.0546	0.0194
2000/2001	1.0563	0.0326	1.0032	0.0214	1.0527	0.0151
2001/2002	1.0466	0.0450	0.9859	0.0349	1.0614	0.0186
2002/2003	1.0515	0.0332	0.9880	0.0181	1.0641	0.0240
2003/2004	1.0540	0.0345	1.0073	0.0211	1.0462	0.0213
2004/2005	1.0464	0.0336	1.0043	0.0190	1.0420	0.0329
1999/2005	1.3367	0.1640	0.9851	0.0807	1.3550	0.1036
<b>Average through Environmental Factors</b>						
1999/2000	1.0374	0.0425	1.0016	0.0314	1.0359	0.0234
2000/2001	1.0297	0.0341	1.0033	0.0352	1.0276	0.0157
2001/2002	1.0240	0.0182	0.9916	0.0208	1.0333	0.0166
2002/2003	1.0134	0.0159	0.9938	0.0116	1.0200	0.0164
2003/2004	1.0133	0.0284	1.0010	0.0276	1.0131	0.0145
2004/2005	1.0079	0.0191	1.0036	0.0175	1.0048	0.0112
1999/2005	1.1057	0.0781	0.9918	0.0507	1.1180	0.0596

Notes: E.F. refers Environmental Factor; SD refers Standard Deviation.

When consider the influence of the Environmental Factors. The Efficiency Change also shows the same trend; expect the change from little deterioration to little progress in the period 1999/2000. But the growth of productivity became quite different under this new estimation. The TFP growth was quite lower than the traditional estimation. The accumulated growth of TFP from 1999 to 2005 was only one third, about 10.57 per cent. Besides, it also shows a dramatic slow down during the past six year, from 3.74 per cent in 1999/2000 to the 0.79 in 2004/2005. The source of this came from the sharp slow down of the Technology Change, from 3.59 per cent to

0.48 per cent at the same period. This may shows the environment factors in fact contributed a large proportion to the TFP growth at the 10<sup>th</sup> five year plan period of the Technology Progress.

When we compared the TFP growth under the consideration of different kinds of pollutions, we can find out the difference of their influence. The average TFP growth with no environmental factors was 5.06 per cent during the period from 1999 to 2005, which made it accumulated growth to 33.67 per cent. The highest TFP growth under single pollution was that of the SO<sub>2</sub>, which is still more than 2 per cents lower. Even though, its accumulated TFP growth is only less than half of the original. Its problems still came from the slower change of Technology Progress, which is 3.03 per cent compared with the annual growth rate of 5.35 per cent. (See Table 7)

The situations of solid waste COD and the waste water are similar like that of SO<sub>2</sub>. The unique of COD is that it has the highest Efficiency Change, which is the only progress of Technology Efficiency among all pollutions. The slowest TFP growth happened when we counted CO<sub>2</sub> as the environmental factor. Its annual growth rate is only 0.4 percent which led to a very low accumulated growth of TFP, 3.49 per cent. This shows the emission of CO<sub>2</sub> had become the most serious threat to the productivity growth to the regional

**Table 7 China's TFP Growth through Environmental Factors**

	Malmquist Index		Efficiency Change		Technology Change	
	Mean	SD	Mean	SD	Mean	SD
<b>Average through Periods</b>						
No E.F.	1.0506	0.0347	0.9973	0.0218	1.0535	0.0219
CO <sub>2</sub>	1.0040	0.0250	0.9990	0.0233	1.0050	0.0089
COD	1.0245	0.0512	1.0051	0.0528	1.0199	0.0205
SO <sub>2</sub>	1.0298	0.0343	0.9995	0.0251	1.0303	0.0252
Solid						
Waste	1.0274	0.0551	0.9928	0.0487	1.0361	0.0552
Waste						
Water	1.0196	0.0330	0.9992	0.0391	1.0215	0.0251
<b>Accumulation 1999/2005</b>						
No E.F.	1.3367	0.1640	0.9851	0.0807	1.3550	0.1036
CO <sub>2</sub>	1.0349	0.0882	0.9943	0.0709	1.0404	0.0348
COD	1.1346	0.1073	1.0225	0.0867	1.1095	0.0461
SO <sub>2</sub>	1.1542	0.1032	0.9961	0.0511	1.1589	0.0848
Solid	1.1259		0.9563		1.1911	
Waste		0.1264		0.1027		0.1878
Waste	1.0832		0.9919		1.0925	
Water		0.0811		0.0704		0.0409

Notes: E.F. refers Environmental Factor; SD refers Standard Deviation.

## **b. Regional Disparity in TFP Growth**

The regional disparity in China's regional TFP growth is obvious under most estimation. Even we do not consider the influence of environmental factor, the annual growth rate of the western China is still 0.8 per cent lower than the eastern part. If we consider its components, we can find out that the Technology Change of the western China is so slower, which is even higher than the middle China. But its lower Efficiency Change make it dropped in

the competition of productivity. The effect of accumulation even makes it

TFP growth nearly 6 per cent less than the middle part from 1999 to 2005.

(See Table 8)

**Table 8 Regional TFP Growth through Periods**

	Eastern			Middle			Western		
	M.I	E.C.	T.C.	M.I	E.C.	T.C.	M.I	E.C.	T.C.
<b>Without Environmental Factor</b>									
1999/2000	1.0553	0.9954	1.0601	1.0439	0.9946	1.0494	1.0461	0.9939	1.0524
2000/2001	1.0599	1.0051	1.0545	1.0540	1.0018	1.0517	1.0538	1.0021	1.0514
2001/2002	1.0492	0.9909	1.0587	1.0491	0.9866	1.0630	1.0406	0.9785	1.0634
2002/2003	1.0546	0.9890	1.0664	1.0547	0.9944	1.0602	1.0440	0.9804	1.0649
2003/2004	1.0591	1.0090	1.0497	1.0537	1.0113	1.0415	1.0475	1.0011	1.0464
2004/2005	1.0452	1.0005	1.0449	1.0497	1.0135	1.0356	1.0446	1.0003	1.0445
1999/2005	1.3682	0.9906	1.3829	1.3439	1.0049	1.3296	1.2876	0.9582	1.3432
<b>Average through Environmental Factors</b>									
1999/2000	1.0425	1.0012	1.0419	1.0424	1.0061	1.0362	1.0256	0.9974	1.0275
2000/2001	1.0285	1.0040	1.0255	1.0279	0.9989	1.0300	1.0330	1.0067	1.0279
2001/2002	1.0304	0.9937	1.0379	1.0203	0.9870	1.0342	1.0191	0.9933	1.0264
2002/2003	1.0205	0.9935	1.0276	1.0125	0.9963	1.0166	1.0050	0.9918	1.0134
2003/2004	1.0199	0.9993	1.0207	1.0210	1.0071	1.0146	0.9969	0.9970	1.0015
2004/2005	1.0134	1.0075	1.0061	1.0095	1.0031	1.0076	0.9990	0.9989	1.0002
1999/2005	1.1247	0.9998	1.1304	1.1374	0.9974	1.1431	1.0488	0.9757	1.0763

Notes: M.I refers Malmquist Index; E.C. refers Efficiency Change; T.C. refers Technology Change.

If we consider the environmental factors, the disadvantages of the western China becomes even more significant. Although all regions show the same trend of slow down in TFP growth, the western China even goes into a negative growth of TFP in the period from 2003 to 2005. The main reason of this comes from its sharp slow down in Technology Change. Its annual growth drops from 5.38 per cent to 1.62 per cent, where is almost no

Technology Progress in 2004/2005. This result may show the technology used in the western China is mainly of the “environmental extensive”, which will be greatly discounted when we count pollution into the growth accounting.

Besides, when we compared the difference of all the five environmental factors, we can find out that the CO<sub>2</sub> still has the most damage effect among all pollutions and the western China still influenced by the environmental factors most. But waste water shows a great influence to the TFP growth of the eastern China; it makes the TFP growth slow down from 5.39 per cent to 1.99 per cent, as much as that of the western China (See Table 9).

From the components of TFP growth, not surprisingly, the main source of the slow down effect also comes from the influence to the Technology Change. Among them, the comparatively high Efficiency Change of Eastern China in COD and SO<sub>2</sub> together with that of Middle China in COD and waste water help these two regions drop not too much in the related TFP growth. At the same time, the worse performance of western China cannot save it in any estimation of the TFP growth under considering the pollutions.

**Table 9 Regional TFP Growth through Environmental Factors**

	Eastern			Middle			Western		
	M.I	E.C.	T.C.	M.I	E.C.	T.C.	M.I	E.C.	T.C.
<b>Average through Periods</b>									
No									
E.F.	1.0539	0.9983	1.0557	1.0508	1.0004	1.0502	1.0461	0.9927	1.0538
CO <sub>2</sub>	1.0064	0.9989	1.0076	1.0031	0.9989	1.0041	1.0013	0.9991	1.0022
COD	1.0317	1.0097	1.0222	1.0248	1.0048	1.0204	1.0147	0.9992	1.0163
SO <sub>2</sub>	1.0387	1.0032	1.0355	1.0284	0.9987	1.0298	1.0191	0.9954	1.0237
Solid									
Waste	1.0342	0.9913	1.0454	1.0278	0.9912	1.0389	1.0186	0.9964	1.0220
Waste									
Water	1.0199	0.9958	1.0247	1.0272	1.0052	1.0228	1.0116	0.9979	1.0159
<b>Accumulation 1999/2005</b>									
No									
E.F.	1.3682	0.9906	1.3829	1.3439	1.0049	1.3296	1.2876	0.9582	1.3432
CO <sub>2</sub>	1.0374	0.9945	1.0432	1.0513	0.9945	1.0556	1.0127	0.9937	1.0190
COD	1.1710	1.0566	1.1074	1.1638	1.0288	1.1326	1.0567	0.9708	1.0892
SO <sub>2</sub>	1.1879	1.0162	1.1678	1.1692	0.9917	1.1798	1.0943	0.9737	1.1261
Solid									
Waste	1.1721	0.9543	1.2551	1.1756	0.9421	1.2534	1.0197	0.9728	1.0505
Waste									
Water	1.0622	0.9744	1.0915	1.1269	1.0298	1.0942	1.0673	0.9773	1.0923

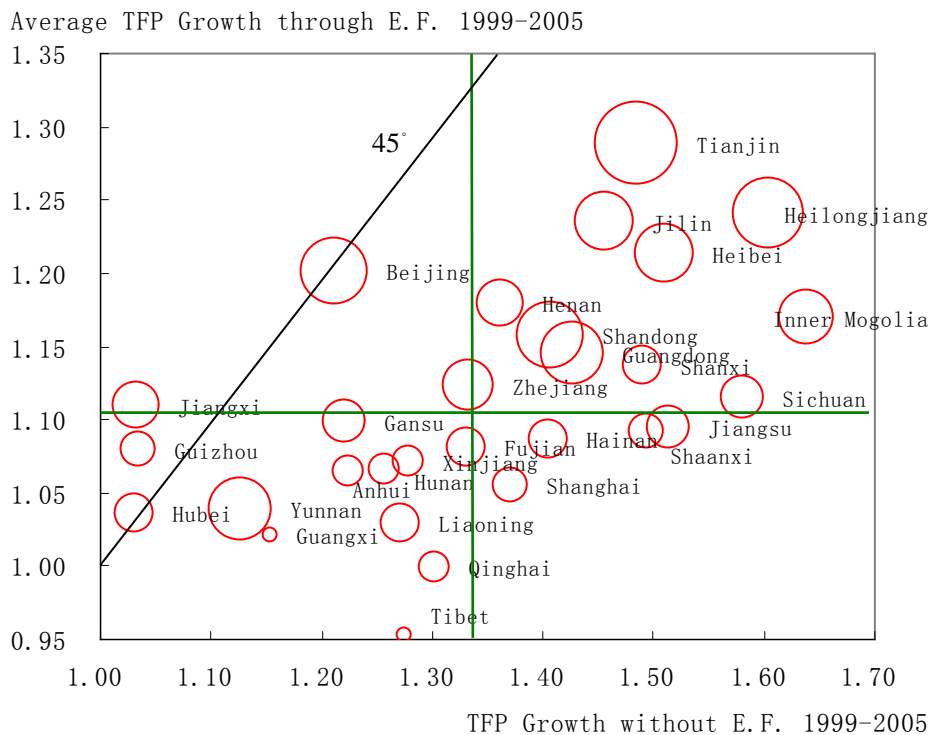
Notes: M.I refers Malmquist Index; E.C. refers Efficiency Change; T.C. refers Technology Change.

### **c. Distribution of Productivity, Technology Efficiency and Technology**

#### **Progress**

We then provide detailed comparison between the two estimation of TFP growth. Almost all provinces are under the 45 degree line, which means they have less TFP growth when considering the environmental factors through the period from 1999 to 2005. Only Jiangxi, Guizhou and Hubei performed better. Those who are close to the line, Beijing, Tianjin, Henan, Gansu and

Hubei, are those who have similar performance under diriment estimation, although a little lower. But those whose who are far from line, like Inner Mongolia, Sichuan, Jiangsu Shaanxi and Qinghai show their great effect of the environmental factors to their TFP growth. (See Figure 1)



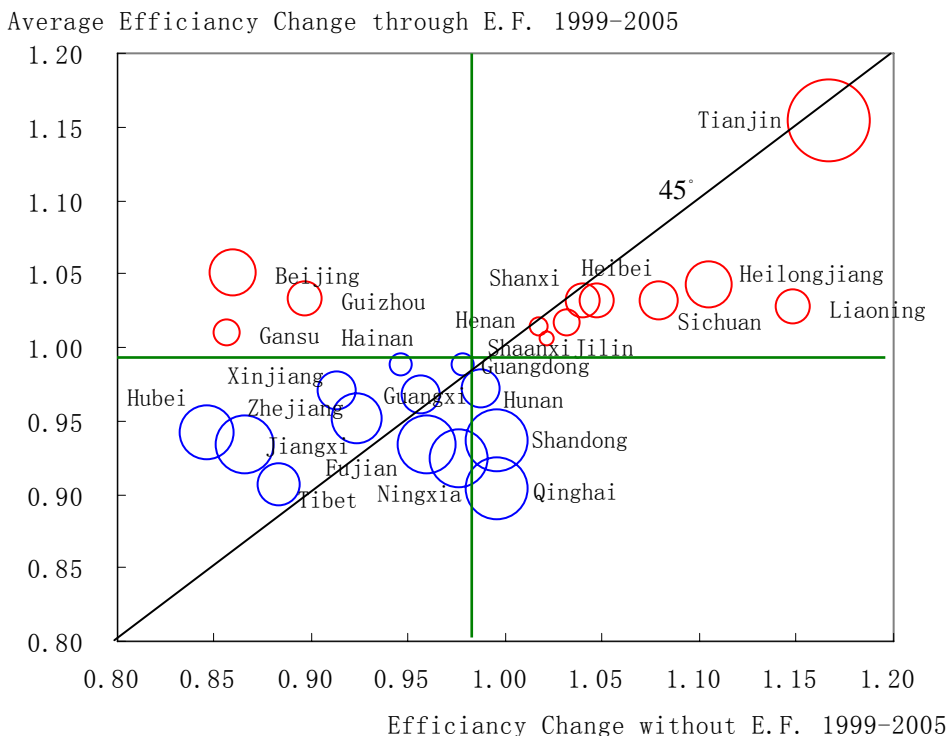
**Figure 1 TFP Growth with and without Environmental Factors**

Notes: The scale of the bubbles shows the annual TFP growth rate.

The cross lines shows the average level of the indicator.

The Efficiency Change seems cannot explain the difference between the two estimation of TFP growth under provincial level. Almost all bubbles are quite close to the 45 degree line, which means they have little difference whether we count the environmental factors in. Some provinces, like Beijing,

Guizhou, Gansu have higher Efficiency Change during 1999 to 2005 and others, like Liaoning, Shandong, Qinghai, Ningxia has much lower ones. (See Figure 2) This shows their different mode of economic growth, especially a newly defined “intensive” or “extensive” under the considering of pollutions.



**Figure 2 Efficiency Change with and without Environmental Factors**

Notes: The scale of the bubbles shows the annual Efficiency Change rate.

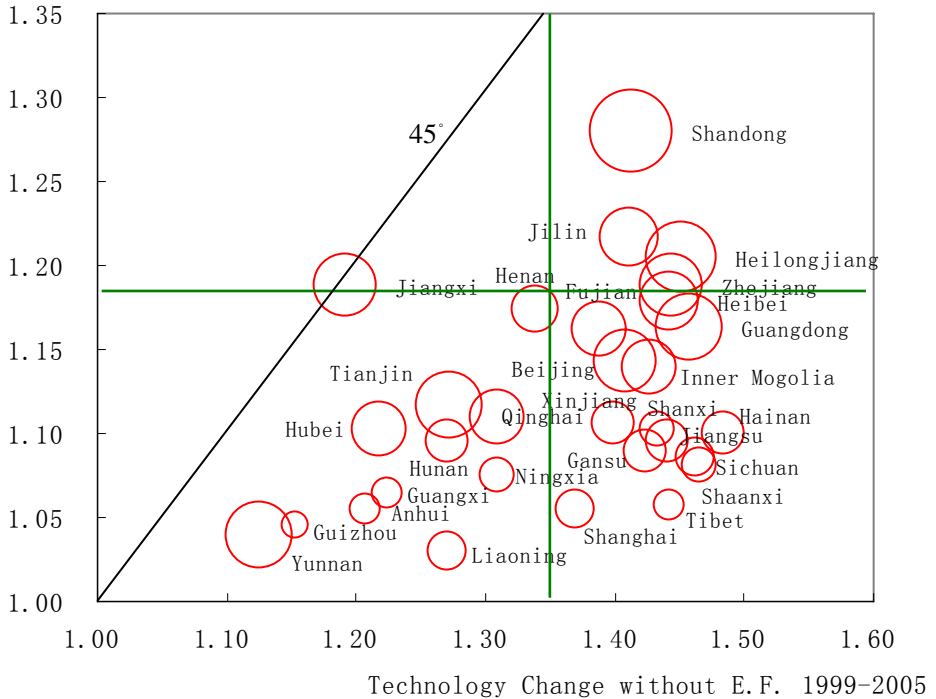
The blue ones are those with negative growth rate.

The cross lines shows the average level of the indicator.

The answer of our question comes from the details of provincial Technology Change. All of them are under the 45 degree line, which means environmental factor are completely negative to their Technology Progress.

Except Jiangxi has little influence from the pollutions, many provinces are far from the line. For example, the accumulative Technology Change with environmental factors of Hainan, Sichuan, Shanxi and Tibet was 40 percent lower than those without, or they discounted 80 per cent of all Technology Progress. (See Figure 3) This shows in most provinces of China, the Technology Progress was much lower if we count the environment factors in, which also lead to the big difference in the estimation of TFP growth.

Average Technology Change through E.F. 1999-2005



**Figure 3 Technology Change with and without Environmental Factors**  
 Notes: The scale of the bubbles shows the annual Technology Change rate.  
 The cross lines shows the average level of the indicator.

## 6. Conclusion

The impact of environmental factors to the economic growth has become more and more noticeable together with the development of China. We use the Total Factor Productivity Model in directional distance function to measure the productivity performance at provincial level taking environmental factors into account.

A significant influence of the environmental factors, as the “undesirable output”, to the Malmquist productivity index was observed, which is mainly of its component of “Technology Change” other than “Efficiency Change”. Considering the less change of the Technology Efficiency in the growth of the provincial economies, the slow down of the TFP growth under this estimation is mainly because of the Technology Progress was discounted by the environmental factors. It means the overuse of environment and natural resource may contribute an increasing part of the Technology Progress and keep the traditional TFP growth as a stable “high” level. Besides, among all pollutions, CO<sub>2</sub> seems has the most significant influence, which is related to the sharply increasing of fossil fuel consumption during the past 10<sup>th</sup> five year plan period.

And, we also compared the difference of the TFP growth through regions and provinces. Although all regions show slow down in TFP growth, it is obvious that the low performance of productivity of western China is only partly of its negative Efficiency Change, but mainly of its heavily discounted Technology Change when count environmental factors in. This is because the technology used in western China is even more “environmental extensive”, which even leads to its negative TFP growth after 2003 under the new estimation. The influence of environmental factors shows even clearer at the provincial level: only three provinces have higher TFP growth when count environmental factors in and none of them perform better in Technology Change then. As the continuous research, we suggest to find out the factors to influence the provincial TFP growth, especially the ones under the new estimation count environmental factors in, which may lead to new understanding of China’s productivity and economic growth.

## References

- Chung, Y. H., Färe, R., and Grosskopf, S., Productivity and Undesirable Outputs: a Directional Distance Function Approach. *Journal of Environmental management*, 51, 229-240, 1997.
- Fare, Rolf, Grosskopf, Shawna, Lovell, C. A. Knox, and Yaisawarng, Suthathip, Derivation of Shadow Prices for Undesirable Outputs: A Distance Function Approach. *Review of Economics and Statistics*, v. 75, iss. 2, pp. 374-80, May 1993.
- Fare, Rolf, Grosskopf, Shawna, Lovell, C. A. Knox, and Pasurka, Carl, Multilateral Productivity Comparisons When Some Outputs Are Undesirable: A Nonparametric Approach *Review of Economics and Statistics*, v. 71, iss. 1, pp. 90-98, February 1989.
- Hu, Angang, China: Green Development and Green GDP (1970-2001). Chinese Science Foundation, No. 2, 2005, published in Chinese.
- Jeon, Byung M. and Robin C. Sickles, The Role of Environmental Factors in Growth Accounting. *Journal of Applied Econometrics*, 19: 567–591, 2004.
- Kaneko, Shinji and Managi, Shunsuke, Economic growth and the environment in China: an empirical analysis of productivity. *International Journal of Global Environmental Issues*, Volume 6, Number 1, Pages: 89 – 133, 2006.

Kaneko, Shinji and Managi, Shunsuke, Environmental Productivity in China.

*Economics Bulletin*, v. 17, iss. 2, pp. 1-10, 2004.

Managi, Shunsuke and Kaneko, Shinji, Productivity Change, FDI, and Environmental Policies in China 1987-2001. Unpublished manuscript, April 2004.

Mäler, Karl-Göran, National accounts and environmental resources. *Journal Environmental and Resource Economics*, Volume 1, Number 1, March 1991.

Pittman, Russell W., Multilateral Productivity Comparisons with Undesirable Outputs. *Economic Journal*, v. 93, iss. 372, pp. 883-91, December 1983.

Reig-Martinez, Ernest, Picazo-Tadeo, Andres, and Hernandez-Sancho, Francesc, The calculation of shadow prices for industrial wastes using distance functions: an analysis for Spanish ceramic pavements firms. *International Journal of Production Economics*, 69, 277-285, 2001.

Simar L, Wilson P. 1998. Sensitivity of efficiency scores, how to bootstrap in non-parametric frontier models. *Management Science* 44: 49-61.

Simar L, Wilson P. 1999. Estimating and bootstrapping Malmquist indices. *European Journal of Operational Research* 115: 459-471.

Simar L, Wilson P. 2000a. A general methodology for bootstrapping in nonparametric frontier models. *Journal of Applied Statistics* 27: 779-802.

- Simar L, Wilson P. 2000b. Statistical inference in nonparametric frontier models: the state of the art. *Journal of Productivity Analysis* 13: 49–78.
- United Nations, Integrated Environmental and Economic Accounting 2003 (SEEA 2003).
- Wolf, Charles, Jr., K. C. Yeh, Benjamin Zycher, Nicholas Eberstadt, and Sungho Lee, Fault Lines in China's Economic Terrain. CA: RAND, 2003.
- World Bank, Expanding the Measure of Wealth Indicators of Environmentally Sustainable Development. Environment Department Washington, D.C., 1997.
- Zheng, Jinghai, Wang, Zheng, and Shi, Jinchuan, Industrial Productivity Performance in Chinese Regions (1987-2002). To be presented at the 18<sup>th</sup> Chinese Economic Association (UK), Nottingham University, UK, April 16-17, 2007.
- Zheng, Jinghai, Zheng Wang, and Jinchuan Shi, The Performance of Industrial Productivity Across Regions of transitional China: Structural Differences, Institutional Shocks and Dynamic Characteristics. Economic Research (Jingji Yanjiu, in Chinese), Nov. 2006.
- Zheng, Jinghai and Angang Hu, (2006). An Empirical Analysis of Provincial Productivity in China, 1979-2001. *Journal of Chinese Economic and Business Studies*, 4 (3), 221-239.

Zheng, Jinghai, Xiaoxuan Liu, and Arne Bigsten, (2003). Efficiency, Technical Progress and Best Practice in Chinese State Enterprises (1980-1994), *Journal of Comparative Economics*, 31 (4), 134-152.

Zheng, Jinghai, Xiaoxuan Liu and Arne Bigsten, (1998). Ownership Structure and Determinants of Technical Efficiency: an Application of Data Envelopment Analysis to Chinese Enterprises (1986-1990),” *Journal of Comparative Economics*, 26 (3), 465-484.

**Table A1 Regional TFP Growth through Environmental Factors**

	No Environmental Factors			CO <sub>2</sub>			COD			SO <sub>2</sub>			Solid Waste			Waste Water		
	M.I.	E.C.	T.C.	M.I.	E.C.	T.C.	M.I.	E.C.	T.C.	M.I.	E.C.	T.C.	M.I.	E.C.	T.C.	M.I.	E.C.	T.C.
Beijing	1.0451	0.9774	1.0685	1.0211	1.0081	1.0129	1.0624	1.0174	1.0448	1.0857	1.0109	1.0754	1.0050	1.0004	1.0046	1.0363	1.0061	1.0313
Tianjin	1.0680	1.0262	1.0408	1.0649	1.0377	1.0268	1.0618	1.0221	1.0393	1.0838	1.0317	1.0503	1.0896	1.0414	1.0505	1.0132	1.0000	1.0132
Hebei	1.0760	1.0078	1.0676	0.9974	0.9959	1.0015	1.0393	1.0228	1.0174	1.0482	1.0083	1.0400	1.0460	0.9944	1.0520	1.0295	1.0050	1.0260
Shanxi	1.0695	1.0067	1.0624	1.0016	0.9992	1.0024	1.0273	1.0153	1.0124	1.0199	1.0015	1.0184	1.0000	0.9998	1.0003	1.0289	1.0109	1.0190
Inner Mongolia	1.0881	1.0233	1.0633	0.9993	0.9958	1.0036	1.0244	1.0101	1.0144	1.0277	0.9951	1.0326	1.0544	1.0102	1.0436	1.0363	1.0119	1.0258
Liaoning	1.0393	1.0000	1.0393	1.0076	1.0000	1.0076	1.0226	1.0000	1.0226	1.0184	1.0000	1.0184	1.0023	1.0000	1.0023	1.0213	1.0000	1.0213
Jilin	1.0744	1.0055	1.0685	1.0070	1.0031	1.0039	1.0252	1.0025	1.0229	1.0487	1.0009	1.0478	1.0460	0.9994	1.0463	1.0328	1.0099	1.0234
Heilongjiang	1.0867	1.0169	1.0687	1.0259	1.0204	1.0055	1.0334	1.0152	1.0183	1.0584	1.0076	1.0504	1.0741	0.9786	1.1129	1.0428	1.0202	1.0229
Shanghai	1.0530	1.0000	1.0530	1.0094	1.0000	1.0094	1.0113	1.0000	1.0113	1.0121	1.0000	1.0121	1.0074	1.0000	1.0074	1.0208	1.0000	1.0208
Jiangsu	1.0717	1.0084	1.0628	1.0042	1.0000	1.0042	1.0105	1.0000	1.0105	1.0288	1.0000	1.0288	1.0117	1.0000	1.0117	1.0265	1.0001	1.0263
Zhejiang	1.0495	0.9869	1.0635	0.9973	0.9892	1.0082	1.0377	1.0159	1.0229	1.0424	0.9897	1.0533	1.0293	0.9749	1.0559	1.0118	0.9877	1.0248
Anhui	1.0360	1.0000	1.0360	1.0067	1.0000	1.0067	1.0131	1.0000	1.0131	1.0048	1.0000	1.0048	1.0021	1.0000	1.0021	1.0171	1.0000	1.0171
Fujian	1.0635	0.9931	1.0709	0.9966	0.9959	1.0007	1.0180	0.9965	1.0221	1.0129	0.9954	1.0175	1.0446	0.9832	1.0625	0.9984	0.9718	1.0276
Jiangxi	0.9899	0.9765	1.0139	0.9894	0.9826	1.0068	1.0207	0.9885	1.0329	1.0341	0.9867	1.0474	1.0450	0.9883	1.0577	1.0219	0.9983	1.0240
Shandong	1.0593	0.9994	1.0599	0.9880	0.9819	1.0063	1.0488	1.0253	1.0235	1.0510	1.0039	1.0470	1.0814	0.9237	1.1794	1.0252	1.0013	1.0250
Henan	1.0755	1.0033	1.0721	1.0091	1.0051	1.0040	1.0396	1.0244	1.0156	1.0246	0.9924	1.0324	1.0104	0.9823	1.0289	1.0205	1.0060	1.0158
Hubei	0.9823	0.9732	1.0101	1.0019	1.0000	1.0019	1.0336	0.9932	1.0424	1.0059	1.0002	1.0059	1.0109	0.9713	1.0419	1.0270	0.9863	1.0427
Hunan	1.0552	0.9981	1.0573	0.9868	0.9843	1.0026	1.0053	0.9938	1.0119	1.0319	1.0039	1.0283	1.0076	0.9912	1.0166	1.0173	1.0033	1.0144
Guangdong	1.0609	0.9965	1.0647	1.0095	1.0013	1.0082	1.0364	1.0082	1.0280	1.0371	0.9986	1.0387	1.0586	0.9891	1.0702	1.0376	0.9928	1.0451
Guangxi	1.0018	0.9928	1.0094	0.9909	0.9884	1.0025	1.0038	0.9953	1.0088	1.0172	0.9997	1.0176	0.9996	0.9971	1.0026	1.0032	0.9920	1.0115
Hainan	1.0586	0.9910	1.0683	0.9899	0.9878	1.0021	1.0276	1.0129	1.0158	1.0272	1.0000	1.0272				1.0150	0.9926	1.0229
Sichuan	1.0794	1.0128	1.0658	1.0192	1.0136	1.0056	1.0196	1.0142	1.0053	1.0327	1.0041	1.0285	1.0003	0.9994	1.0009	1.0137	0.9976	1.0183
Guizhou	0.9953	0.9825	1.0136	1.0024	1.0038	0.9985	1.0191	1.0072	1.0124	1.0089	1.0019	1.0070	1.0001	0.9998	1.0004	1.0253	1.0147	1.0118
Yunnan	1.0129	1.0000	1.0129	0.9988	1.0000	0.9988	1.0376	1.0000	1.0376	1.0279	1.0000	1.0279	1.1187	1.0000	1.1187	1.0102	1.0000	1.0102
Tibet	1.0438	0.9801	1.0650				1.0076	0.9879	1.0237	1.0058	1.0000	1.0058	0.9998	0.9982	1.0016	0.9967	0.9901	1.0039
Shaanxi	1.0700	1.0039	1.0660	0.9954	0.9920	1.0035	1.0211	1.0121	1.0094	1.0272	0.9986	1.0286	1.0007	0.9989	1.0018	1.0228	1.0041	1.0230
Gansu	1.0337	0.9748	1.0606	1.0071	1.0019	1.0053	1.0103	0.9947	1.0174	1.0219	0.9932	1.0288	1.0003	0.9984	1.0019	1.0432	1.0267	1.0282
Qinghai	1.0704	0.9993	1.0712	1.0043	1.0022	1.0021	0.9986	0.9826	1.0168	1.0108	0.9726	1.0379	1.0394	0.9824	1.0547	1.0006	0.9883	1.0129
Ningxia	1.0675	0.9960	1.0718	0.9822	0.9832	0.9990	1.0061	0.9965	1.0094	1.0110	0.9988	1.0122	1.0077	0.9913	1.0166	0.9796	0.9667	1.0141
Xinjiang	1.0418	0.9851	1.0575	1.0010	0.9965	1.0046	1.0122	0.9977	1.0147	1.0259	0.9895	1.0367	1.0006	0.9991	1.0015	1.0124	0.9928	1.0207

**Table A2 Regional TFP Growth through Periods**

	1999/2000			2000/2001			2001/2002			2002/2003			2003/2004			2004/2005		
	M.I.	E.C.	T.C.	M.I.	E.C.	T.C.	M.I.	E.C.	T.C.	M.I.	E.C.	T.C.	M.I.	E.C.	T.C.	M.I.	E.C.	T.C.
Beijing	1.0571	0.9883	1.0703	1.0540	1.0231	1.0302	1.0389	1.0101	1.0291	1.0404	1.0020	1.0390	1.0282	1.0001	1.0283	1.0339	1.0279	1.0060
Tianjin	1.0871	1.0511	1.0337	1.0597	1.0218	1.0368	1.0909	1.0609	1.0283	1.0405	0.9698	1.0745	1.0589	1.0118	1.0467	1.0388	1.0441	0.9960
Hebei	1.0584	1.0147	1.0437	1.0312	1.0055	1.0274	1.0234	0.9751	1.0500	1.0278	1.0045	1.0235	1.0214	1.0084	1.0130	1.0302	1.0237	1.0065
Shanxi	1.0359	1.0239	1.0121	1.0114	0.9967	1.0153	1.0156	0.9927	1.0232	1.0085	0.9987	1.0100	1.0141	1.0119	1.0027	1.0077	1.0081	0.9997
Inner Mongolia	1.0417	1.0116	1.0300	1.0216	0.9974	1.0249	1.0354	0.9931	1.0428	1.0062	0.9841	1.0224	1.0352	1.0225	1.0126	1.0305	1.0190	1.0113
Liaoning	1.0395	1.0000	1.0395	1.0161	1.0000	1.0161	1.0222	1.0000	1.0222	1.0173	1.0000	1.0173	1.0091	1.0000	1.0091	0.9826	1.0000	0.9826
Jilin	1.0602	1.0071	1.0530	1.0683	1.0321	1.0351	1.0322	0.9891	1.0438	1.0290	1.0100	1.0192	1.0187	0.9966	1.0223	0.9834	0.9841	0.9996
Heilongjiang	1.0817	1.0139	1.0670	1.0384	0.9795	1.0647	1.0347	0.9780	1.0601	1.0274	1.0153	1.0123	1.0784	1.0787	1.0025	1.0210	0.9850	1.0454
Shanghai	1.0119	1.0000	1.0119	1.0111	1.0000	1.0111	1.0131	1.0000	1.0131	1.0189	1.0000	1.0189	1.0157	1.0000	1.0157	1.0026	1.0000	1.0026
Jiangsu	1.0261	1.0000	1.0261	1.0095	0.9954	1.0142	1.0270	1.0047	1.0222	1.0137	0.9968	1.0171	1.0141	1.0033	1.0107	1.0076	1.0000	1.0076
Zhejiang	1.0331	0.9850	1.0483	1.0282	1.0090	1.0207	1.0136	0.9614	1.0542	1.0249	0.9972	1.0280	1.0263	0.9947	1.0321	1.0163	1.0016	1.0148
Anhui	1.0062	0.9996	1.0066	1.0186	1.0004	1.0182	1.0120	1.0000	1.0120	1.0082	1.0000	1.0082	1.0064	1.0000	1.0064	1.0012	1.0000	1.0012
Fujian	1.0228	0.9886	1.0345	1.0222	0.9981	1.0245	1.0369	1.0050	1.0320	1.0020	0.9717	1.0316	1.0065	0.9794	1.0280	0.9942	0.9886	1.0059
Jiangxi	1.0552	0.9949	1.0606	1.0485	1.0102	1.0378	1.0128	0.9828	1.0304	0.9979	0.9687	1.0300	1.0048	0.9728	1.0333	1.0142	1.0039	1.0106
Shandong	1.0778	0.9964	1.0890	1.0367	0.9724	1.0720	1.0193	0.9369	1.0942	1.0270	0.9999	1.0274	1.0345	1.0118	1.0226	1.0378	1.0058	1.0323
Henan	1.0477	1.0017	1.0463	1.0246	1.0014	1.0249	1.0216	0.9850	1.0373	1.0126	1.0081	1.0046	1.0082	1.0079	1.0008	1.0103	1.0080	1.0024
Hubei	1.0100	0.9959	1.0142	1.0076	0.9792	1.0305	1.0131	0.9829	1.0314	1.0234	0.9820	1.0434	1.0236	0.9801	1.0447	1.0174	1.0212	0.9973
Hunan	1.0429	1.0065	1.0364	1.0118	0.9934	1.0188	1.0053	0.9795	1.0264	0.9990	1.0000	0.9995	0.9998	0.9937	1.0061	1.0000	0.9986	1.0014
Guangdong	1.0467	0.9934	1.0535	1.0135	0.9804	1.0340	1.0626	1.0079	1.0544	1.0380	1.0030	1.0353	1.0452	1.0126	1.0324	1.0090	0.9907	1.0188
Guangxi	1.0120	0.9910	1.0212	1.0202	1.0062	1.0142	1.0035	0.9876	1.0161	0.9892	0.9917	0.9977	0.9972	0.9940	1.0032	0.9956	0.9965	0.9992
Hainan	1.0370	1.0065	1.0305	1.0396	1.0364	1.0043	1.0128	0.9748	1.0390	1.0061	0.9858	1.0206	0.9822	0.9757	1.0066	1.0118	1.0107	1.0011
Sichuan	1.0208	1.0135	1.0073	1.0191	0.9945	1.0257	1.0195	0.9944	1.0256	1.0021	0.9927	1.0093	1.0148	1.0169	0.9990	1.0262	1.0227	1.0035
Guizhou	1.0225	1.0122	1.0103	1.0129	1.0020	1.0120	1.0121	0.9949	1.0174	0.9962	0.9936	1.0028	1.0093	1.0156	0.9943	1.0140	1.0146	0.9994
Yunnan	1.0698	1.0000	1.0698	1.0609	1.0000	1.0609	1.0339	1.0000	1.0339	1.0501	1.0000	1.0501	1.0174	1.0000	1.0174	0.9997	1.0000	0.9997
Tibet	0.8713	0.8610	1.0102	1.1788	1.1672	1.0109	1.0466	1.0273	1.0187	1.0022	0.9940	1.0084	0.9049	0.9005	1.0069	1.0111	1.0143	0.9975
Shaanxi	1.0322	1.0212	1.0113	1.0119	0.9825	1.0319	1.0138	0.9840	1.0309	1.0087	1.0005	1.0082	1.0078	1.0136	0.9959	1.0063	1.0051	1.0013
Gansu	1.0416	1.0344	1.0085	1.0331	0.9946	1.0409	1.0039	0.9693	1.0375	0.9905	0.9717	1.0200	1.0200	1.0378	0.9904	1.0102	1.0101	1.0007
Qinghai	1.1434	1.0526	1.0825	0.9711	0.9447	1.0328	1.0204	0.9889	1.0321	0.9972	0.9934	1.0034	0.9766	0.9778	0.9990	0.9557	0.9562	0.9995
Ningxia	0.9893	0.9699	1.0197	0.9982	0.9823	1.0167	1.0096	0.9922	1.0179	0.9985	0.9943	1.0043	1.0268	1.0236	1.0032	0.9617	0.9616	1.0001
Xinjiang	1.0398	1.0118	1.0280	1.0110	0.9922	1.0193	1.0119	0.9884	1.0240	0.9998	0.9861	1.0142	0.9941	0.9868	1.0078	1.0060	1.0055	1.0006