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Impacts of Environmental Regulation on Technical
Efficiency and Productivity Loss in China

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Impacts of Environmental Regulation on Technical Efficiency and Productivity Loss in China

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Abstract: This study employs radial efficiency measure of Data Envelopment Analysis (DEA) to compute output distance functions which can show technical efficiencies for the strong and weak disposability of pollutants. We define the environmental efficiency index (EEI) as the ratio of two technical efficiencies so as to calculate productivity loss which can be estimated as GDP multiplied (1-EEI). The study focuses on 28 provinces and municipalities in China, which are divided into three regions, including the East, the Middle and the West. We find that the East paid the largest cost for environmental regulation among three regions. The rate of productivity loss of the East for environmental regulation is 4.24% while those of the Middle and the West are 1.53% and 1.72%, respectively. In addition, we also find that productivity loss from controlling wastewater is larger that from controlling SO2 for all the country. The rate of productivity loss from environmental regulation for wastewater is 1.43% whereas that from regulation for SO2 is 0.46%.

1. Introduction

Since its opening-up to the world economy, China has achieved astonishing economic growth and industrialization. Undoubtedly, the continuous and rapid economic growth has contributed to providing industrial infrastructure to improve the standard of living of people powerfully, however, it has increased enormous pressure on China's environment.

Air and water pollution in China, especially in urban areas, are most serious in the world. That the level of pollution exceeds international standards to a large extent has brought enormous burden to China. If air pollution level had fallen to the government's standard, China could avoid the death of 289,000 people per year according to the World Bank Report (1997). In other words, the current economic loss from air and water pollution is estimated approximately 3–8% of GDP per year in China.

Needless to say, industrial pollution is a main source of environmental problems in

China. It is really fatal as much as life-threatening level in China. In fact, Chinese government started environmental regulation to prevent industrial pollution in the 1980s, however, environmental laws and policies were not practically enacted so that they have not successfully regulated industrial pollutant emissions. Severe industrial pollution has been continuing to harm China's environment. Consequently, the reinforcement of environmental regulation has increasingly become indispensable.

Environmental regulation can result in reduction of pollutant emissions to improve the living environment of people at the expense of economic growth. That is to say, the enactment of environmental regulation will bring negative influence on productivity. If China strictly executes environmental regulations, how will the impact of environmental regulation on productivity be? In this paper, we use the data of 1990s to investigate it.

That the eastern coastal regions developed first resulted in unbalanced development in China, that is, there are gaps among provinces for technical efficiency and productivity. Therefore, we connect the analysis of impacts of environmental regulation on technical efficiency and productivity loss with China's regional economy. We focus on 28 provinces and municipalities which are divided into three regions, including the East, the Middle and the West.

The purpose of this paper is to analyze the impacts of strict environmental regulation on technical efficiency and productivity loss in 28 provinces and municipalities of China, especially to focus on the difference of impacts of environmental regulation in three regions. We try to find which pollutant brings larger cost due to environmental regulation between wastewater and SO2. In addition, we also want to know the movement of industrial pollutions due to unbalanced development among three regions.

We follow radial efficiency measure (Fare et al., 1986) of DEA approach based on output distance function in this paper.[1] We estimate technical efficiencies for the strong and weak disposability of pollutants and compare the level of technical efficiency change due to environmental regulation.[2]   In addition, we measure the productivity

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[1] There are two main methods used in measuring the impacts of environmental regulation on technical efficiency and productivity. One is the radial efficiency measure which considers the increase of desirable outputs and pollutants. Another is the hyperbolic efficiency measure that allows for the improvement of production and the reduction of pollution simultaneously. China paid attention to economic development policy more than environmental policy in the 1990s. It is considered that China could not practically distinguish desirable outputs and pollutants and almost merely pursued the increase of desirable outputs and pollutants. Therefore, the radial efficiency measure will be used in this paper.

[2] The strong disposability of pollutants refers to the ability to dispose of pollutants with no private cost. The weak disposability of pollutants refers to the ability to dispose of

loss came from environmental regulation by technical efficiency change. In details, we test technical efficiency change and productivity loss in three cases. One case is to include wastewater and SO2. Other two cases are only to consider one pollutant respectively. Additionally, we compare the impacts of environmental regulation on technical efficiency and productivity loss under different pollutants.

The variables in this paper are desirable output, pollutants and inputs. The desirable output is real GDP of the manufacturing industry. Pollutants include industrial wastewater, SO2 and waste solids. Inputs are real capital stock and labor force of the manufacturing industry. Data are taken from China's statistical yearbook of 1994-1999.

The paper is organized as follows. Section 2 presents the model which includes the theoretic and empirical model. The strong and weak disposability of pollutants will be introduced in the theoretic model. According to different technical efficiencies for two disposability, we can know the impacts of environmental regulation on technical efficiency and productivity. The radial efficiency measure of DEA approach is used to measure technical efficiencies for two disposability. Section 3 contains a brief description of the data and a discussion of the empirical results. Section 4 is summary and conclusions of this paper.

2. The model

2.1 The theoretical model

Different technologies about production equipment and operation incur different production performances. These performances can be measured as technical efficiency. This is the premise of our model. We categorize production technology as the strong and weak disposability technology. The strong disposability technology is a production technology without restriction of environmental regulation, whereas the weak disposability technology is the one under the restriction of environmental regulation. Technical efficiencies under two disposability technologies are different due to environmental regulation. Therefore, potential impact of environmental regulation on production can be measured by the two different technical efficiencies.

We assume our model as joint-production in which producers produce desirable outputs and undesirable pollutants simultaneously. Increase or reduction of desirable outputs and pollutants is decided freely in the strong disposability assumption, whereas

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pollutants at positive private cost, that is, all of pollutants are paid cost due to environmental regulation under the assumption of weak disposability of pollutants.

that is restricted in the weak disposability assumption. When desirable outputs are reduced due to environmental regulation, a certain cost to production will be accompanied with environmental regulation.

To describe the theoretical background of the model used, we suppose that the set of $k = \{1,...,K\}$ activities produce $y \in R_+^N$ desirable outputs and $w \in R_+^J$ pollutants using $x \in R_+^M$ inputs. Let Y and W denote the $(K \times N)$ matrix of observed desirable outputs and $(K \times J)$ matrix of observed pollutants, respectively. And let X denote the $(K \times M)$ matrix of observed inputs. Finally, let $z \in R_+^K$ be a $(K \times 1)$ vector of intensities that are used to weight the different activities in constructing the reference frontier to evaluate producer k. This vector enables us to shrink or expand individual observed activities, for the purpose of constructing unobserved but nonetheless feasible activities. It thus provides weights which facilitate the construction of the linear segments of the boundary of the technology.

Assuming that technology satisfies both constant returns to scale and the strong disposability of desirable outputs, pollutants and inputs, production set under the strong disposability of pollutants is written as the following:

$$P^S(x) = \{(y,w) : zY \geq y, zW \geq w, zX \leq x, z \geq 0\} \tag{1}$$

where P^S denotes output set under the strong disposability of pollutants. $z \geq 0$ means that production scale is under constant return to scale. This production set shows how much output can be produced. The intensity vector z serves to construct the boundary of production set from the convex combinations of the observed inputs and outputs. Thus, this set makes maximum desirable outputs achieved, given input vector X. Y is the output vector, and W is the pollutants vector. y, w, x are actual desirable output, actual pollutant emissions and actual inputs, respectively.

Similarly we need the production set under the weak disposability of pollutants. The production set that satisfies weak disposability of pollutants and strong disposability of desirable outputs and inputs is represented as the following:

$$P^W(x) = \{(y,w) : zY \geq y, zW = w, zX \leq x, z \geq 0\} \tag{2}$$

where P^W denotes output set under the weak disposability of pollutants. The equality zW=w implies that pollutants w cannot be freely disposable in the pollutants vector W, and pollutant emissions which exceed the current discharge are not be allowed. Therefore, it is possible to realize the reduction of pollutants to some extent. In Figure 1, the equality allows for feasible radial contractions of pollutants to the origin. Intuitively,

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Eq.(1) and Eq.(2) represent reference technologies relative to technical efficiency of each production unit according to the observed inputs and outputs.

Figure 1 clearly shows difference between $P^s(x)$ and $P^w(x)$ when there are a desirable output and a pollutant. Figure 1 expresses the production frontier curve by an output and a pollutant. $P^s(x)$ includes an area bounded by region OFBCD. $P^w(x)$ is restricted by region OABCD. The region OABF represents production possibilities that are feasible under the strong disposability of all outputs, but not feasible under the weak disposability of pollutants. The line CD represents the strong disposability of desirable output in which the reduction of output is freely achieved without decreasing inputs or w. If $P^w(x) \subseteq P^s(x)$, the output may be lost due to the restriction of the weak disposability. If disposal of pollutant w is costless, the FB segment is a technological part explainable for this situation. In other words, the reduction of w can be realized without the increase of inputs or decreasing desirable output. If disposal of w is not costless, some inputs like capital and labor would be pulled out of the production of desirable output in order to clean up w. Therefore, the FB segment is no longer feasible for this situation. Inputs also must be expended in deleting the pollutants. Output OF is impossibly given by the reduced inputs, that is, the OF segment can not be achieved when w is not costless. Reducing w is achieved under a certain cost along line OA and AB. Therefore, the region OFBCD $P^s(x)$ represents the strong disposability of w, desirable output and inputs. And the region OABCD $P^w(x)$ represents the strong disposability of inputs and desirable output as well as the weak disposability of pollutants w. The production set, which can be attainable without environmental regulation, cannot be reached under environmental regulation because production frontier curve is restricted. Hence, using the gap between the two production sets, we estimate technical efficiency of production under the restriction of environmental regulation.
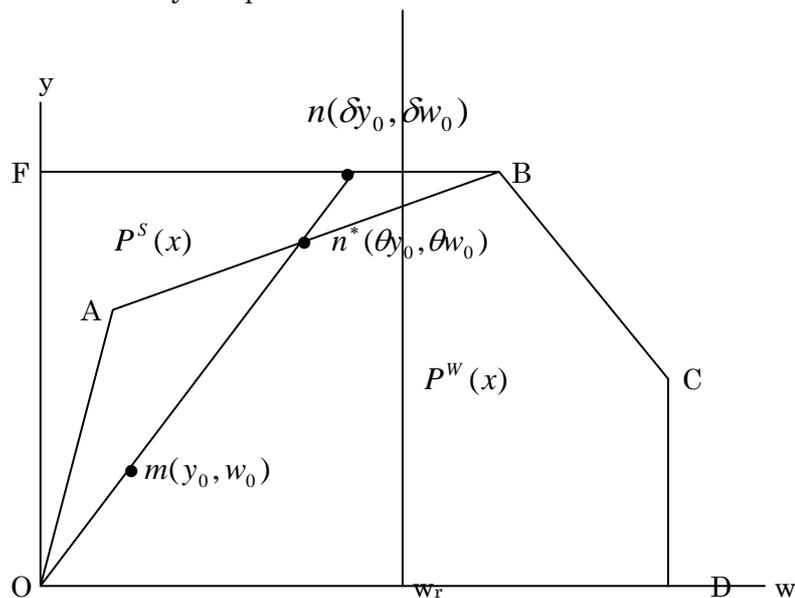
Figure 1. Output sets for the strong and weak disposability of pollutants

2.2 The empirical model

We introduce distance function, which describes a multi-input, multi-output production technology without the need to specify a behavioral objective (such as cost-minimization or profit-maximization). One may specify both input distance functions and output distance functions. An input distance function characterizes the production technology by looking at a minimal proportional contraction of the input vector, given an output vector. An output distance function considers a maximal proportional expansion of the output vector, given an input vector. It is considered that China pursued the maximum of output more than the minimum of input in the 1990s of China. Therefore, we will focus on output distance function in this paper. Shephard (1970) defined the output distance function and Fare et al. (1986) firstly proposed the radial efficiency measure based on the output distance function. He defined the radial efficiency measure for equiproportional increases of all outputs- desirable output and pollutants as the following:

$$D_O(x, y, w) = \min\{\lambda : ((y, w) / \lambda) \in P\} \tag{3}$$

where Do means output distance function, is technical efficiency level, and P is production set.[3] Output distance function is defined as reciprocal of maximum output vector for actual output vector given input vector.

A random point of production set within the frontier curve $(D(x, y, w) \prec 1)$ is inefficient, while a point on the frontier curve $(D(x, y, w) = 1)$ is efficient. Using this output distance function, we estimate technical efficiency under the strong disposability of pollutants. At the same time, we also can measure the technical efficiency under the weak disposability of pollutants. According to the two technical efficiencies, we can also calculate the opportunity cost of environmental pollution.

Practically, linear programs are used in measuring technical efficiency of a random point in the production set. First, a measure of technical efficiency that satisfies the strong disposability of inputs, desirable outputs and pollutants is the same as

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[3] Technical efficiency means the effects of catching up with advanced technology, i.e., movement from an internal point to a point on the production frontier. It is distinguished from technical progress, which means the consequence of innovation or creation of new technology, indicating the shift of frontier.

follows:

$$\left\{D_O^S(x, y, w)\right\}^{-1} = Max\,\theta^S$$

$$z_k Y \geq \theta^S y_k$$

$$z_k W \geq \vartheta^S w_k \qquad\qquad (4)$$

$$z_k X \leq x_k$$

$$z_k \geq 0$$

where θ^S is Farrell's technical efficiency, which shows a reciprocal with output distance function D_O^S under the strong disposability of inputs and outputs. Y is an output vector which forms a maximum output combined with intensity vector z_k. W is a pollutant vector which forms a maximum pollutant by intensity vector z_k. Input vector X with z_k makes a combination of minimum input which is always less than producer's actual input. y_k and w_k are k producer's actual output and actual pollution emission. x_k is actual input.

Next, the linear program of technical efficiency for the technology, which satisfies the weak disposability of pollutants and the strong disposability of inputs and desirable outputs, is the same as follows:

$$\left\{D_O^W(x, y, w)\right\}^{-1} = Max\,\theta^W$$

$$z_k Y \geq \theta^W y_k$$

$$z_k W = \theta^W w_k \qquad\qquad (5)$$

$$z_k X \leq x_k$$

$$z_k Y \leq w_r$$

$$z_k \geq 0$$

where θ^W is also Farrell's technical efficiency, which shows a reciprocal with output distance function D_O^W under the weak disposability of pollutants.

We can estimate D_O^S and D_O^W using Eq.(4) and Eq.(5), respectively. The linear program in Eq.(4) maximizes potential output relative to the production set $P^S(x)$, while Eq.(5) maximizes potential output relative to the production set $P^W(x)$. A sign of inequality denotes the strong disposability of inputs and desirable outputs, and a sign of equality represents the weak disposability of pollutants. $D_O^S(x, y, w)$ and $D_O^W(x, y, w)$ have random values between 0 and 1. As seen in Figure1, one point on the frontier curve has maximum efficiency 1, but an internal point in the frontier curve has inefficiency less than 1.

Therefore, we can measure the actual levels of efficiency far away from maximum efficiency with D_O^S and D_O^W. For example, when a random production level is the point m in Figure 1, the efficiency level at m may be compared with a radial point, n and n^*. The efficiency level at the point m is $D_O^S = om/on \prec 1$ under the strong disposability technology, and that is $D_O^W = om/on^* \prec 1$ under the weak disposability technology. The gap between two efficiency levels under the restriction of environmental regulation occurs as $0 \leq D_O^S \leq D_O^W \leq 1$. An inefficiency point n^* under the unregulated condition can be an efficient point under the enforcement of regulation $(n^* | P^S : on^*/on \prec 1 \rightarrow n^* | P^W : on^*/on^* = 1)$. Though the desirable output y decreases from n to n^*, pollutant emission w also decreases at the certain rate with the reduction of desirable outputs. The movement of production point from n to n^* implies the corresponding reduction of pollutants instead of decreasing constant desirable outputs. The result shows that the reduction of pollutant emissions improves due to environmental regulation, but production decreases at the same time. The technical efficiency also improves because of environmental regulation. Hence, we can use technical efficiency change to calculate productive loss due to environmental

regulation or the opportunity cost of pollutants based on the relative gap between two output distance functions. For instance, if a government regulates polluters to be in compliance with environmental regulation, desirable outputs and pollutants are on trade-off, and the opportunity cost of pollutants may be estimated as the loss of desirable outputs due to the reduction of pollutants.

For investigating the productivity loss from environmental regulation, we first define environmental efficiency index (EEI) with the relative rate of two efficiencies as the following:

$$EEI = D_O^S / D_O^W \qquad (6)$$

where if $EEI = 1 (D_O^S = D_O^W)$, there is no technical constraints followed by compliance of environmental regulation, i.e., the transformation of the strong disposability into the weak disposability do not require the opportunity cost at all, and environmental regulation do not trigger on additional cost for polluters. Conversely, EEI<1 implies that the compliance of environmental regulation constraints production and require the opportunity cost of technical transformation or incur additional cost of producers. Therefore, the additional cost due to environmental regulation, that is, productive loss due to environmental regulation is measured by environmental efficiency index. That is, the more EEI is close to 1, the less productivity loss due to environmental regulation is. Therefore, we can calculate the productivity loss as (1−EEI)× output, and the rate of productivity loss as 1−EEI.

3. Data and results

We use China's regional output, pollutants, and inputs for 1993-1998 as sample data in the empirical test. All of data are taken from China's statistical yearbook of 1994-1999. Actual data variables in empirical test are GDP of the manufacturing industry, industrial waste water discharge, SO2, solid wastes, labor force of the manufacturing industry and capital stock, respectively.[5] GDP and capital stock was transformed into real values with GDP deflator (1978=100). With linear programs for optimal solution, we measure two different technical efficiencies under the strong and weak disposability

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[5] Because of no capital stock of the manufacturing industry, we have to use total capital stock of every province. It is the limitation of data in the paper.

of pollutants. As the production frontier curve is formed by sample data in the program, the best practice in the sample has maximum efficiency level 1. We use "What's Best" computer program available for optimal solution of linear program. The linear program will be repeatedly computed for estimation of technical efficiencies under the strong and weak disposability of pollutants.

Before turning to empirical results, it is instructive to check the pattern of sample data for 1993-1998. What we observe with sample data are as follows: First, we will examine the change of desirable output, pollutants and inputs. Assuming that other variables are generally constant, increase of desirable output will bring out the improvement of technical efficiency and productivity, while increase of pollutants and inputs can deteriorate them. Second, sample data can show the connection of desirable output, pollutants and inputs. If economic growth is not accompanied by technological development of pollution abatement, pollutants will also increase with desirable output's increase. Third, we can compare the different patterns of growth for 28 provinces and municipalities that are divided into three regions by sample data.

Table 1. presents average annual growth rate of output, industrial wastewater discharge, waste gas discharge, waste solids discharge, capital stock and labor in the manufacturing industry in 28 provinces and municipalities as well as three regions over the 1993-1998 period. The national annual growth rate of output in the manufacturing industry is 12.23%, the East 12.52%, the Middle 13.45%, the West 10.96% for 1993-1998.[6] The growth rate of the Middle showed largest among three regions, followed by the East, at last the West. In the annual change rate of industrial wastewater discharge, the national change rate is −1.12%, the East −0.43%, the Middle −2.96%, and the West −0.35%. Wastewater discharge of three regions decreased in the 1990s and the change rate of the Middle is largest. In the annual change of SO2 discharge, most of provinces showed an increasing pattern. The nation is 4.53%, the East 4.12%, the Middle 6.22%, and the West 3.59%. In the annual growth rate of capital stock, most of provinces kept high growth rate. The East is 11.86%, the Middle 10.99%, the West 10.96%. In the annual growth rate of labor, all of three regions showed a decreasing pattern. The Nation is −1.55%, the East −1.93%, the Middle −1.54%, the West −1.19%. All of three regions show the minus growth rate of labor because many provinces and cities in China used the control policy of labor force for enterprises in the 1990s.

Table 1. shows that China's manufacturing industry had a high economic growth supported by the increase of capital stock. Industrial wastewater discharge over the

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[6] The annual growth rate of GDP including industry, agriculture and service trade is that, that of the East is 11.4%, the Middle 11.4%, and the West 9.2%.

same period showed a decreasing trend, while SO2 and industrial waste solids discharge increased by 4.64% and 6.60%, respectively. It implies that environmental regulation for wastewater relatively fulfilled its function in the 1990s, however, the effects of environmental regulation for SO2 and industrial waste solids were weak, especially for waste solids.

Table 2. shows technical efficiency ignoring pollution emissions, technical efficiencies of the strong and weak disposability with considering wastewater, SO2 and waste solids discharge simultaneously, environmental efficiency index and rate of productivity loss in China's 29 provinces and municipalities for 1993-1998. A linear program for output efficiency measure is used to get technical efficiency. When ignoring pollutants, technical efficiency is very low in China, the nation 0.794, the East 0.871, the Middle 0.811 and the West 0.712. Under the strong disposability of pollutants which indicates free disposability of pollutants without the burden of pollution control cost, the technical efficiency overall became larger comparing with that without considering pollutants. Its cause is that producers can improve the technical efficiency by including pollution factor in decision-making of production. The national technical efficiency is 0.925, implying that some provinces had technical inefficiency as much as 7.5%. The East shows the lowest efficiency, 0.908, and then the Middle 0.931, at last the West 0.935. Due to technical efficiency, actual desirable output y and pollutants w will be expanded i.e. y/ , w/ . Therefore, the smaller technical efficiency is, the larger desirable output y and pollutants are. From the above result, we can know that both of desirable output and pollution for the East are largest among three regions. It corresponds to the reality.

Measuring the technical efficiency for the weak disposability of pollutants based on the assumption that producers should pay pollution control cost, we can examine the effect of desirable output reduction due to control of pollution emission. Here, the technical efficiency under the weak disposability of pollutants means the efficiency when environmental regulation is strictly enforced. Because China could not strictly enforce environmental regulation in the 1990s, the results in this paper should be different from actual technical efficiency and productivity loss in the presence of environmental regulation to some extent. The technical efficiency and productivity loss got from the paper will indicate those under the strict enforcement of environmental regulation. Table 2. shows that maximum efficiency increased from 8 to 17 provinces under the weak disposability of pollutants. As expected in Figure 1, it indicates that the frontier curve was more shrunk under the weak disposability of pollutants. Its reason is that the increase of technical efficiency under the weak disposability of pollutants results from the reduction of output due to environmental regulation. The national average technical efficiency under the weak disposability is 0.969, higher than that

under the strong disposability, 0.926. Three regions' technical efficiencies under the weak disposability are respectively higher than those under the strong disposability. The East is 0.984, the Middle 0.975, and the West 0.950. All of three regions keep a higher technical efficiency under the weak disposability. The gap of technical efficiency between the strong and weak disposability can show the effect of constraint due to environmental regulation. A large gap denotes that environmental regulation can bring more production cost to provincial economies. The provinces or municipalities that show a significant gap between two technical efficiencies are Beijing, Tianjin , Hebei and Zhejiang in the East, Henan in the Middle, Qinghai and Xinjiang in the West. The regions that have no any change between two technical efficiencies are Liaoning and Shanghai in the East, Heilongjiang and Hunan in the Middle, Guangxi, Sichuan, Guizhou, Yunnan and Tibet in the West. Other provinces and municipalities show some difference between the two technical efficiencies under the strong and weak disposability, though there exists the difference of extent.

Environmental efficiency index (EEI) computed by two technical efficiencies under the strong and weak disposability of pollutants is used in measuring the extent of impact of environmental regulation on productivity. EEI close to 1 indicates low technical efficiency change and low impact of regulation, that is, it shows low rate of productivity loss due to regulation, while EEI far away from 1 means large technical efficiency change as well as high production burden, that is, it shows large rate of productivity loss due to regulation. When three types pollutants are considered at the same time, the national EEI is 0.958, very close to 1. The East's EEI is lowest, 0.929, then the West 0.970, the Middle 0.978. The rate of productivity loss for the whole nation is 4.24%. And that for the East is 7.05%, the West 3.03% and the Middle 2.22%. Hence, we can know that the technical efficiency change due to environmental regulation in the East is largest, that is, the East shouldered the largest burden for regulation among the three regions. We also can say that the impact of environmental regulation on productivity loss in the East is largest. In fact, the East relatively enacted environmental regulation more than the other two regions in the 1990s. Thus, it is obvious that the East practically paid the largest cost for environmental regulation in the three regions. Its main reason is that the East is depended on high pollution emission, and its economic structure is not sound enough to absorb environmental regulation. Generally, a high EEI means that a national economy or a provincial economy has a sound economy structure enough to absorb environmental regulation. But the Middle and the West's higher environmental efficiencies index are not the result from an advanced economic structure, but from a relatively low pollution emission compared with the East over the same period. Due to the difference of impacts of environmental regulation on technical efficiency change and productivity loss among

three regions, that is, the difference of the opportunity cost of pollutant emissions for three regions, it appears that pollution was trending to move from the East to the Middle and the West in China, especially wastewater. It became one serious issue for China.

Table 3. shows the technical efficiencies of the strong and weak disposability, environmental efficiency index and rate of productivity loss under only considering wastewater. In this case, the technical efficiency of the East is 0.882, the Middle 0.895, and the West 0.818 under the strong disposability of pollutants. Those under the weak disposability of pollutants are 0.911, 0.896 and 0.824, respectively. Hence, the EEIs of three regions are 0.968, 0.999, and 0.993, respectively. The rate of productivity loss for the three regions is 3.20%, 0.07% and 0.69%, respectively. It is evident that the EEI of the East is lower than those of the Middle and the West. It indicates that the impact of environmental regulation on technical efficiency change and productivity loss for the East is largest in the three regions when only considering wastewater discharge, that is, the East paid the largest cost due to environmental regulation for wastewater. Between the Middle and the West, there is no large difference. The burden for the West is a little larger than that of the Middle. Practically, the environmental regulation for wastewater was relatively enacted in all of three regions. Hence, we can know that the East carried the largest burden for controlling wastewater in reality. That is why the enterprises whose water pollutions were serious tried to move to the Middle and the West so that backward technology and water pollution were moved from the East to the Middle and the West.

Table 4. shows the technical efficiencies of the strong and weak disposability, environmental efficiency index, the rate of productivity loss when only considering SO_2 discharge. In this case, the technical efficiency of the East is 0.893, the Middle 0.843 and the West 0.856 under the strong disposability of pollutants. Those under the weak disposability of pollutants are 0.904, 0.844 and 0.880, respectively. Thus, the EEIs of three regions are 0.988, 0.999, 0.972, respectively. The rate of productivity loss for three regions is 1.19%, 0.11% and 2.83%, respectively. The result implies that the Middle did pay less cost for environmental regulation for SO_2. The East and the West also did not have larger impacts due to environmental regulation for SO_2. In fact, SO_2 emissions in the three regions increased in the 1990s, their growth rate is 4.12%, 6.22% and 3.95% for the East, the Middle and the West. It indicates that Chinese Government could not strictly control SO_2 emission by environmental regulation. Even if Chinese government had strictly enforced environmental regulation for SO_2, China would not pay much cost for controlling SO_2. Comparing with the increase of SO_2 in each region, the rate of productivity loss is rather low. Therefore, it is feasible for China to strength the environmental regulation for SO_2 in the future without corresponding large cost

increase.

Table 5 shows the technical efficiencies of the strong and weak disposability, environmental efficiency index and the rate of productivity loss when only considering waste solids discharge. In this case, the technical efficiency of the East is 0.894, the Middle 0.864, and the West 0.810 under the strong disposability. And those under the weak disposability are 0.926, 0.885 and 0.845, respectively. Therefore, the EEIs of three regions are 0.966, 0.976 and 0.959, respectively. And the rate of productivity loss of three regions are 3.44%, 2.37% and 4.08%, respectively. All of three regions showed higher technical efficiency change and productivity loss. In other words, all of them had to shoulder larger burdens for controlling waste solids. This case is different from the above-mentioned two cases. The result implies that China had to pay larger cost for waste solids under the strict environmental regulation. The pollution of solids is currently the most difficult issue in China's environmental problems. To resolve waste solids' problem, each region should introduce and develop the advanced technology to increase technical efficiency in order to absorb the impact of environmental regulation.

4. Summary and conclusions

This paper applied the radial efficiency measure of DEA approach to measure technical efficiencies for the strong and weak disposability in order to analyze the impacts of environmental regulation on technical efficiency and productivity loss in China's 29 provinces and municipalities from 1993-1998. According to economic growth level, 29 provinces and municipalities were classified into three regions. The most developed region is the East, followed by the Middle and the West. We focused our research on three regions. In three regions, technical efficiencies increased due to the enforcement of environmental regulation. As for the impact of environmental regulation on productivity loss, three regions showed different results respectively. The rate of productivity loss from environmental regulation for the East is 7.08%, while the Middle is 2.22%, and the West is 3.05% when considering three pollutants including wastewater, SO2 and waste solids simultaneously. We knew that the East paid the largest cost for controlling environmental pollutions from our results. That is why back technology and pollutions were moved from the East to the Middle and the West from 1990s.

In addition, we also estimated the impact of environmental regulation on productivity loss considering different pollutants respectively. As a result, the impacts came from wastewater and waste solids for the East are 3.08% and 3.29%, respectively. For the Middle, only regulation for waste solids influenced productivity loss, that from

others are very low. For the West, regulations for SO2 and waste solids brought larger productivity losses that are 2.84% and 3.67%, respectively. From these results, we could know that all of three regions did not pay large cost for controlling SO2 under the assumption of strict enactment of environmental regulation. It implies that China can strength environmental regulation for SO2 without corresponding large cost increase in the current situation. Except for the SO2, the productivity losses from other pollutants are not low. Comparing to growth rate of each region that the East is 12.52%, the Middle 13.45 and the West 12.37%, the output losses from regulation are not easily ignored, especially for the East, larger than a half of growth rate of GDP when including three pollutants. It is somewhat difficult for China to generally realize the strict enforcement of environmental regulation in the current situation. Therefore, with strengthening environmental regulation, China has to change its old production pattern, which merely purses the increase of outputs but does not distinguish desirable output and pollutants, to sustainable production pattern which achieves the increase of desirable outputs and the reduction of pollutants simultaneously. In one word, resource-saving, energy-saving and the development of environmental technology are fundamental ways to decrease the impact of environmental regulation on productivity loss in China.

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Table 1. Average annual growth rate of output, pollutants and input (1993-1998) (%)

	GDP	Waste water	SO2	Capital	Labor
Nation	12.23	-1.12	4.53	11.29	-1.55
Beijing	8.02	-2.72	-0.37	14.61	-4.42
Tianjin	11.09	-1.86	4.88	12.17	-5.10
Hebei	13.81	5.40	7.28	19.82	2.88
Liaoning	6.81	-3.85	-1.60	2.30	-6.99
Shanghai	9.71	-6.67	2.09	18.67	-6.18
Jiangsu	12.07	-0.65	6.24	9.72	-2.32
Zhejiang	16.48	3.36	9.45	11.55	0.16
Fujian	18.94	-1.33	1.86	16.22	-0.19
Shandong	14.57	6.67	5.34	9.34	1.08
Guangdong	13.73	-2.67	6.07	4.23	1.80
The East	12.52	-0.43	4.12	11.86	-1.93
Shanxi	12.70	3.17	14.73	7.57	-2.13
Jilin	5.68	-2.60	2.54	5.42	-6.78
Heilongjiang	12.44	-3.87	0.32	0.61	-5.3
Anhui	14.73	-6.37	2.67	12.44	0.55
Jiangxi	15.44	-8.20	4.94	8.48	-1.89
Henan	15.25	-0.18	13.98	14.77	4.06
Hubei	16.76	-2.34	5.67	16.54	-0.92
Hunan	14.64	-3.24	4.88	12.07	0.12
The Middle	13.45	-2.96	6.22	10.99	-1.54
Inner Mongolia	11.54	-1.01	5.72	2.48	-3.07
Guangxi	10.74	-0.92	5.18	9.63	1.40
Sichuan	14.01	-6.68	-8.24	8.18	-6.73
Guizhou	10.24	4.03	8.90	14.34	2.30
Yunnan	14.46	-0.08	3.62	13.39	1.40
Tibet	26.46	-0.46	7.60	12.31	6.15
Shaanxi	8.88	0.30	0.42	12.44	-1.63
Gansu	13.16	-1.15	-0.19	16.81	-1.60
Qinghai	7.42	-5.29	8.49	12.66	-3.03
Ningxia	10.00	3.96	2.63	11.57	1.40
Xinjiang	9.19	3.31	9.35	8.11	-2.35
The West	12.37	-0.36	3.95	11.08	-0.52

Source: China's Statistical Yearbook (1994-1999)

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Table 2. Technical efficiency and rate of productivity loss under considering discharge
of wastewater, SO2 (1993-1998)

	$D^{no(1)}$	D^s	D^w	EEI	RPL(%)
National	0.794	0.904	0.928	0.974	2.57
Beijing	0.710	0.716	0.768	0.932	6.81
Tianjin	0.844	0.865	0.981	0.882	11.84
Hebei	0.730	0.794	0.800	0.993	0.67
Liaoning	0.871	0.954	0.954	1.000	0.00
Shanghai	1.000	1.000	1.000	1.000	0.00
Jiangsu	0.896	0.929	0.931	0.998	0.23
Zhejiang	0.877	0.883	0.910	0.970	2.97
Fujian	0.921	0.926	1.000	0.926	7.38
Shandong	0.931	0.941	1.000	0.941	5.90
Guangdong	0.934	0.934	1.000	0.934	6.57
The East	0.871	0.894	0.934	0.958	4.24
Shanxi	0.827	0.944	0.971	0.972	2.76
Jilin	0.717	0.770	0.774	0.995	0.47
Heilongjiang	1.000	1.000	1.000	1.000	0.00
Anhui	0.844	0.901	0.904	0.997	0.30
Jiangxi	0.769	0.905	0.934	0.969	3.11
Henan	0.803	0.816	0.822	0.993	0.73
Hubei	0.824	0.951	1.000	0.951	4.90
Hunan	0.705	1.000	1.000	1.000	0.00
The Middle	0.811	0.898	0.917	0.985	1.53
Inner Mongolia	0.665	0.890	0.905	0.983	1.75
Guangxi	0.754	1.000	1.000	1.000	0.00
Sichuan	0.980	1.000	1.000	1.000	0.00
Guizhou	0.624	1.000	1.000	1.000	0.00
Yunnan	0.946	0.973	0.975	0.998	0.15
Shaanxi	0.612	0.781	0.793	0.984	1.56
Gansu	0.630	0.880	0.880	1.000	0.00
Qinghai	0.652	0.668	0.688	0.972	2.83
Ningxia	0.593	0.998	0.998	1.000	0.00
Xinjiang	0.815	0.882	0.990	0.891	10.89
The West	0.712	0.910	0.915	0.983	1.72

Note(1): D^{no} means technical efficiency without considering environmental
factor.

Table 3. Technical efficiency, environmental efficiency index and the rate of productivity loss under only considering discharge of wastewater (1993-1998)

	D^s	D^w	EEI	RPL(%)
Nation	0.863	0.876	0.986	1.43
Beijing	0.712	0.760	0.942	5.84
Tianjin	0.846	0.929	0.914	8.61
Hebei	0.732	0.738	0.992	0.80
Liaoning	0.937	0.937	1.000	0.00
Shanghai	1.000	1.000	1.000	0.00
Jiangsu	0.924	0.924	1.000	0.00
Zhejiang	0.878	0.889	0.987	1.26
Fujian	0.926	0.934	0.991	0.86
Shandong	0.931	1.000	0.931	6.87
Guangdong	0.934	0.999	0.935	6.53
The East	0.882	0.911	0.968	3.20
Shanxi	0.839	0.842	0.996	0.44
Jilin	0.768	0.768	1.000	0.00
Heilongjiang	1.000	1.000	1.000	0.00
Anhui	0.900	0.900	1.000	0.00
Jiangxi	0.897	0.897	1.000	0.00
Henan	0.806	0.807	0.998	0.15
Hubei	0.951	0.951	1.000	0.00
Hunan	1.000	1.000	1.000	0.00
The Middle	0.895	0.896	0.999	0.07
Inner Mongolia	0.690	0.691	0.998	0.22
Guangxi	1.000	1.000	1.000	0.00
Sichuan	1.000	1.000	1.000	0.00
Guizhou	0.739	0.739	1.000	0.00
Yunnan	0.962	0.962	1.000	0.00
Shaanxi	0.644	0.644	1.000	0.00
Gansu	0.796	0.796	1.000	0.00
Qinghai	0.667	0.672	0.993	0.69
Ningxia	0.689	0.689	1.000	0.00
Xinjiang	0.815	0.871	0.942	5.80
The West	0.800	0.807	0.992	0.78

Table 4. Technical efficiency, environmental efficiency index and the rate of
productivity loss under only considering discharge of SO2 (1993-1998)

	D^s	D^w	EEI	RPL(%)
Nation	0.876	0.880	0.995	0.46
Beijing	0.716	0.716	1.000	0.00
Tianjin	0.865	0.865	1.000	0.02
Hebei	0.791	0.791	1.000	0.00
Liaoning	0.922	0.922	1.000	0.00
Shanghai	1.000	1.000	1.000	0.00
Jiangsu	0.916	0.916	1.000	0.00
Zhejiang	0.883	0.887	0.995	0.50
Fujian	0.921	0.987	0.933	6.73
Shandong	0.983	0.983	1.000	0.00
Guangdong	0.934	0.971	0.963	3.69
The East	0.893	0.904	0.988	1.19
Shanxi	0.944	0.944	1.000	0.00
Jilin	0.729	0.729	1.000	0.00
Heilongjiang	1.000	1.000	1.000	0.00
Anhui	0.862	0.862	1.000	0.00
Jiangxi	0.797	0.797	1.000	0.00
Henan	0.816	0.816	1.000	0.00
Hubei	0.838	0.841	0.996	0.04
Hunan	0.763	0.763	1.000	0.00
The Middle	0.843	0.844	0.999	0.11
Inner Mongolia	0.888	0.888	1.000	0.00
Guangxi	0.894	0.894	1.000	0.00
Sichuan	1.000	1.000	1.000	0.00
Guizhou	1.000	1.000	1.000	0.00
Yunnan	0.972	0.972	1.000	0.00
Shaanxi	0.779	0.779	1.000	0.00
Gansu	0.795	0.795	1.000	0.00
Qinghai	0.658	0.671	0.984	1.65
Ningxia	0.986	0.986	1.000	0.00
Xinjiang	0.882	0.882	1.000	0.00
The West	0.885	0.887	0.998	0.23