Under the Shadow of Asian Brown Clouds: the Unbalanced Regional Productivities in China with Environmental Concerns

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Abstract. China has seen the fruit of its rapid economic growth over the past two decades, but severe environmental problems have accompanied this, such as the looming danger of Asian Brown Clouds. This paper analyzes the regional development of China by examining economic performance as well as environmental factors. Technical efficiency and productivity changes of thirty-one regions in China during the period 1997-2001 are computed. In the case when regional GDP is simply concerned, the fast-developing eastern (coastal) regions experience higher technical efficiency and productivity growth than the inland central and western regions. When environmental factors are incorporated, the eastern regions still perform better than the inland ones both from static and dynamic analysis. This phenomenon is minted as the 'double deterioration' of the inland areas in China. Double deterioration is attributed to the lack of economic resources to replace highly-polluting production equipment and technology in those less developed regions.

Keywords: Data envelopment analysis (DEA), Malmquist productivity index, environment, sustainable development

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1. Introduction

A three-kilometer thick cloud of toxic pollution looming over Asia, known as 'Asian Brown Clouds', caught global concern at the 2002 World Summit on Sustainable Development in South Africa. This thick layer of haze that hangs over a wide expanse of territory covering southern to eastern Asia (South Asia, India, Pakistan, Southeast Asia, and China) is a direct result of damaging development trends (CNN News, 2002), for which the whole world now has to work together so as to help reverse it. Asian Brown Clouds are made of soot, ash, dust, and airborne chemicals, which are all products of man-made pollutions. This toxic haze could kill hundreds of thousands of people prematurely and cause deadly flooding and drought. Scientists warn the impact could be global since winds can push pollutants halfway around the world, including to Europe and even the Americas in a week, according to *Concept Paper on Asian Brown Clouds* (2001). Therefore, Asian Brown Clouds are not only an important subject for China and its people, but also for all the people of the world.

Ever since China adopted the policy of economic reform and opened up to the outside world in the late 1970s, it has experienced double-digit growth. Although China has experienced rapid economic growth for more than a decade, its environment is rapidly deteriorating. Soot, dust, and sulfur dioxide, the main components of Asian Brown Clouds, are the major pollutants being emitted. Only recently has the Chinese government taken action to cope with these environmental problems, especially on air and water pollution (World Bank, 2001). Although the dust emission has declined, sulfur dioxide and soot emissions have been climbing in recent years (Liu, 2001), and these problems can be attributed to old-fashioned and inefficient technology, as well as highly polluting engines and fuels (Ramanathan and Crutzen, 2001).

There are numerous theoretical and empirical studies considering the relationship between economic development and environmental quality - the famous Environmental Kuznets Curve (EKC) postulates an inverted-U relationship between economic growth and pollution. It suggests that environmental degradation should increase at low incomes, reach a peak (turning point), and eventually decrease at high income. EKC implies that persistent economic growth can be accompanied by reductions of environmental degradation in the long run (Neumayer, 1999). The other optimistic view, the Porter hypothesis, states that reducing environmental impacts of production will improve productivity, hence simultaneously benefiting economic growth and the environment (Porter and van der Linde, 1995). Furthermore, more profitable firms are more likely to adopt clear technologies (Dasgupta et al., 2002). This arouses our curiosity: Do China's fast-developing east regions both economically and environmentally perform better than the less-developing inland ones? Do their rankings in regional productivities drastically change after taking into account environmental factors? After its entrance into the World Trade Organization (WTO) in 2001, problems of rising regional economic disparities and environmental protection have become more imminent to China.

For OECD members, the objective to pursue a balance between pro-development and pro-environment has received considerable attention. Lovell et al. (1995) study the macroeconomic performance of 19 OECD countries during 1970-1990 by taking four services (real GDP, a low rate of inflation, a low rate of unemployment, and a favorable trade balance) into analysis. When two environmental disamenities (carbon and nitrogen emissions) are included into the service list, the rankings change while the relative scores of the European countries decline. Environmental indicators do seem to have crucial effects on a nation's relative performance.

Incorporating the economy and the environment together, the concept of sustainable development has become a key element of policies not only at national levels, but also at regional levels (Gibbs, 1998). One can recall the old radical green slogan "think globally, act locally." In other words, development towards sustainability can be introduced by starting from areas on a local or regional level (Wallner et al., 1996; Dryzek, 1997). This type of sub-national scale can be emphasized as a key site for the integration of economic and environment policy (Gibbs, 2000). This would seem to be of particular importance to various regions in China, in light of their geographical and economic diversity.

In this paper we will examine the overall performance of each region in China by comparing the relative technical efficiency and productivity change before and after incorporating environmental impacts. All major kinds of emission for Asian Brown Clouds will be included in our analysis. We use a linear programming technique known as Data Envelopment Analysis (DEA) to analyze the relative macroeconomic performance of regions in China. DEA, first developed by Charnes, Cooper, and Rhodes (1978), is a methodology for constructing a best practice frontier, which tightly envelops observed data on producers' inputs and outputs. The relative performance of a decision-making unit is evaluated in terms of its proximity to the best practice frontier. DEA was originally intended for use in microeconomic environments to measure the performance of schools, hospitals, and the like, and it is also ideally suited to macroeconomic performance analysis (Lovell et al., 1995).

Although DEA is useful to identify the best performers in a certain year, performance improvement over time (including productivity changes) is not considered there. Productivity changes can be measured by the Malmquist productivity index,[1] which takes panel data into account. This method is applied by Färe et al. (1994) to analyze productivity growth of OECD countries, by considering labor and capital as inputs and GDP as an output. Chang and Luh (2000) adopt the same method to analyze the productivity growth of ten Asian economies.

This paper is organized as follows: Following this section, the next section provides an overview of China's regional economic disparities. Section 3 introduces a non-parametric approach for the measurement of technical efficiency and productivity change, including the DEA and the Malmquist index. Section 4 describes data selection. Section 5 presents empirical results. Section 6 concludes this paper.

2. Regional Economic Disparities in China

From the perspective of China's development and political factors, its provinces, autonomous regions, and municipalities are usually divided into three major areas: the east, central, and west. The east area stretches from the province of Liaoning to Guangxi, including Shandong, Hebei, Jiangsu, Zhejiang, Fujian, Guandong, and Hainan, and the municipalities of Beijing, Tianjin, and Shanghai. Among the three major areas, the east area has experienced the most rapid economic growth. In the early 1980s, the Chinese government established and opened up four special economic zones and fourteen coastal cities to foreign investment and trade. Since

[1] The index was introduced by Caves et al. (1982), who name it the Malmquist productivity index. Sten Malmquist is the first person to construct quantity indices as ratios of distance functions.

then, the special economic zones and the coastal open areas have enjoyed considerable autonomy, special tax treatment, and preferential resource allocations (Litwack and Qian, 1998). They have attracted the most foreign capital, technology, as well as managerial know-how. Rapid economic growth has made this area a magnet for attracting investment and migrant workers. The central area consists of Heilongjiang, Jilin, Inner Mongolia, Henan, Shanxi, Anhui, Hubei, Hunan, and Jiangxi. This area has a large population and a home base of farming. Foreign investment in this area is not as much as in the east coastal regions, and existing equipment relatively lags behind. The west area covers more than half of China, including the provinces of Gansu, Guizhou, Ningxia, Qinghai, Shaanxi, Tibet, Yunnan, Xinjiang, Sichuan, and the municipality of Chongqing. Compared to other two, this area generally has a low population density and is the least developed.

The high economic inequality in China can be mainly attributed to the growing inland-coastal disparity (Chang, 2002; Yang, 2002). This big issue has caught considerable attention in the recent research. For instance, the rich coastal provinces perform better with respect to per capita production and consumption than the inland ones during the reform period (Kanbur and Zhang, 1999; Yao and Zhang, 2001). The total factor productivity of the coastal provinces is roughly twice as high as that of the non-coastal provinces (Fleisher and Chen, 1997). General explanations for these disparity issues are from the advantageous geographic factors which will reduce transportation cost and the government's preferable policies for the coastal areas (Yang, 2002).

The locations of the provinces and municipalities and the per capita GDP of each region in China are shown in Figure 1. There is an apparently economic disparity between the coastal and inland areas. Regional economic disparities are because of a greater access to world markets, better infrastructure, a higher-educated labor force, and the government's preferential policies on foreign investment for the east area (World Bank, 1997). Figure 2 presents the industry composition[2] (primary, secondary, and tertiary industry[3]) of these three areas in 1999. Compared to the inland central and west areas, the east area has higher proportions of secondary and tertiary industries and a far lower proportion of primary industry.

[Insert Figure 1 and Figure 2 about here]

3. Method

In this section the data envelopment analysis (DEA) approach and Malmquist productivity index will be used to measure technical efficiency and productivity changes of China, without and with the incorporation of environmental impacts.

3.1 Measuring technical efficiency: the Data Envelopment Analysis (DEA) approach

DEA is known as a mathematical programming method for assessing the comparative efficiencies of a DMU[4] (in this case, a region is counted as a DMU). DEA is a non-parametric method that allows for efficient measurement, without specifying either the production functional form or weights on different inputs and outputs. This methodology defines a non-parametric best practice frontier that can be used as a reference for efficiency measures. Comprehensive reviews of the

[2] This is a percentage of an industry's output value of GDP. Figures are from the authors' computation. The percentage compositions of other years are quite similar.

[3] Primary industries include agriculture (farming, forestry, animal husbandry, and fishery). Secondary industries include mining and quarry, manufacturing, production and supply of electricity, water and gas, and construction. Tertiary industries include all other industries not included in the primary or secondary industry.

[4] DMU is the abbreviation for a 'decision-making unit.'

development of efficiency measurement can be found in Lovell (1993). Assume that there are M inputs and N outputs for each of the K DMUs. For the pth DMU, its multiple inputs and outputs are presented by the column vectors x_i and y_j, respectively. The technical efficiency score (η_p) of DMU p can be found by solving the following linear programming problem:

$$\max_{\lambda,\eta_p} \quad \eta_p \tag{1}$$

$$\text{s.t.} \quad x_{ip} - \sum_{r=1}^{K} x_{ir}\lambda_r \geq 0 \qquad \text{for } i = 1,2,\ \dots,\ M,$$

$$-y_{jp}\eta_p + \sum_{r=1}^{K} y_{jr}\lambda_r \geq 0 \qquad \text{for } j = 1,2,\ \dots,\ N,$$

$$\lambda_r \geq 0 \quad \text{for } r = 1,2,\ \dots,\ p,\ \dots,\ K,$$

where η_p is the efficiency score; x_i is the ith input; y_j is the jth output of the production; and λ_r is the weight of each observation. The above procedure constructs a piecewise linear approximation to the frontier by minimizing the quantities of the M inputs required to meet the output levels of the DMU p. The weight λ_r serves to form a convex combination of observed inputs and outputs. The efficiency score η_p measures the maximal radial expansion of the outputs given the level of inputs. It is an output-orientated measurement of efficiency.

Procedure (1) is also known as the CCR model, named after its authors, Charnes, Cooper, and Rhodes (1978), and it assumes that all production units are operating at their optimal scale of production. Banker, Charnes, and Cooper (1984) suggest an extension of the CRS model to account for variable returns to scale (VRS) situations. This model is called the BCC model, named after its authors. It can be obtained by adding one more constraint $\sum_{r=1}^{K}\lambda_r = 1$ on process (1). This constraint essentially ensures that an inefficient DMU is only ‘benchmarked’ against DMUs of similar size. Under the assumption of constant returns to scale (CRS), the results from these two approaches are identical, whereas under variable returns to scale (VRS), the results could be different.

3.2 Measurement of productivity change: the Malmquist index

The efficiency measured from the above procedure is static in nature, as the performance of a production unit is evaluated in reference to the best practice in a given year. The shift of the frontier over time cannot be obtained from DEA. To account for dynamic shifts in the frontier, we use the Malmquist productivity index (MALM) developed by Färe et al. (1994). This method is also capable of decomposing the productivity change into efficiency and technical changes, which are components of productivity change.

For each time period $t = 1, \dots, T$, the Malmquist index is based on a distance function, which takes the form of:

$$D^t(X^t, Y^t) = \min\{\delta : (X^t, Y^t/\delta) \in S^t\}, \tag{2}$$

where δ determines the maximal feasible proportional expansion of output vector Y^t for a given input vector X^t under production technology S^t at time period t. If and only if the input output combination (X^t, Y^t) belongs to the technology set S^t, the distance function has a value less than or equal to one; that is, $D^t(X^t, Y^t) \leq 1$. If $D^t(X^t, Y^t) = 1$, then the production is on the boundary of technology and the production is technically efficient.

Caves et al. (1982) originally define the Malmquist index of productivity change between time period s (base year) and time period t (final year), relative to the technology level at time period s:

$$M^s = \frac{D^s(X^t, Y^t)}{D^s(X^s, Y^s)}. \tag{3}$$

It provides a measurement of productivity change by comparing data (combination of input and output) of time period t with data of time period s using technology at time s as a reference. Similarly, the Malmquist index of productivity change relative to technology at time t can be defined as

$$M^t = \frac{D^t(X^t, Y^t)}{D^t(X^s, Y^s)}. \tag{4}$$

Allowing for technical inefficiency, Färe et al. (1994) extend the above models and propose an output-oriented Malmquist index of productivity change from time period s to period t as a geometric mean of the two Malmquist productivity indices of (3) and (4). A CRS technology is assumed to measure the productivity change, and the MALM is expressed as

$$\text{MALM} = \left[\frac{D^s_{\text{CRS}}(X^t, Y^t)}{D^s_{\text{CRS}}(X^s, Y^s)} \frac{D^t_{\text{CRS}}(X^t, Y^t)}{D^t_{\text{CRS}}(X^s, Y^s)} \right]^{\frac{1}{2}}. \tag{5}$$

Note that if $X^s = X^t$ and $Y^s = Y^t$ (for example, there has been no change in inputs and outputs between the periods), then the productivity index signals no change when revealing $\text{MALM}(\cdot) = 1$. Equation (5) of productivity change can be rearranged by decomposing into two components, the efficiency change (EFFCH) and the technical change (TECHCH), which take the following forms:

$$\text{Efficiency change (EFFCH)} = \frac{D^{t}_{\text{CRS}}(X^{t}, Y^{t})}{D^{s}_{\text{CRS}}(X^{s}, Y^{s})}. \quad (6)$$

$$\text{Technical change (TECHCH)} = \left[\frac{D^{s}_{\text{CRS}}(X^{t}, Y^{t})}{D^{t}_{\text{CRS}}(X^{t}, Y^{t})} \frac{D^{s}_{\text{CRS}}(X^{s}, Y^{s})}{D^{t}_{\text{CRS}}(X^{s}, Y^{s})}\right]^{\frac{1}{2}}. \quad (7)$$

The term EFFCH measures the changes in relative position of a production unit to the production frontier between time period *s* and *t* under CRS technology. Term TECHCH measures the shift in the frontier observed from the production unit's input mix over the period.[5] How much closer a region gets to the 'regions' frontier' is called 'catching up', and is measured by EFFCH. How much the 'regions' frontier' shifts at each region's observed input mix is called 'innovation', shown by TECHCH. Improvements in productivity yield Malmquist indices and any components in the Malmquist index greater than unity. On the other hand, deterioration in performance over time is associated with a Malmquist index and any other components less than unity.

3.3 The analytical process

The growth of a nation's output depends on capital formation as well as efficiency and productivity improvement. Labor and capital are two major inputs in production. When measuring an economy's overall output, gross domestic product (GDP) is commonly used. For an economy, while GDP (income) is desirable, emissions (pollution) are undesirable. The changes in income and pollution have a two-way relation: First, increasing income directly deteriorates the environment because pollution is a byproduct of a production process and is costly to dispose of. In reverse, the growth of income is accompanied by public increasing demand for

[5] In summary, the MALM is in the form: MALM = EFFCH × TECHCH.

better environmental quality through driving forces such as the control measures, technological progress and the structural change of consumption. The desirable GDP and undesirable pollution should be both taken into account in order to correct an economy's total product. This concept is called 'green GDP.' Green GDP is derived from the traditional GDP concept through a deduction of negative environmental and social impacts.

In this study, we treat pollution as a result of using environmental goods during the production. Therefore, given the same output level, an increase in emission will directly decrease the efficiency and productivity of a DMU (López, 1994; Smulders, 1999; de Bruyn, 2000). The emission proxies used in this analysis are treated as inputs, in order to represent how much environmental goods are used in the production process. The major components of Asian Brown Clouds (soot, dust, and sulfur dioxide) are treated as to in our BCC and Malmquist models.

4. Data Selection

From *China Statistical Yearbook*, we establish a data set for 31 regions in China (27 provinces and 4 municipalities) during 1997[6] to 2001. In the analysis without environmental impacts, there are two inputs and one output. The two inputs are gross capital formation[7] and number of employed persons. The one output is GDP of a specific region. These are aggregated input and output proxies. The analysis of environmental impact involves five inputs and one output. In addition to those two inputs and one output, three inputs of emissions, which are treated as cost of production, are added: volumes of sulfur dioxide emission, industrial soot emission,

[6] Complete panel data of these variables started from 1997.
[7] This is the sum of gross fixed capital formation and changes in inventories.

and industrial dust emission. These are China's three most serious emissions and constitute the major components of Asian Brown Clouds.

Macroeconomic performance is evaluated in terms of the ability of a region to maximize the one desirable output GDP and to minimize the three environmental disamenities. The value of monetary inputs and outputs such as GDP and capital are in 1997 prices. Summary statistics of these inputs and output ordered by year and area are shown in Tables 1 and 2, respectively. We use the freeware Deap 2.1, kindly provided by Coelli (1996), to solve the linear programming problems.

[Insert Table 1 and Table 2 about here]

5. Results and Discussions

The compositions of the efficiency frontier compared without and with environmental impacts in each year are given in section 5.1. This part of our study captures the static aspect of the relative performance of each region. Section 5.2 presents the Malmquist productivity index changes without and with environmental factors.

5.1 Efficiency frontier

The efficiency frontier consists of the most efficient regions for each particular year. Regions on the frontier are assigned an efficiency score of one. Regions with scores approximating to one are those who are closer to the frontier. Compositions of efficiency frontiers without and with environmental factors during 1997 to 2001 are shown in Table 3.

[Insert Table 3 about here]

Generally speaking, about one-sixth of the regions in the sample are on the frontier at least once for the time period from 1997 to 2001 when environmental factors are not considered. With environmental factors, about one-third of the regions are on the frontier. With or without environmental factors, Liaoning (06), Shanghai (09), Guangdong (19), and Tibet (26) are on the frontier every year. Heilongjiang (08) is on the frontier in some years without environmental factors and is on the frontier for every year with environmental factors. Jiangsu (10), Fujian (13), and Hainan (18) behave most efficiently for every year after taking the environmental factors into account. Two municipalities, Beijing (01) and Tianjin (02), are on the frontier for two years with environmental factors. Most of these best performers are in the highly developing areas of China.

Composition of the efficiency frontier sorted by areas of China is in Table 4. The east coastal regions are on average in a better position no matter with or without environmental factors. Taking into account environmental factors makes the number of regions on the frontier be twice as many. The total amount of regions gained on the frontier mainly results from the east area. The efficiency frontier derived from technical efficiency is a relative concept. We cannot conclude that those east coastal regions in the frontier have absolutely good environmental conditions. However, these provinces perform better than their inland peers when both economic and environmental factors are concerned.

[Insert Table 4 about here]

5.2 Productivity change

In the above analysis, the efficiency frontier for each year is constructed from the efficient regions of the given year. This is a kind of static analysis that disregards movements of the frontier, and regions on the frontier have the same efficiency score of one. Geometric means of the Malmquist productivity change summary indices and the components of growth for each sample region are listed below.

Table 5 shows a comparison of regional Malmquist indices with and without environmental factors. On the left side of Table 5, the Malmquist indices and its components without environmental factors are listed. The average Malmquist index is 0.997, with 19 regions' indices exceeding unity, implying that they have positive production growth. The east regions overall perform better with a positive productivity growth, except for Guangxi (20) and Hainan (21). Shanghai (09) has the highest productivity growth in China, followed by two other municipalities: Tianjin (02) and Beijing (01). The sources of productivity growth for these three regions are technical change rather than efficiency change. Most west regions and some central ones lie in the rear of the list. This result is consistent with the developing disparity in China (World Bank 2001) whereby the east areas have better economic conditions.

After incorporating the case of the three undesirable and costly emissions as inputs, regional performance rankings on average do not change: The Malmquist indices and its components with environmental factors are listed on the right side of Table 5. The average Malmquist index is 0.996, with 12 regions showing a positive productivity growth. The overall rankings of Malmquist indices change slightly by incorporating environmental factors. Compared to other regions, three municipalities (Shanghai (09), Beijing (01) and Tianjin (02)) still perform better when environmental factors are considered. The regions whose ranks of position improve for a larger extent (more than 5 positions) are: Hainan (21) in the east; Jilin (7) in the central; Gansu (28) and Qinghai (29) in the west. Those regions regressing for more than 5 positions are: Jiansu (10), Zhejiang (11), Fujian (13), Guangding (19) in the east; Anhui (12) and Hubei (17) in the central.

In order to examine whether an association exits between the two rank lists without/with environmental factors, the test of Spearman rank correlation coefficient is used for this purpose. This is a nonparametric rank correlation procedure for making inferences about the association between two rank series. The Spearman correlation coefficient for the Malmquist indices is 0.815 at the 1% significance level; hence it strongly rejecting the null hypothesis that there is no association between the two rank series. Therefore, it can be generally concluded that those regions with higher productivity while GDP is solely concerned still rank superior when both GDP as well as environmental factors are considered.

[Insert Table 5 about here]

As mentioned above, Lovell et al. (1995) find that the inclusion of two environmental indicators did change the performance ranking among the OECD countries, implying that the environment is a decisive variable when assessing a nation's relative performance. However, this is not to say that environmental factors are not important for Chinese regional comparison because of this unchanged productivity ranking. It is rather a warning of the extreme developing disparity in China, whereby the non-coastal areas are frail in not only economic growth but also in environmental protection. We call this phenomenon the 'double deterioration' of regional development in China.

The double deterioration in China can also be clearly observed through the regional indices changes without/with environmental factors summarized in Figure 3. Figure 3 presents the decomposition of the Malmquist index by area. There appears to be an obvious difference between the east and the inland-central-west areas: No matter whether or not the environmental factors are added, almost every single index (MALM, EFFCH and TECHCH) in the eastern area outperform those of inland central and western area except the EFFCH. While the productivity growth (MALM) is positive in the east area, it exhibits negativity in the central and west areas with environmental factors. With and without environmental factors, the east area leads the central and western areas for technical changes (TECHCH). For efficiency changes (EFFCH) without environmental factors, the eastern area performs worse than the central area. However, this gap becomes smaller after taking into account environmental factors.

[Insert Figure 3 about here]

One may wonder whether or not the industry composition creates the disparities since the pollution emitted is mainly from the secondary industry. Recall Figure 2, which presents the industry composition of the three areas in section 2: The percentage of secondary industry in the east area is higher than that of the other two areas. A postulate that an area with a higher percentage of secondary industry performs even worse under environmental concerns is definitely not supported. A possible explanation is that the secondary industry in the inland area is pollution-intensive, such as basic metals and chemicals. Their production equipment and environmental control skills are less developed, hence inducing higher pollution. 'Double deterioration' is a consequence of inefficient funds to replace dirty equipment and fuel for the poor regions.

6. Conclusions

Two decades of rapid economic growth have brought about a steady deterioration to the environment in China. Air pollution alone contributes to the premature death of more than a quarter of a million people each year (World Bank, 1997). With the threat of Asian Brown Clouds, this problem is starting to prompt global attention. In this paper we have provided an evaluation of the performance of those regions responsible for the conduct of economic development and environmental problems in China.

This study appears to be the first to incorporate environmental considerations accompanying rapid economic issues in China from a sub-national perspective. We believe that regional development performances should be biased when neglecting a number of important respects such as environmental factors. In this paper three severe air emissions (soot, dust, and sulfur dioxide) are included as proxies of undesirable externalities. We treat these pollutions as costly inputs used for production. A 1997-2001 panel data set of thirty-one regions in China is used. The relative technical efficiency and productivity change of these thirty-one regions in China without/with environmental factors are delivered and discussed.

The empirical results can be summarized as follows: First, the fast developing east coastal regions experience comparatively higher technical efficiency and productivity growth than the other inland regions when GDP is solely considered as a region's output. Second, in static analysis, taking into account environmental factors makes the number of regions on the frontier be twice as many. The total amount of regions gained on the frontier mainly results from the progress of east area. Third, in dynamic analysis, the ranking lists without/with environmental factors change just slightly. This result is statistically significant which provide evidence that these two rank series without/with environmental factors are highly related. The possible interpretation for this phenomenon is that for those regions with inferior productivity suffer from costly environmental problems at the same time. In this study, we called it as a 'double deterioration" in China. Fourth, in the comparison of the Malmquist index and its components, the eastern area performs better than the inland central and western ones after the adjustment adding into environmental factors. The above phenomenon should be attributed to the highly-polluting production process rather than the industrial composition.

Receiving $45 billion in 1998, China was the largest FDI (Foreign Direct Investment) host country among the developing Asian economies (United Nations, 1999). However, per capita FDI in the west area is only eight percent of that in the east (Hu, 2001). Traditional rules, such as 'economy first, environment later' or 'the coastal first, the inland later,' still dominate the national development policy. Furthermore, China open up for all industries without discrimination after it entered the WTO in 2001. People in China, especially in the areas with lower income, may welcome dirtier industries so as to increase their income. China hence faces a dilemma of economic growth versus environmental protection.

Our empirical findings are consistent with EKC theory: while the poorer inland areas are on the increasing stage of per output pollution, the richer east is on the decreasing stage of per output pollution. Better environmental performance has been accompanied with economic achievement for the fast-developing area. On the other side, double deterioration of the inland area is indeed a warning for China to pursue balanced regional development. The inland regions may produce and mine using a lower grade of equipment that is highly polluting, and they still cannot afford better equipment to treat the pollutants. According to EKC theory, with persistent economic growth, the environment of the inland China will sooner or later improve. However, before this turning point occurs, they are now suffering from a double deterioration of economic performance and environment.

The following principles may serve as some inspirations to speed up the development of the inland China: The first is to diminish transportation expenses in these areas. Most western regions are relatively disadvantageous in not only having a longer distance to market, but also higher transportation costs, which are also obstacles to import the latest pollution abatement technologies and information. The second is to ask for domestic and international assistance in financing, local environmental policy reforms, and education. In the long term, growth without environmental protection could lead the industry to be less competitive under pressure from a world that needs to adhere to environmental protection. Our warning of a 'double deterioration' may be beneficial in promoting sustainable development of China's economy as well as that of the global village.

Environmental disamenities are frequently trans-regional, and may not be entirely under the control of a particular region. However, this study can serve as a starting point to inspire attention towards the balance between economic growth and environmental protection. For future research, we may study the effects of a region's industrial structure, environmental policies, and the local government's power on its performance. The efficiency and productivity approaches used in this paper can be applied to other regional holistic development studies.

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Table 1

Summary statistics of inputs and outputs by year

		1997	1998	1999	2000	2001
Inputs						
Gross Capital Formation	Mean	1 068.48	1 100.62	1 060.34	1 060.97	1 092.42
(100 million RMB)	Std. Dev.	847.59	861.08	853.25	870.83	870.51
Number of Employed Persons	Mean	2 053.76	2 046.01	2 015.92	2 128.35	2 019.70
(10,000 persons)	Std. Dev.	1 408.80	1 363.67	1 412.84	1 425.89	1 443.79
Volume of Sulfur Dioxide	Mean	439 558	513 878	470 998	511 640	484 979
Emissions (ton)	Std. Dev.	327 707	403 600	342 767	368 056	356 231
Volume of Industrial Soot	Mean	220 844	379 163	307 559	312 784	274 867
Emission (ton)	Std. Dev.	152 050	344 907	218 799	224 387	221 522
Volume of Industrial Dust	Mean	176 901	426 510	379 129	315 022	266 548
Emission (ton)	Std. Dev.	112 955	324 119	301 655	246 890	219 508
Outputs						
Gross Domestic Product	Mean	2 482.45	2 468.56	2 48.57	2 502.62	2 570.18
(100 million RMB)	Std. Dev.	1 915.91	1 922.50	1 920.20	1 997.68	2 061.67

Note:

(1) The monetary values are in 1997 prices.

(2) Data source: *China Statistical Yearbook*, 1996-2000

Table 2

Summary statistics of inputs and outputs by area

		Area of China		
		East	*Central*	*West*
Inputs				
Gross Capital Formation	Mean	1 973.44	1 084.27	545.23
(100 million RMB)	Std. Dev.	1 158.07	5 00.33	410.16
Number of Employed Persons	Mean	2 242.71	2 422.49	1 492.03
(10,000 persons)	Std. Dev.	1 423.50	1 335.82	1 252.69
Volume of Sulfur Dioxide	Mean	603 158	470 748	353 590
Emissions (ton)	Std. Dev.	448 745	236 683	269 773
Volume of Industrial Soot	Mean	290 239	393 908	224 231
Emission (ton)	Std. Dev.	231 634	222 962	249 638
Volume of Industrial Dust	Mean	356 233	382 006	198 463
Emission (ton)	Std. Dev.	297 724	261 551	174 525
Outputs				
Gross Domestic Product	Mean	4 426.05	2 742.67	1 242.27
(100 million RMB)	Std. Dev.	2 692.76	1 179.67	1 053.79

Note:

(1) The monetary values are in 1997 prices.

(2) Data source: *China Statistical Yearbook*, 1996-2000

Table 3

Technical efficiency score of region for variable returns to scale

ID	Region	Area	1997		1998		1999		2000		2001	
			w/o[a]	*w/*[b]	*w/o*	*w/*	*w/o*	*w/*	*w/o*	*w/*	*w/o*	*w/*
01	Beijing	E	0.820	0.861	0.742	0.956	0.666	0.916	0.731	1.000	0.727	1.000
02	Tianjin	E	0.935	1.000	0.946	1.000	0.888	0.930	0.882	0.882	0.873	0.875
03	Hebei	E	0.767	0.767	0.744	0.744	0.745	0.745	0.740	0.740	0.768	0.768
04	Shanxi	C	0.829	0.829	0.617	0.617	0.682	0.682	0.675	0.675	0.708	0.708
05	Inner Mongolia	C	0.754	0.754	0.755	0.773	0.713	0.721	0.703	0.703	0.803	0.803
06	Liaoning	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
07	Jilin	C	0.851	0.879	0.831	0.927	0.787	0.826	0.821	0.821	0.827	0.843
08	Heilongjiang	C	0.973	1.000	0.807	1.000	0.931	1.000	1.000	1.000	1.000	1.000
09	Shanghai	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	Jiangsu	E	0.920	1.000	0.926	1.000	0.936	1.000	0.935	1.000	0.955	1.000
11	Zhejiang	E	0.833	0.876	0.805	0.807	0.820	0.824	0.824	0.878	0.849	0.911
12	Anhui	C	0.818	0.884	0.793	0.903	0.855	0.949	0.855	0.929	0.883	0.939
13	Fujian	E	0.896	1.000	0.798	1.000	0.783	1.000	0.782	1.000	0.792	1.000
14	Jiangxi	C	0.826	0.912	0.836	0.961	0.814	0.927	0.855	0.888	0.865	0.915
15	Shandong	E	0.909	0.909	0.904	0.904	0.905	0.933	0.884	0.884	0.886	0.886
16	Henan	C	0.845	0.847	0.821	0.821	0.809	0.813	0.803	0.804	0.829	0.829
17	Hubei	C	0.795	0.831	0.765	0.838	0.725	0.791	0.730	0.754	0.793	0.823
18	Hunan	C	0.950	0.984	0.870	0.955	0.907	0.963	0.903	0.933	0.897	0.912
19	Guangdong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	Guangxi	E	1.000	1.000	0.929	0.929	0.940	0.940	0.931	0.931	0.924	0.924
21	Hainan	E	0.828	1.000	0.984	1.000	0.723	1.000	0.680	1.000	0.712	1.000
22	Chongqing	W	0.785	0.853	0.758	0.879	0.777	0.884	0.706	0.789	0.680	0.742
23	Sichuan	W	0.886	0.911	0.828	0.834	0.812	0.852	0.853	0.853	0.836	0.836
24	Guizhou	W	0.762	0.771	0.730	0.730	0.663	0.663	0.618	0.618	0.577	0.577
25	Yunnan	W	0.725	0.847	0.738	0.847	0.773	0.837	0.827	0.861	0.709	0.752
26	Tibet	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
27	Shaanxi	W	0.752	0.754	0.684	0.684	0.680	0.680	0.597	0.597	0.603	0.611
28	Gansu	W	0.743	0.781	0.774	0.784	0.711	0.761	0.693	0.728	0.772	0.784
29	Qinghai	W	0.670	0.670	1.000	1.000	0.583	0.664	0.573	0.639	0.534	0.572
30	Ningxia	W	0.701	0.701	1.000	1.000	0.563	0.563	0.522	0.522	0.491	0.491
31	Xinjiang	W	0.776	0.776	0.678	0.698	0.701	0.754	0.781	0.829	0.700	0.718
	Mean		0.850	0.884	0.841	0.890	0.803	0.859	0.803	0.847	0.806	0.846

Note:

(1) [a] Technical efficiency of the region during the period 1997-2000 without environmental factors.

(2) [b] Technical efficiency of the region during the period 1997-2000 with environmental factors.

(3) E is the abbreviation for east area, C is the abbreviation for central area, and W is the abbreviation for west area.

Table 4

Composition of the efficiency frontier for variable returns to scale

		Without environmental factors					*With environmental factors*				
		1997	1998	1999	2000	2001	1997	1998	1999	2000	2001
	East	4	3	3	3	3	8	7	6	7	7
Area of China	*Central*				1	1	1	1	1	1	1
	West	1	3	1	1	1	1	3	1	1	1
	Total	5	6	4	5	5	10	11	8	9	9

Note: The numbers in this table are the number of regions on the frontier

Table 5

Decomposition of the Malmquist index without/with environmental factors by region

			Without Environmental factors				*With Environmental factors*			
ID	Region	Area	Malmquist index (MALM)	Efficiency change (EFFCH)	Technical change (TECHCH)	Rank	Malmquist index (MALM)	Efficiency change (EFFCH)	Technical change (TECHCH)	Rank
01	Beijing	E	1.030	0.973	1.059	3	1.131	1.043	1.084	2
02	Tianjin	E	1.038	0.987	1.051	2	1.053	0.984	1.070	4
03	Hebei	E	1.009	1.001	1.008	13	0.993	0.996	0.997	13
04	Shanxi	C	0.965	0.962	1.003	26	0.959	0.962	0.997	25
05	Inner Mongolia	C	1.022	1.017	1.005	7	1.031	1.017	1.014	5
06	Liaoning	E	1.016	1.000	1.016	9	1.016	1.000	1.016	7
07	Jilin	C	0.999	0.993	1.006	20	1.002	0.990	1.012	12
08	Heilongjiang	C	1.021	1.008	1.013	8	1.016	1.000	1.016	7
09	Shanghai	E	1.057	1.000	1.057	1	1.153	1.000	1.153	1
10	Jiangsu	E	1.010	0.977	1.033	12	0.983	0.962	1.021	20
11	Zhejiang	E	1.024	0.991	1.033	6	0.992	1.005	0.987	14
12	Anhui	C	1.025	1.031	0.994	5	1.004	1.014	0.990	11
13	Fujian	E	1.003	0.970	1.035	17	0.923	0.992	0.930	29
14	Jiangxi	C	1.006	1.011	0.995	16	0.992	1.000	0.992	14
15	Shandong	E	1.008	0.981	1.027	15	0.989	0.985	1.004	17
16	Hennan	C	1.003	1.006	0.997	17	0.989	0.995	0.994	17
17	Hubei	C	1.011	1.002	1.009	10	0.985	0.997	0.988	19
18	Hunan	C	0.989	0.997	0.992	23	0.968	0.981	0.987	22
19	Guangdong	E	1.009	0.981	1.029	13	0.979	1.000	0.979	21
20	Guangxi	E	0.966	0.980	0.986	25	0.954	0.980	0.974	26
21	Hainan	E	0.998	0.986	1.012	21	1.008	0.973	1.036	9
22	Chongqing	W	0.961	0.965	0.996	27	0.954	0.966	0.988	26
23	Sichuan	W	0.993	1.002	0.991	22	0.966	0.978	0.988	23
24	Guizhou	W	0.921	0.935	0.986	30	0.914	0.933	0.980	31
25	Yunnan	W	0.989	0.994	0.994	23	0.964	0.972	0.992	24
26	Tibet	W	1.030	1.044	0.987	3	1.113	1.000	1.113	3
27	Shaanxi	W	0.941	0.947	0.994	29	0.941	0.949	0.991	28
28	Gansu	W	1.002	1.011	0.991	19	1.005	1.006	0.999	10
29	Qinghai	W	0.957	0.950	1.008	28	0.990	0.982	1.008	16
30	Ningxia	W	0.921	0.917	1.004	30	0.920	0.917	1.002	30
31	Xinjiang	W	1.011	0.980	1.032	10	1.024	0.989	1.035	6
	mean		0.997	0.987	1.011		0.996	0.986	1.010	

Note:

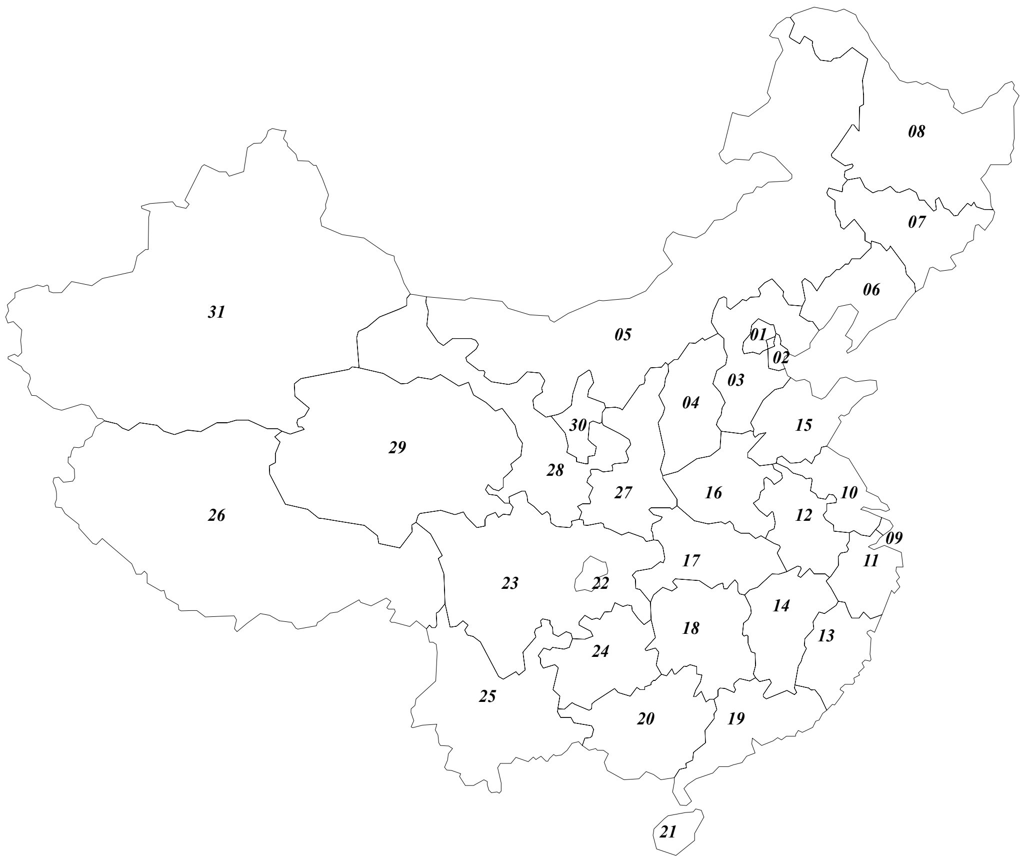
(1) All Malmquist index averages are geometric means.

(2) E is the abbreviation for east area, C is the abbreviation for central area, and W is the abbreviation for west area.

(3) The Spearman rank correlation coefficient for the Malmquist indices is 0.815 with p-value less than 0.0001.

Figure 1

Regions of China and average per capita GDP 1997-2001 (RMB)



East Area		***Central Area***		***West Area***	
01 Beijing	20,609	***04*** Shanxi	5,020	***22*** Chongqing	4,955
02 Tianjin	16,545	***05*** Inner Mongolia	5,489	***23*** Sichuan	4,571
03 Hebei	7,112	***07*** Jilin	6,450	***24*** Guizhou	2,518
06 Liaoning	10,242	***08*** Heilongjiang	8,072	***25*** Yunnan	4,470
09 Shanghai	31,347	***12*** Anhui	4,752	***26*** Tibet	4,208
10 Jiangsu	10,945	***14*** Jiangxi	4,674	***27*** Shaanxi	4,243
11 Zhejiang	12,383	***16*** Henan	5,081	***28*** Gansu	3,652
13 Fujian	10,877	***17*** Hubei	6,743	***29*** Qinghai	4,783
15 Shandong	8,881	***18*** Hunan	5,279	***30*** Ningxia	4,589
19 Guangdong	11,983			***31*** Xinjiang	6,795
20 Guangxi	4,313				
21 Hainan	6,426				

Figure 2

The industry composition among areas (% of GDP in 1997)

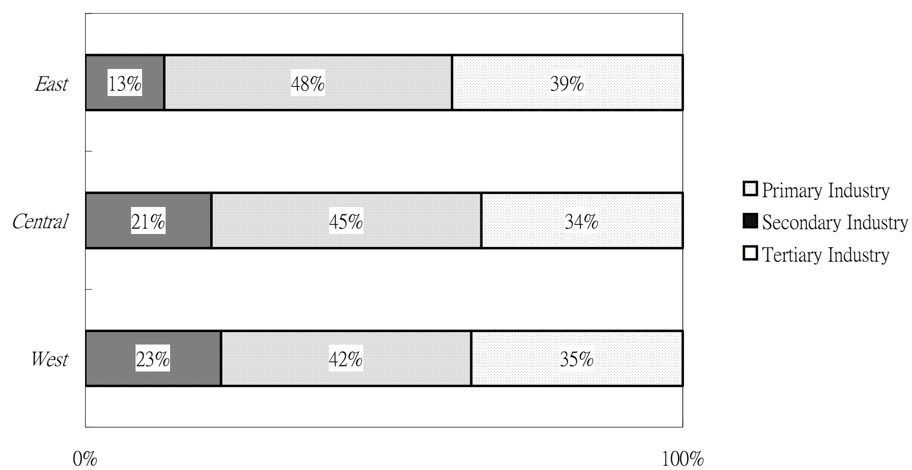


Figure 3

Decomposition of Malmquist index without/with environmental factors by area