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Environmental Productivity in China

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Abstract

Environmental problems are threatening China's sustainable future. China began implementation of several environmental policies for the late 1970s and stringency of the regulations is increasing over time. We utilize a province−level economy wide data set over 1987−2001 to measure various components of productivity within a joint production model, which considers both market and environmental outputs. While productivity level of a joint production is relatively constant over time, environmental productivity decreased, especially during the periods of 1991−1994. This was a period of significant improvements in the economy and productivity for the Chinese market. This inescapable fact directs our attention to a conventionally neglected dimension of productivity, i.e., the less efficient utilization of pollution abatement technologies.

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1. INTRODUCTION

China's economic growth has been extremely rapid in the past two decades, with an annual growth rate of about 10% in the last two decades (World Bank 2003). Subsequently, environmental problems are threatening China's sustainable future[1]. For example, pollution damage is estimated to be around $54 billion annually and close to 8% of Chinese GDP (World Bank 1997). China began implementation of environmental policies from the late 1970s in response to air pollution, water pollution and solid waste disposal, and the stringency of the regulations keeps increasing over time (Sinkule and Ortolano, 1995).

More efficient utilization of pollution abatement technologies, defined as the environmental productivity, at least in part, influences the costs of alternative production and pollution abatement technologies (e.g., Jaffe, Newell, and Stavins, 2003). An extensive theoretical literature examines the role of environmental policy in encouraging (or discouraging) productivity growth[2]. On the one hand, abatement pressures may stimulate innovative responses that reduce the actual cost of compliance below the original estimates. On the other hand, firms might be reluctant to innovate if they believe regulators will respond by ratcheting up standards even tighter (e.g., McCain 1978). Thus, whether environmental productivity is increasing is an empirical question. The principal focus of this paper is to measure technological/productivity change for non-market (i.e., environmental) outputs using unique province-level economy wide data set over 1987-2001. We find environmental managements are deteriorating over time in China.

2. MODEL

Production frontier analysis provides the Malmquist indexes (e.g., Malmquist, 1953; Caves *et al*, 1982), which can be used to quantify productivity change and can be decomposed into various constituents, as described below. Malmquist total factor productivity is a specific output-based measure of Total Factor Productivity (TFP). It measures the TFP change between two data points by calculating the ratio of two associated distance functions (e.g., Caves *et al.* 1982). A key advantage of the distance function approach is that it provides a convenient way to describe a multi-input,

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[1] For more information, see World Bank (2001).

[2] Jaffe, Newell, and Stavins (2003) and Kemp (1997) provide thorough surveys of the literature relating technological change and the environment.

multi-output production technology without the need to specify functional forms or behavioral objectives, such as cost-minimization or profit-maximization.

Using the distance function specification, our problem can be formulated as follows. Let **x**, **b**, **y** be vectors of inputs, environmental output (or undesirable output) and market outputs, respectively, and then define the production possibilities set by;

$$\mathbf{P}^t \equiv \{(\mathbf{x}^t, \mathbf{b}^t, \mathbf{y}^t): \mathbf{x}^t \text{ can produce } (\mathbf{y}^t, \mathbf{b}^t)\}, \tag{1}$$

which is the set of all feasible production vectors. We assume that $\mathbf{P}^t$ satisfies standard axioms, which suffice to define meaningful output distance functions (see Fuss and McFadden 1978). The directional distance function is defined at t as;

$$\vec{\mathrm{d}}_o^{\,t}(\mathbf{y}^t, \mathbf{x}^t, \mathbf{b}^t; \mathbf{g}^t) = \sup\{\varphi : (\mathbf{y}^t, \mathbf{x}^t, \mathbf{b}^t) + \varphi\, \mathbf{g}^t \in \mathrm{P}^t\}, \tag{2}$$

where **g** is the vector of directions which outputs are scaled. For this output oriented distance function, we define **g**=(**y**, **0**, **-b**), i.e. desirable outputs are proportionately increased, inputs are held fixed and environmental outputs (pollution) are proportionately decreased.

Chung *et al.* (1997) define an output-oriented Malmquist-Luenberger productivity index that is comparable to the Malmquist productivity index, but that includes productivity changes with respect to both desirable and undesirable outputs. We calculate the Malmquist-Luenberger productivity index by comparing distance functions in two different years (*t* and *t+1*). Consider year *t*, the distance function for state *i* is calculated as;

$$\begin{aligned} &\vec{d}_o^{\,t}(\mathbf{y}^t, \mathbf{x}^t, \mathbf{b}^t; \mathbf{g}^t | \text{CRS}) = \max_{\varphi,\lambda} \ \varphi \\ &\quad s.t. \quad -(1+\varphi)y_i^t + \mathrm{Y}^t\lambda \ge 0 \\ &\qquad\quad\ (1-\varphi)b_i^t - B^t\lambda = 0 \\ &\qquad\quad\ x_i^t - \mathrm{X}^t\lambda \ge 0 \\ &\qquad\quad\ \lambda \ge 0 \end{aligned} \tag{3}$$

where $1/\varphi$ is the efficiency index for state *i* at year *t*, λ is a $\mathrm{N}\times 1$ vector of weights, *Y*, *B*, *X* are the vectors of market output *y*, environmental output *b* and input *x*. The constraints in equation (3) construct the reference (or frontier) technology from the data of year *t*. Every point is this technology set is a linear combination of observed output/environmental output/input vectors or a point dominated by a linear combination of observed points. TFP can be decomposed into measures associated with Technological Change (TC), which is the shifts in the production frontier, and Efficiency Change (EC), which is the changes in the position of a production unit relative to the frontier-so-called “catching up”, following Färe *et al.* (1994)[3]: The following equation implies the multiplicative formation of two components to explain TFP.

$$\mathrm{TFP} = \mathrm{TC} \times \mathrm{EC} \tag{4}$$

The measure of technological change under constant return to scale (CRS) can be further decomposed into measures of input biased technological change (IBTC), output biased technological change (OBTC), and magnitude change (MC) (Färe *et al.* 1997). MC is the measure of Hicks neutral technological change if there is no biased technological change. Thus, if the output and input biased measures of technological change are both equal to one, then the technological change is Hicks neutral. Under variable return to scale (VRS), the measure of TFP can be decomposed into measures of technological change, efficiency change and scale change (Ray and Desli 1997)[4]. Where $\mathrm{TC_V}$, $\mathrm{EC_V}$, and SC are technological change, efficiency change, and scale change under VRS, respectively. Scale change measures shifts in productivity due to changes in the scale of operations relative to the optimal scale.

We estimate the productivity in environmental pollution abatement (or environmental productivity) by disaggregating the usual market productivity from the productivity of market output and environmental output following Managi *et al.* (2004b). We use two versions of the models to measure and decompose productivity changes. First, a base model is used to calculate total productivity change, $\mathrm{TFP_{all.}}$ which measures the total effect of increases in productivity due to improvements in technology for the multi-production production of market and non-market (environmental) goods (Chung *et al.*, 1997). Thus, increases in market output, such as production, or/and reduction in pollution, given input level, will increase the $\mathrm{TFP_{all}}$. Second model measures $\mathrm{TFP_{market}}$ that only take account the market data (see Managi and Kaneko (2004) for detailed analysis in China). Dividing the total measure of productivity by the productivity measure for market output (i.e., $\mathrm{TFP_{env}} = \mathrm{TFP_{all}} / \mathrm{TFP_{market}}$), the $\mathrm{TFP_{env}}$ provides the measure of the increase (or decrease) in productivity due to environmental sector.

3. APPLICATION

This study uses panel data, which consists of annual data for 1987-2001; twenty-nine of thirty-one provinces (including three municipalities) of the People’s

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[3] See Managi et al (2004a) for intuitive explanation of DEA.

[4] TFP index under CRS is equivalent to the TFP under VRS (Ray and Desli, 1997).

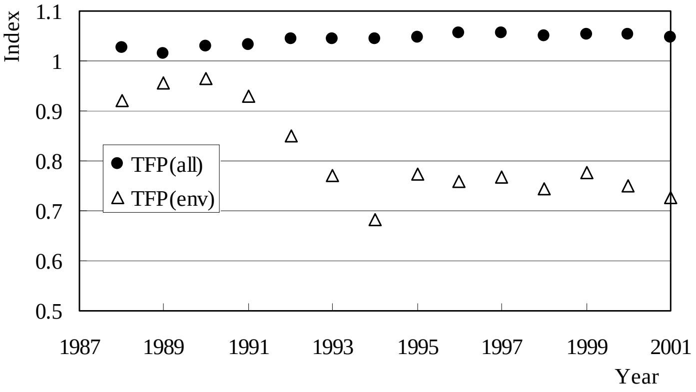

Figure 1. Total Factor Productivity

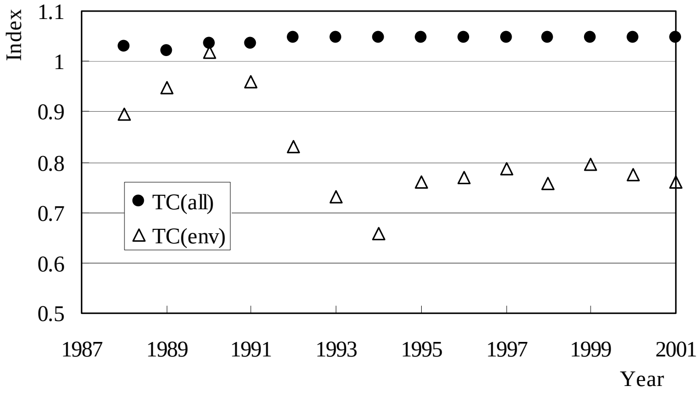

Figure 2. Technological Change under constant returns to scale

Republic of China. Tibet is excluded because some of the relevant data is not available. Hainan, the new province started in 1988, is also excluded. All data in this study are taken from the Comprehensive Statistical Data and Materials on 50 Years of New China, China Environmental Statistical Data and Materials, and China Statistical Yearbook.

Gross Regional Product (*GRP*) is the dollar of final goods and services produced across the each province economy for each year. *Labor* is the number of employees. The capital stock (*Capital*) is estimated from annual productive net of depreciation in the industries. Pollution abatement cost and expenditure (*PACE*) associated with the fund actually used for the environmental pollution of wastewater, waste gas and solid waste. The PACE is considered as environmental inputs, while *Wastewater*, *Waste gas* and *Solid wastes* are environmental outputs. Wastewater quantity measured as the weight of wastewater discharge. Waste gas quantity measured as the volume of waste gas emissions, which is not treated. Solid wastes quantity measured as the discharge amount of solid wastes. Value of deflator came from the China Statistical Yearbook. We measure and decompose productivity change over time in China.

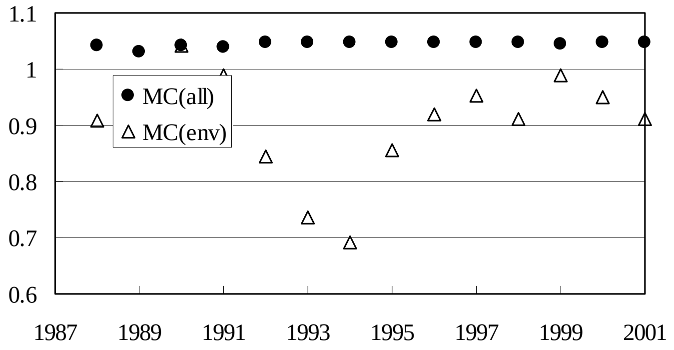

Figure 3.1. Magnitude Component under constant returns to scale

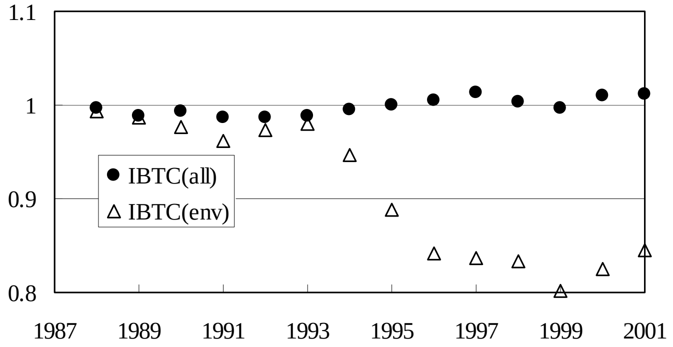

Figure 3.2. Input Biased Technological Change under constant returns to scale

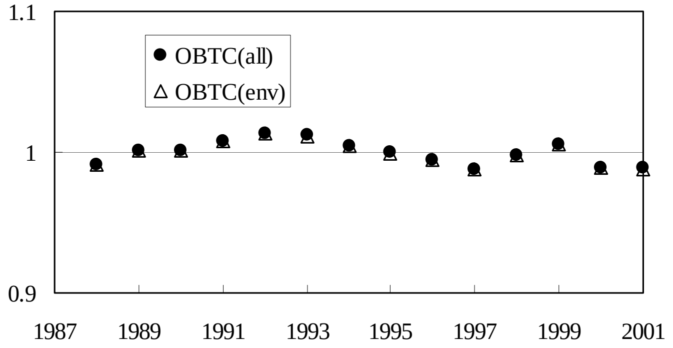

Figure 3.3. Output Biased Technological Change under constant returns to scale

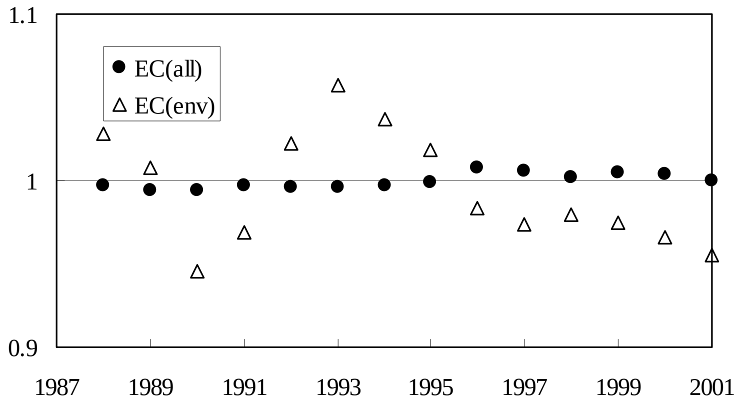

Figure 4. Efficiency Change under constant returns to scale

The results for cumulative change of TFP both for all (i.e., market and environmental) and environmental cases are presented in Figure 1[5]. TFP growth for all (or joint) outputs is small and only 4.9 % increase over 1987-2001. This small change is similar for all of the following joint production cases. Thus, we focus on the analysis on environmental productivities. TFP for environmental output decreases by about 27 percent from 1987 through 2001, or a geometric mean rate of about 2.3 percent decrease per year. The significant drop over 1991-1994 mainly causes this decrease in the trend. Similar trend appears for TC for environment (Figure 2).

The decomposition of the TC is shown in Figure 3.1, 3.2, and 3.3. Significant changes between 1991 and 1995 are caused by MC and IBTC. Especially, the significant drop of the MC over 1991-1994 is the main cause of the change in TC. The biased TC, which is the product of input-biased and output-biased TC, is 0.99 and it is closed to 1. This result indicates technologies are Hicks neutral until 1993. After 1994, IBTC decreases 20 % and, therefore, technological change is biased on the input-sides reflecting less efficient input use.

The value of EC is presented in Figure 4. Although the cumulative change is only 4.6 % over study periods, EC continues to decrease after 1993. Figure 5.1, 5.2, and 5.3 show the TC, EC, and SC under VRS, respectively. TC and EC are similar to the case of the values under CRS. SC measures shifts in productivity due to changes in the

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[5] The values of geometric mean are presented in each figure.

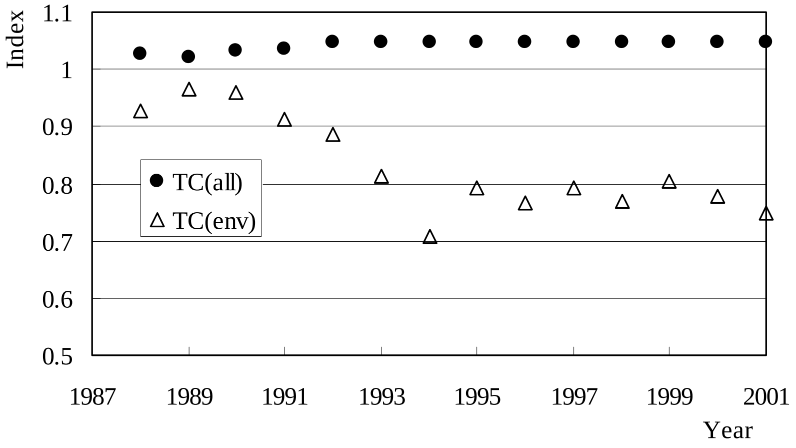

Figure 5.1. Technological Change under variable returns to scale

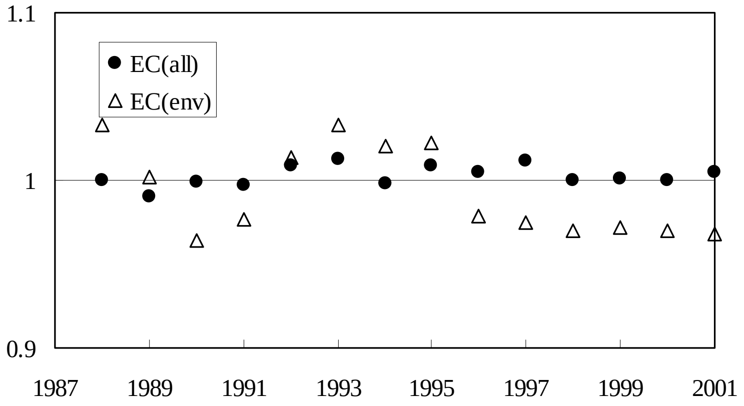

Figure 5.2. Efficiency Change under variable returns to scale

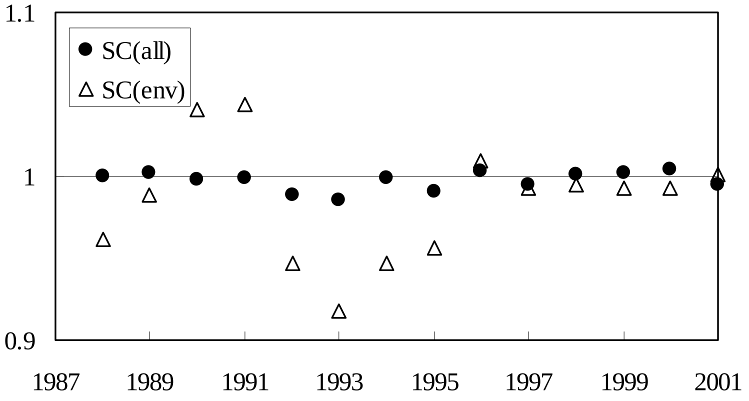

Figure 5.3. Scale Change under constant returns to scale

scale of operations relative to the optimal scale and stays relatively constant.

4. CONCLUSION

Environmental problems are threatening China's sustainable future. Pollution damage is estimated to be around $54 billion annually and closed to 8 % of Chinese GDP (World Bank 1997). Starting from the late 1970s, China began implementation of several environmental policies and stringency of the regulations is increasing over time (Sinkule and Ortolano, 1995). Productivity improvements can play an important role in addressing environmental problems while simultaneously improving standards of living. Most of the empirical studies in the literature, however, are focused on the analysis in developed countries. To our knowledge, there are no existing studies that have estimated the efficiency changes of environmental technology or management in developing countries. We apply production frontier analysis to a province-level economy wide data set over 1987-2001 and measure various components of total factor productivity within a joint production model, which considers both market and environmental outputs. TFP growth for joint outputs is small and only 4.9 % increase over our study periods. We find environmental managements are deteriorating over time in China. TFP and TC for environmental output (or environmental productivity) decrease by about 27, and 24 percent, respectively. The significant drop over 1991-1994 mainly causes this decrease in the trend. During the periods of 1991-1994, there are significant improvements in Chinese market economy and productivity (see Managi and Kaneko, 2004), our results show the existence of an inescapable fact that directs our attention to a neglected dimension of productivity, i.e., less efficient utilization of pollution abatement technologies.

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