

ANALYSIS

Environmental productivity and Kuznets curve in India[☆]

Shunsuke Managi^{a,*}, Pradyot Ranjan Jena^b

^aFaculty of Business Administration, International Graduate School of Social Sciences, Yokohama National University, 79-4, Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan

^bDepartment of Humanities and Social Sciences, National Institute of Technology Rourkela, Rourkela 769008, India

Keywords:

India
Environmental productivity
Productivity measures
Kuznets curve

As a result of India's extremely rapid economic growth, the scale and seriousness of environmental problems are no longer in doubt. Whether pollution abatement technologies are utilized more efficiently is crucial in the analysis of environmental management because it influences the cost of alternative production and pollution abatement technologies. In this study, we use state-level industry data of sulfur dioxide, nitrogen dioxide, and suspended particular matter over the period 1991–2003. Employing recently developed productivity measurement technique, we show that overall environmental productivities decrease over time in India. Furthermore, we analyze the determinants of environmental productivities and find environmental Kuznets curve type relationship existences between environmental productivity and income. Panel analysis results show that the scale effect dominates over the technique effect. Therefore, a combined effect of income on environmental productivity is negative.

1. Introduction

It has been a tough trade-off decision between economic growth and environmental protection especially in developing countries. Tireless efforts to accelerate economic growth had kept environmental considerations as secondary objectives in policy making in these countries. This indifference towards environmental protection has led to serious environmental problems in the developing countries and has threatened their sustainable future. For example, damage caused by pollution in India is estimated to cost \$14 billion annually: amounting to close to 4.5% to 6% of GDP (Economic Survey of India, 1998–1999). In response, many developing countries have started enacting and implementing environmental policies in relation

to air and water pollution and solid waste disposal to limit the severity of environmental degradation and the stringency of these regulations has been increasing over the years.

It has been increasingly recognized that technological progress can play a key role in maintaining a high standard of living in the face of these increasingly stringent environmental regulations. However, the extent of the contribution of technological progress depends on how well environmental policies are designed and implemented. Successful environmental policies can contribute to technological innovation and diffusion (Jaffe et al., 2003) while poor policy designs can inhibit innovation.

On the other hand, successful implementation of environmental regulations may crucially be linked with the pattern of economic growth. This argument is the basis of the

[☆] The authors thank two anonymous referees for their helpful comments, and also thank Yutaka Ito for his assistance. This research was funded by the Yokohama National University, and Grant-in-Aid for Scientific Research (B) from the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT), No.70372456. The results and conclusions of this paper do not necessarily represent the views of the funding agencies.

* Corresponding author. Tel.: +81 45 339 3720.

E-mail address: managi@ynu.ac.jp (S. Managi).

environmental Kuznets curve (EKC) hypothesis, which has gained tremendous popularity among the researchers over the past decade. EKC draws its roots from the pioneering study by Grossman and Krueger (1993), which established the empirical relationship between measures of environmental quality and national income. An inverted U-shaped relationship of the EKC imply that environmental degradation increases with income at low levels of income and then decreases once a threshold level of per capita income is reached.

After the study by Grossman and Krueger (1993), many studies such as Seldon and Song (1994) and Holtz-Eakin and Selden (1995) had investigated this relationship for alternative measures of environmental degradation with levels of pollutants or pollutant intensities (see Dinda (2004), Stern (2004), and Managi (2006) for recent literature). There are studies that supported the EKC relationship between pollution and per capita national income. Their argument for such finding was that after a certain level of income, concern for environmental degradation becomes more relevant and a mechanism to reduce environmental degradation is put in place through necessary institutional, legal and technological adjustments.

However, a major criticism against these studies is that they have adopted a reduced form approach to examine the relationship between per capita income and pollution emissions (Stern, 1998). These two variables are merely the outcomes of a production process but they do not explain the underlying production process, which converts inputs into outputs and pollutants. In fact, the transformation of this production process may lead to environmental improvement at a higher level of income (Zaim and Taskin, 2000). Therefore, studies that examine the transformation of production process by quantifying the opportunity cost of adopting alternative environmentally superior technologies are more relevant to our study.

The more efficient utilization of pollution abatement technologies, at least in part, influences the cost of alternative production and pollution abatement technologies (e.g., Jaffe et al., 2003). An extensive body of theoretical literature examines the role of environmental policy in encouraging (or discouraging) productivity growth. On the one hand, abatement pressures may stimulate innovative responses that reduce the actual cost of compliance below those originally estimated. On the other hand, firms may be reluctant to innovate if they believe regulators will respond by 'ratcheting-up' standards even further. Therefore, in addition to the changes in environmental regulations and technology, management levels also affect environmental performance level or environmental productivity, which explains how efficiently pollutions are treated, defined by Managi et al. (2005). Thus, whether environmental productivity increases over time is an empirical question.¹

Against this backdrop, the objective of this paper is two-fold; First, attempts are made to measure technological/productivity change for environmental (non-market) outputs of data of

sulfur dioxide (SO₂), nitrogen dioxide (NO₂), and suspended particulate matter (SPM) in India using state-level industry data over the period 1991–2003; second, the change in environmental productivity in different states are linked with their respective per capita income to find an EKC type relationship. We intend to measure environmental productivity following the traditional productivity literature.² The regulations requiring more stringent pollution abatement do not necessarily change environmental productivity since the linear expansion of pollution abatement costs and pollution reduction does not necessarily change the pollution reduction per abatement cost.

The paper is structured as follows. Section 2 briefly reviews the environmental policies in India. The empirical model and data are explained in Section 3 while the results are presented in Section 4. The concluding remarks and further discussions are provided in Section 5.

2. Environmental policies in India

To combat the problem of environmental degradation, several environmental polices were initiated by the Government of India from late 1970s. India was the first country to insert an amendment into its Constitution allowing the State to protect and improve the environment for safeguarding public health, forests and wild life. The 42nd amendment was adopted in 1976 and went into effect January 3, 1977. The *Directive Principles of State Policy* (Article 47) requires not only a protectionist stance by the state but also compels the state to seek the improvement of polluted environments.

The Air (Prevention and Control of Pollution) Act was passed in 1981 and the Parliament had passed the Environmental Protection Act in 1986. The responsibility of administering new legislations fell on the central and state pollution control boards. The Department of Environment (DOE) was created in 1980, which was supposed to appraise the environmental aspects of development projects, to monitor air and water quality, to establish an environmental information system, to promote environmental research, and to coordinate activities between federal, state and local governments. The DOE was criticized, however, by environmental groups for its small political and financial base. Environmentalists recognized quickly that the DOE would essentially serve as an advisory body with few enforcement powers.

This deficiency was soon recognized and a Ministry of Environment and Forests (MoEF) was created in 1985. It continued the same functions that the DOE originally had, such as monitoring and enforcement, conducting environmental assessments and surveys, but also provided promotional work about the environment. The MoEF's implementation of a monitoring system was noteworthy (see MoEF, 2001). In 1984, there were 28 monitoring stations for air pollution in India. It had increased to 290 stations by 1994 including 51 stations from the Global Environmental Monitoring System (GEMS).

¹ Most current empirical studies focus on developed countries (Managi et al., 2005). To the authors' knowledge, there are few studies that have estimated the efficiency changes of environmental technology or management in the context of developing countries. See Murtya et al. (2006) for recent application to the Indian Sugar industry.

² There are several studies that measures market productivity, For example, Pallikara (2004) finds 2.8% annual increase of market TFP using Solow residual type total factor productivity over 1992 and 2001.

In December 1993, the MoEF completed its Environmental Action Plan to integrate environmental considerations into developmental strategies, which, among other priorities, included industrial pollution reduction. However, the control of environmental pollution had not been found to be satisfactory mostly because of the growth oriented policies of the economy. Since the adoption of the reform policies in India in 1991, the economy has climbed upon a higher trajectory in its growth rate. Between 1993–1994 and 1997–1998, the Indian economy has averaged to more than 7% growth rate per annum (Economic Survey of India, 1998–1999). The growth of industrial production and manufacturing has averaged at 8.4% and 8.9% respectively during these years. This expansion of economic activities had a heavy toll on the environmental quality in the country. Further, lack of properly functioning markets for environmental goods and services and market distortions created by price controls and subsidies have aggravated the environmental problems.

The weakness of the existing system lies in the enforcement capabilities of the environmental institutions both at the centre and the state. There is no effective coordination amongst various Ministries/institutions regarding integration of environmental concerns at the inception/planning stage of the project (Economic Survey of India, 1998–99). Further, it was analyzed that the current policies are also fragmented across several government agencies with differing policy mandates. Lack of trained personnel and comprehensive database delay many projects. Most of the state government institutions are relatively small suffering from inadequacy of technical staff and resources.

Although, it was claimed by the Central Pollution Control Board (CPCB, 2001) that the overall quality of Environmental Impact Assessment (EIA) process have improved over the years, little is known about how environmental productivity has changed over time in India. By considering the divergence of policy intention and actual implementation in each province/state, this study measures the efficiency of environmental management in India using two techniques explained in the following section.

3. Models

3.1. Measurement of productivity

We measure productivity change in a joint production model, with a vector of market and non-market outputs using production frontier analysis (see Kumar (2006) for the literature). This approach uses the Luenberger productivity index, which is the dual to the profit function and does not require the choice of an input–output orientation (Chambers et al., 1996).³ In contrast, the more commonly used Malmquist productivity index requires the choice between of an output

or input orientation corresponding to whether one assumes revenue maximization or cost minimization as the appropriate behavioral goal (Färe et al., 1985). Since the Luenberger productivity index can be applied with an output or input-oriented perspective, it is a generalization of, and superior to, the Malmquist productivity index (Luenberger, 1992a,b; Chambers et al., 1998; Boussemart et al., 2003). In this study, we estimate Luenberger productivity index.

Following Managi et al. (2005), this study uses two datasets, of which one includes only market input/output, TFP_{Market} , and the other includes environmental input/output in addition to the market input/output, TFP_{Joint} , considering the maximum expansion of good outputs and contraction of bad outputs. The total factor productivity (TFP) associated with environmental outputs, TFP_{Env} or environmental productivity, is then calculated as:

$$TFP_{Env} = TFP_{Joint} - TFP_{Market} \quad (1)$$

where TFP is Luenberger indices, which takes the difference of the two models. This is because Luenberger indices employ the difference method (see Chambers et al., 1998). The TFP includes not only the change in technology, but also the effect of management-level changes in institutions, including environmental regulations. Thus, even though the technology level remains constant, there are cases where there are changes in TFP.

Production frontier analysis yields the Luenberger index (e.g., Luenberger, 1992a), which can then be used to quantify productivity change. The index-based approach measures the TFP change between two data points by calculating the ratio or difference of two associated distance functions or shortage functions (e.g., Caves et al., 1982; Luenberger, 1992a). This approach has several advantages. One advantage is the immediate compatibility with multiple inputs and outputs. This is important for environmental applications since pollutants, as the by-product of market outputs, can be multiple. This technique estimates the weight given to each observation, such as the weight or shadow price for each item such as environmental pollution data, and implicitly combines these into the one index. In addition, this approach can incorporate the inefficient behavior of the decision maker and avoid the need for the explicit specification of the production function (see Managi et al. (2005) for further details).

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;

$$P^t = \{(x^t, b^t, y^t) : x^t \text{ can produce } (y^t, b^t)\}, \quad (2)$$

which is the set of all feasible production vectors. We assume that P^t satisfies standard axioms, which suffice to define meaningful directional distance functions. Especially, we use capital stock and labor at manufacturing industries as inputs (unit of 10^4 rupee and worker, respectively; note all monetary units are real term of 1993), SO_2 , NO_2 , and SPM as bad outputs (unit of ton), and gross state product as market output in this study (unit 10^4 rupee; real GDP level for each state manufacturing). It is important to note that, although traditional non-parametric approach to production or demand analysis suffers from a lack of invariance to the measurement scaling (see,

³ Though Luenberger Productivity is theoretically well developed, there is very little empirical work in the literature (Boussemart et al., 2003). A commonly used technique in productivity measurement is growth accounting, which forms a residual after taking the impact of changes in capital and labor inputs out of changes in real output. Compared with the approach used, however, this approach has a number of disadvantages, including an assumption of constant returns-to-scale and zero inefficiency.

Chavas and Cox, 1988; Chalfant and Zhang, 1997, 2000; Chavas, 2000), our method of Data Envelopment Analysis (DEA) formulation is unit-free and therefore avoid the problem of units of measurement (Charnes et al., 1978). The directional distance function is defined at t as;

$$D^t(y^t, x^t, b^t; g^t) = \sup\{\delta : (y^t, x^t, b^t) + \delta g^t \in P^t\}, \quad (3)$$

where g is the vector of directions which outputs are scaled. For this directional 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. In contrast to the traditional market productivity measurements, which simply seek to maximize good production, this directional distance function is able to credit the reduction of pollution in the same time.

The DEA formulation calculates the Luenberger productivity index under variable returns-to-scale (VRS) by solving the following optimization problem (Chambers et al., 1996):

$$\begin{aligned} D^t(y^t, x^t, b^t) = & \max_{\delta, \lambda} \delta \\ \text{s.t.} \quad & Y^t \lambda \geq (1 + \delta) y_i^t \\ & B^t \lambda \geq (1 - \delta) b_i^t \\ & X^t \lambda \leq x_i^t \\ & N' \lambda = 1 \\ & \lambda \geq 0 \end{aligned} \quad (4)$$

where $N1$ is an identity matrix, λ is a $N \times 1$ vector of weights, Y^t , X^t , B^t , are the vectors of market outputs, y^t , inputs, x^t and environmental outputs, b^t .

As in Malmquist indices, several different proportional distance functions are necessary to estimate the change in productivity over time. For the mixed period distance function, we have two years, t and $t+1$. For example, $D^t(y^{t+1}, x^{t+1}, b^{t+1})$ is the value of the distance function for the input-output vector of period $t+1$ and technology at t . Luenberger productivity index defined by Chambers et al. (1996) and Chambers (2002) is as follows:

$$\text{TFP} = \frac{1}{2} [(D^t(y^t, x^t, b^t) - D^t(y^{t+1}, x^{t+1}, b^{t+1})) + (D^{t+1}(y^t, x^t, b^t) - D^{t+1}(y^{t+1}, x^{t+1}, b^{t+1}))]. \quad (5)$$

This is an arithmetic mean of period t (the first difference) and period $t+1$ (the second difference) Luenberger indices, as an effort once again to avoid any arbitrary selection of base years (e.g., Balk, 1998). This study measures the TFP index of market outputs ($\text{TFP}_{\text{Market}}$) and TFP of both market and environmental output ($\text{TFP}_{\text{Joint}}$) in a joint production analysis. These two TFP indices are then used to estimate the TFP of environmental output (TFP_{Env}).

TFP includes all categories of productivity change, which can be decomposed into two components including technological change and efficiency change. Technological Change (TC) and Efficiency Change (EC) have additive relations to compose TFP. TC measures shifts in the production frontier while EC measures changes in the position of a production unit relative to the frontier-so-called “catching up” (Färe et al., 1994; Managi et al., 2004).

3.2. Kuznets curve relationship: environmental productivity and income level

According to the EKC literature, successful implementation of environmental regulations depends upon the pattern and

stages of their growth. It is expected that higher income regions would be more sensitive towards implementing environmental regulations thereby curbing pollution. Recent work by Zaim and Taskin (2000) undertakes an efficiency approach in the EKC literature. They measure the environmental efficiency of Organisation for Economic Co-operation and Development (OECD) countries over 1980–1990 using DEA with a proxy for environmental quality as the EKC dependent variable. Finding the determinants of the factors underlying the changes in the environmental efficiency are their main concern. They find a Kuznets curve in the efficiency.

We attempt to find a relationship between state-wise per capita income and their respective environmental productivity indices. To analyze the determinants of the productivity change, several variables are used as independent variables such as per capita gross state product (GSP), population density, education level, and urbanization. The following equation is estimated in this study:

$$E_{\text{kit}} = \beta_1 + \beta_2 \text{GSP}_{\text{it}-1} + \beta_3 \text{GSP}_{\text{it}-1}^2 + \beta_4 \text{PO}_{\text{it}} + \beta_5 \text{UR}_{\text{it}} + \beta_6 \text{ED}_{\text{it}} + \varepsilon_{\text{it}} \quad (6)$$

where, E_{kit} is the environmental productivity index (environmental TFP) or joint TFP of the pollution parameter k in state i in year t ; GSP is the log of real gross state product (GSP) per capita;⁴ PO is the population density; UR is the urbanization index; ED is an education index; β_s are the coefficients and ε_{it} is the random error term. There are concerns pertaining to scaling and invariance in estimated results of logarithmic form suffers from. We only note in this paper that our estimated results are robust to the changes in the scaling of the variables.

It is expected that per capita income has a negative relation with environmental productivity. This is because an increase in income in the initial phase of growth raises pollution, which would eventually reduce the productivity. Therefore, β_2 should bear a negative sign from our regressions. However, this negative effect might be reversed and therefore, we expect a positive relation between per capita income square and environmental productivity. After a sufficiently high per capita income is reached, further increment in income is expected to increase environmental productivity, i.e., β_3 is positive.

Population density variable may bear a negative sign since there might be more pressure on the environment in more densely populated areas. A positive association is expected between the education index variable and environmental productivity. Education level of a society affects the level of environmental awareness among people. Some studies have considered a time variable to capture this unobservable factor in their models (Grossman and Krueger, 1995; Seldon and Song, 1994; Antweiler et al., 2001). They have argued that increase in

⁴ The TFP indices of environmental variables are transformed into their logarithmic form. Since most of the observations are in negative values and a simple log-transformation was not possible, TFP data are converted into $(1 + \text{TFP})$ form to make the observations positive. Grossman and Krueger had done such transformation in their 1993 paper to avoid the negative values of data series. Furthermore, since the dependent variable for one year is the difference of the productivity between current year and the base year. Therefore, the TFP for year t is affected by the per capita income of year $t-1$. Therefore, log TFP are regressed on one-year lagged values of log GSP.

environmental awareness and knowledge over time would lead to reduction in environmental degradation. However, it is meaningful to consider an observable variable, which can capture the relevant character of this factor. Therefore, awareness level index is used to represent environmental awareness in our study. The level of education is one indicator that shows the awareness level among people regarding environmental degradation and the need for its protection. Therefore, an education proxy index is constructed by taking all persons who have passed at least matriculation in a particular year in a state. Finally, urbanization, which is measured as urban population as a percentage of total population, is expected to bear a negative sign due to its spiraling effect on environmental quality.

We employ panel regression techniques to estimate Eq. (6). Panel data approach encompasses data across cross-sections and over time series, thus provides a comprehensive analysis to examine variables of interest. However, this type of two-step approach, where productivity measures are estimated by DEA in the first step and regressed on explanatory variables in the second step, should be treated with caution. Following [Simar and Wilson \(2007\)](#), productivity measures estimated by DEA are serially correlated. They argue that a bootstrapping method should be used. However, the use of panel data and dynamic specifications make this problem more complex. Alternatively, to eliminate the serial correlation problem, [Zhengfei and Oude Lansink \(2006\)](#) suggest the use of a dynamic generalized method of moments (GMM) model to analyze TFP measures estimated by DEA. Therefore, in addition to the sensitivity analysis of OLS method and fixed effects model, we employ dynamic GMM to analyze productivity change as described in [Zhengfei and Oude Lansink \(2006\)](#).

The previous year's productivity change has an impact on the current year's productivity change because further improvement of productivity after high growth in the previous year might be more difficult. To address the dynamics, two lags of the dependent variable are included in Eq. (6). Furthermore, error term of ε consists of an individual effect η and random disturbance, i.e., $\varepsilon_{it} = \eta_i + v_{it}$. In the first-differenced model we estimate, all observations of the dependent variable before $(t-2)$ are valid instruments. [Arellano and Bond \(1991\)](#) proposed a difference GMM estimator, in which all the valid historical instruments are used in the equation. [Arellano and Bond \(1991\)](#) and [Blundell and Bond \(1998\)](#) propose a system GMM in which the moment conditions in the differenced model and levels model are combined. In their study, it is shown that the system GMM can dramatically improve the problem of weak instruments. Therefore, the system GMM is used in this article.

The dataset consists of annual data for the period 1991–2003 for 16 states in India. For conventional market output, state-level manufacturing data are from *Annual Survey of Industries (ASI)* constructed by the Central Statistical Organization ([CSO, 1995, 2004](#)). This study uses real gross manufacturing output as market output in the model. Capital stock and labor as number of worker from ASI are employed as inputs. Data of gross state product are collected from various issues of the *Economic Survey of India* reports and data of the control variables such as urbanization, education level and pollution densities are collected from various editions of the *Statistical Abstract of India*. On the other hand, environmental output is treated as a by-product from the industries in the production

Table 1 – Market and joint productivity changes (average changes in each period)

Periods	Market productivity			Joint productivity		
	TFP	EC	TC	TFP	EC	TC
1991–1994	–0.022	0.007	–0.029	–0.008	–0.003	–0.005
1995–1998	0.013	0.000	0.013	–0.012	–0.001	–0.011
1999–2002	0.004	0.004	0.000	–0.010	–0.003	–0.007
Mean	–0.001	0.004	–0.005	–0.010	–0.002	–0.008

process in this study. To account for environmental outputs, data of SO₂, NO₂, and SPM are extracted from the various years' reports of *National Air Quality Monitoring Programme (NAMP)* (see [CPCB, 1995, 1998, 2003](#)). The name of the states is provided in the Appendix.

4. Results

4.1. Productivity analysis

Separate frontiers are estimated for each year, and shifts in the frontiers over time are used to measure the technological change. The arithmetic mean of the Luenberger productivity indices for each state in each year⁵ are estimated under the assumptions of VRS production technologies. Note that we also estimate the productivities under the assumptions of constant returns to scale and find similar results.

Arithmetic mean values of TFP, TC and EC across the states for each period are presented in [Tables 1 and 2](#).⁶ In these tables, the study period (1991–2002) is divided into three sub-periods of 1991 to 1994 (1st periods), 1995 to 1998 (2nd periods), and 1999 to 2002 (3rd periods). The purpose of this division is to compare productivity indices between the sub-periods to assess how changes in productivity have taken place vis-à-vis policy changes.

4.2. Market productivity

The results of market productivity are presented in [Table 1](#). The results of TFP_{Market} have two different phases of 1991–1996 and 1997–2002. In the initial phase the productivity index has negative values showing a decline in the productivity from the base period. However, though the absolute value of the index has decreased during this period, the rate of decline has narrowed down by 60%, i.e. –0.025 in 1991 to –0.010 in 1996. In the latter phase, changes in TFP_{Market} are positive values indicating a net productivity gain.

Overall, the movement of the index suggests that the productivity of market declines in the initial years of the economic reforms in India. In fact, the country goes through a transition phase in the early 1990s following a massive policy change in 1991 that has resulted in a turbulent period in the industrial sector. The growth rates in both GDP and manufacturing output are low during 1991–1992 and 1992–1993. However, during mid-1990s, the

⁵ See [Balk \(1998\)](#) for theoretical reasoning underlying the use of arithmetic means to average data.

⁶ Note that the Luenberger TFP technique is difference based technique and therefore minus value implies that productivity decreases compared to base period. On the other hand, a plus value reflects a positive increase.

Table 2 – SO₂, NO₂, and SPM productivity changes (average changes in each period)

Periods	SO ₂			NO ₂			SPM		
	TFP	EC	TC	TFP	EC	TC	TFP	EC	TC
1991–1994	–0.028	–0.022	–0.005	–0.011	–0.006	–0.005	–0.008	–0.002	–0.005
1995–1998	–0.007	0.003	–0.011	–0.017	–0.005	–0.011	–0.012	–0.001	–0.012
1999–2002	0.005	0.012	–0.006	–0.031	–0.022	–0.009	–0.010	–0.003	–0.007
Mean	–0.010	–0.002	–0.007	–0.020	–0.011	–0.009	–0.010	–0.002	–0.008

industrial sector recovers from the early shocks of the reform process and registers reasonable growth rates. This is reflected in the positive changes in TFP later in the decade. The value of EC decreases from 0.007 of first period to 0 of the second period and finally it increased to 0.004 of the third period. On the other hand, the TC increases from –0.029 of first period to 0.013 of the second period, and it decreases to 0.00 of third period.

4.3. Joint output productivity

Joint output productivity indices are constructed using a joint output production technology in which both desired output (conventional good) as well as undesired outputs (environmental pollutions) of SO₂, NO₂, and SPM are jointly produced, the latter being the by-product.⁷ Luenberger productivity index uses directional distance functions that attempt to maximize market output while minimizing the undesired by-products, while minimizing inputs.

The results in Table 1 show that TFP_{joint} has negative values in almost all the years showing consistent decline in the productivity. The TFP_{joint} declines from –0.008 to –0.012, a 50% deceleration while moving from the first period to the second period and then it remains steady with a mean value of –0.010 in the third period. This shows that the productivity of joint output does not show any improvement in the post-reform periods in India. Moreover, combining the market output productivity and joint output productivity indices, it can be suggested that while the former starts increasing from the mid-1990s, the latter consistently declines throughout our study periods. This finding indicates that the productivity of environment declines continuously. Technological progress increases market productivity simultaneously creates possible threats to society, which are unknown in the early phase of the implementation of technology. Currently, India might face this problem. However, it is difficult to say which of the three pollutants, SO₂, NO₂, and SPM is the main cause of the overall environmental productivity decrease from these results. Therefore, each specific environmental productivity of these pollutants is estimated and the indices are provided in the Table 2.

4.4. Environmental productivity

The environmental productivity indices in our study are calculated by taking the difference of market productivity indices and joint productivity indices. We have estimated separate productivity indexes for the three pollution variables of SO₂, NO₂, and SPM, respectively. For example, environmen-

tal productivity of SO₂ is represented as TFP_{SO₂}, i.e., SO₂ pollution productivity. The TFP_{SO₂} given in Table 2 shows that the productivity declines from 1991 to 1999. Although the first two periods show negative sign, the deteriorating rate decreases. In the third period, the index shows positive sign. These results indicate that the implementation of environmental regulations to control and prevent emissions of sulfur dioxide improves over the years in India and more particularly so in the recent years caused by the increase in EC. This indicates that externalities of SO₂ are identified as social institutions formulate laws and regulations to consider SO₂ pollution. The generation of new technologies to reduce SO₂ is more efficiently implemented in catching-up to the frontier states, which is reflected by the increase in EC.

In contrast, the changes in TFP_{NO₂} (also both of TC and EC) are monotonously negative over the whole study period showing a continuous decline of the productivity. Moreover the alarming feature of the trend is that the rate of this decline is actually increasing over the years. The mean value of the index declines from –0.011 in the first periods to –0.017 in the second periods with a 55% decline in the productivity and it has further gone down to –0.031 in the third periods with an 82% decline in the productivity. This is quite significant and seriously questions the implementation efficiency of the government pollution control boards in controlling the emission and concentration of nitrogen oxides in India. The CPCB annual report (2003–2004) also raises concerns about the unabated spiraling of nitrogen oxide in industrial cities in the country.

Finally, the estimated productivity indexes of the third pollutant in our study, i.e. SPM show that the performances of TFP, EC, and TC are not any better than the NO₂ case. The index has been negative in all the years indicating a net decrease in the productivity. The mean values show that the index has decreased from –0.008 of first periods to –0.012 of second periods, thus registering a 50% decline in the productivity. The rate of decrease in the third periods is smaller than that of NO₂. Nevertheless it raises serious concerns for the policy makers in the country.

The discussion above reveals that though the market productivity recovered after mid 1990s from a slump in the early stages of economic reforms, on the other hand, the environmental productivity has deteriorated constantly. Except the productivity of SO₂, which has shown some improvement after 1999, the abatement of other forms of air pollution has been worse.

4.5. Environmental Kuznets curve test

Furthermore, the analysis of environmental productivity in the individual states suggests that there is variation among the states in terms of productivity. For example, productivity of SO₂ improves in states like Andhra Pradesh, Gujarat, Haryana, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Uttar

⁷ The number of observations per year is relatively small and therefore potentially many states tend to lie on each-year's frontier compared to the cases we had more observations.

Dependent variable	SO ₂			NO ₂		
Estimation technique	OLS	Fixed effects	Dynamic GMM	OLS	Fixed effects	Dynamic GMM
Intercept	0.018*** (13.04)	–	–	0.056*** (4.719)	–	–
Gross State Product (GSP)	–0.016*** (–11.78)	–0.029*** (–17.17)	–0.034*** (–17.74)	–0.058*** (–4.41)	–0.078*** (–6.76)	–0.087*** (–7.23)
GSP ²	0.004*** (11.82)	0.005*** (11.93)	0.006*** (11.99)	0.011*** (3.45)	0.019*** (6.60)	0.016*** (6.01)
Population density	–1.11e–06*** (–4.11)	–9.08e–06*** (–3.13)	–9.83e–06*** (–3.52)	1.49e–07 (0.119)	–1.45e–05*** (–3.16)	–4.72e–03*** (–4.43)
Urbanization	7.79e–06 (0.32)	0.003*** (10.67)	0.009*** (11.41)	–0.0002*** (–2.20)	–0.0007* (–1.75)	–0.0011*** (–2.53)
Education index	–4.60e–05*** (–4.45)	7.00e–07 (0.03)	2.72e–02*** (3.09)	0.0002*** (6.00)	0.0005*** (5.40)	0.0013*** (6.41)
R ²	0.01	0.18	0.21	0.01	0.13	0.16
F-statistic	0.35	4.26***	4.35***	1.25	4.89***	4.95***

Note: *** Significant at 1%, ** Significant at 5%, * Significant at 10%. t statistics are in parentheses.

A 1% increase in linear term of GSP reduces the TFP of SO₂ by 0.034%. The TFP of the environmental parameter reflects in one

The regression estimates of TFP of NO₂, SPM and Joint output are given in [Table 3 and 4](#), respectively. The signs of the estimated coefficients of GSP and GSP² with these variables are similar to that of SO₂, with the former having negative sign and the latter having positive sign. Therefore, the scale effect is negative and the technique effect is positive across all the environmental variables. In case of NO₂, an 1% increase in per

Dependent variable	SPM			Joint outputs		
Estimation technique	OLS	Fixed effects	Dynamic GMM	OLS	Fixed effects	Dynamic GMM
Intercept	0.014*** (49.16)	–	–	0.026*** (8.85)	–	–
Gross State Product (GSP)	–0.01*** (–39.20)	–0.01*** (–37.03)	–0.02*** (–41.05)	–0.02*** (–7.32)	–0.02*** (–6.25)	–0.03*** (–6.97)
GSP ²	0.002*** (25.96)	0.002*** (41.22)	0.003*** (36.52)	0.004*** (4.65)	0.008*** (10.60)	0.009*** (11.46)
Population density	1.59e–08 (0.285)	–4.80e–06*** (–23.05)	–3.47e–03*** (–20.52)	–9.41e–07* (–2.57)	–9.30e–06*** (–4.68)	–4.88e–04*** (–5.71)
Urbanization	–7.04e–05*** (–20.62)	–0.001*** (–35.61)	–0.003*** (–25.53)	6.35e–05 (1.37)	–0.002*** (–8.11)	–0.011*** (–8.74)
Education index	1.32e–05*** (5.53)	2.40e–05*** (7.41)	1.42e–03*** (6.94)	2.63e–05* (2.36)	7.81e–05** (2.99)	2.74e–03*** (3.14)
R ²	0.04	0.14	0.19	0.01	0.34	0.36
F-statistic	1.37	6.25***	6.29***	0.35	5.43***	5.73***

Note: *** Significant at 1%, ** Significant at 5%, * Significant at 10%. t statistics are in parentheses.

capita income reduces the TFP of NO₂ by 0.087% and at the margin an 1% increase in per capita income square, productivity increases by 0.078%. With SPM, the coefficients are -0.02 and 0.015 with GSP and GSP², respectively, on the other hand, the coefficients of these variables with joint output are -0.03 and 0.009 respectively.

These elasticities can be added together to arrive at a net effect of income (i.e., summation of scale effect and technique effect) on the productivity. For example, in case of SO₂, scale elasticity is -0.034 and technique elasticity is 0.029; adding them together we find the net elasticity of -0.005. Similarly, the net elasticity for NO₂ and SPM are -0.009 and -0.005, respectively. It can be noticed that the net effect of income on the environmental productivity is negative. Although, at the margin increase in per capita income (technique effect) has the potential to improve the productivity, but this effect is insignificant to offset the dominant scale effect. Therefore, negative scale effect outperforms the positive technique effect to render productivity to decline. The lower TFP index values in high-income states articulate these results. Scale effect of income in the states have been stronger than the technique effect and thus, increase in per capita income fuelled by higher growth trajectory leads. In the case of joint output results, net elasticity is 0.014, implying that increase in income level induces better performance including both of market and environmental outputs. Negative results in environmental productivities are caused by the higher market productivity.

Among the other control variables, population density has negative coefficients with productivity indices implying environmental performances are adversely affected in densely populated areas. The urbanization variable has also found to be negatively associated with environmental productivity. The education index, which measures the level of environmental awareness, has positive coefficients, though the magnitude of these coefficients is small. These findings suggest that regions with higher level of education seem to have experienced lesser amount of environmental degradation.

5. Concluding remarks

As a result of India's extremely rapid economic growth, the scale and seriousness of environmental problems are no longer in doubt. Whether pollution abatement technologies are utilized more efficiently is crucial in the analysis of environmental management because it influences the cost of alternative production and pollution abatement technologies, at least in part (e.g., Jaffe et al., 2003). Using recently developed productivity measurement technique, we show that overall environmental productivity decreases over time in India. At present, the existing environmental management is not sufficient to bring sustainable development in the country. However, once we disaggregate the pollutants to specific pollution of SO₂, NO₂, and SPM, we find environmental productivity recently increases in SO₂. The results for NO₂ and SPM are the main causes of the productivity reduction over the study periods.

Furthermore, we analyze the determinants of environmental productivity and find EKC type relationship existences between environmental productivity and income. However, the environmental productivities, in general, decline more in high-income states in comparison to the low-income states. Panel analysis results show that the scale effect is negative and dominant over the positive technique effect. Therefore, a combined effect of income on environmental productivity is negative which answers the puzzle why productivity has declined faster in developed states than their underdeveloped counterparts.

We conclude that if the ongoing pace of industrialization is not met with effective environmental management then there would be untoward consequences in India. Their society is required to innovate environmental practices based on incentives for industries to perform well in their environmental management, formulate economic and environmental policies simultaneously in order to achieve sustainability of the growth process.

Appendix A

Table A1: TFP changes of SO₂ in India

States	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Andhra Pradesh	-0.002	0.018	-0.004	-0.049	-0.03	0.008	0.031	0.011	-0.007	0.003	0.041	0.002
Delhi	-0.007	-0.0003	-0.011	-0.007	0.014	-0.001	-0.002	1.5e-05	0.002	0.013	-0.01	-0.034
Goa	-0.164	0.069	-0.283	0.039	-0.213	-0.259	-0.126	-0.071	-0.153	-0.066	-0.012	-0.087
Gujarat	-0.016	-0.188	-0.044	-0.58	-0.003	0.54	-0.316	-0.219	0.24	-0.006	0.049	0.068
Haryana	0.008	-0.011	-0.02	-0.02	-0.019	-0.012	-0.009	0.069	-0.079	0.041	0.011	0.064
Himachal Pradesh	-0.0005	0.0003	-0.001	0.0002	5.8e-05	-0.002	0.0006	0.002	-0.001	-0.002	0.0002	0.0004
Karnataka	-0.012	-0.02	-0.001	-0.039	-0.029	-0.021	-0.037	-0.005	0.058	0.021	-0.003	-0.002
Kerala	-0.002	-0.004	-0.003	0.003	-0.002	-0.003	-0.003	-0.013	-0.026	0.018	0.003	-0.006
Madhya Pradesh	-0.004	-0.034	0.021	-0.066	-0.043	-0.0004	0.022	0.083	-0.098	0.051	0.036	0.021
Maharashtra	0.08	-0.12	-0.12	-0.14	0.11	-0.20	0.15	0.08	0.0009	-0.04	0.065	0.067
Orissa	-0.004	-0.011	0.003	0.003	0.003	-0.004	-0.007	0.022	0.003	-0.001	-0.002	0.007
Punjab	-0.0004	-0.013	0.003	0.007	0.018	-0.023	-0.002	0.002	0.013	0.01	0.01	0.002
Rajasthan	-0.0003	-0.012	0.003	-0.008	-0.004	0.005	0.003	0.01	-0.025	0.012	0.0005	0.016
Tamilnadu	-0.007	-0.007	-0.037	-0.073	0.127	-0.082	0.013	0.066	-0.061	-0.082	-0.104	0.063
Uttar Pradesh	0.006	-0.022	0.044	0.098	-0.008	-0.022	-0.058	0.069	-0.033	0.003	0.071	0.035
West Bengal	0.043	-0.013	-0.052	0.013	0.018	-0.048	-0.11	0.069	0.09	0.046	0.033	-0.007
Mean	-0.005	-0.023	-0.031	-0.051	-0.004	-0.008	-0.028	0.011	-0.005	0.001	0.012	0.013

- Antweiler, W., Copeland, B., Taylor, S., 2001. Is free trade good for the environment? *American Economic Review* 91 (4), 877–908.
- Arellano, M., Bond, S., 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58, 277–297.
- Balk, B.M., 1998. *Industrial Price, Quantity, and Productivity Indices: The Micro-Economic Theory and an Application*. Kluwer, Boston.
- Blundell, R., Bond, S., 1998. Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics* 87, 115–143.
- Boussemart, J.P., Briec, W., Kerstens, K., Poutineau, J.C., 2003. Luenberger and Malmquist productivity indices: theoretical comparisons and empirical illustration. *Bulletin of Economic Research* 55, 391–405.
- Caves, D.W., Christensen, L.R., Diewert, W.E., 1982. The economic theory of index numbers and the measurement of input, output and productivity. *Econometrica* 50, 1393–1414.
- Central Pollution Control Board, 1995, 1998, 2003. *National Air Quality Monitoring Programme Report*. Ministry of Environment and Forest, New Delhi.
- Central Pollution Control Board, 2001. *Annual Report*. Ministry of Environment and Forest, New Delhi.
- Central Statistical Organization, 1995, 2004. *Annual Survey of Industries*. Ministry of Planning and Programme Implementation, Calcutta, Government of India.
- Chalfant, J.A., Zhang, B., 1997. Variations on invariance or some unpleasant nonparametric arithmetic. *American Journal of Agricultural Economics* 79, 1164–1176.
- Chalfant, J.A., Zhang, B., 2000. Variations on invariance or some unpleasant nonparametric arithmetic: reply. *American Journal of Agricultural Economics* 82, 234–235.
- Chambers, R.G., 2002. Exact nonradial input, output, and productivity measurement. *Economic Theory* 20, 751–765.
- Chambers, R.G., Färe, R., Grosskopf, S., 1996. Productivity growth in APEC countries. *Pacific Economic Review* 1, 181–190.
- Chambers, R.G., Chung, Y., Färe, R., 1998. Profit, directional distance functions, and Nerlovian efficiency. *Journal of Optimization Theory and Applications* 98, 351–364.
- Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring efficiency of decision making units. *European Journal of Operational Research* 2, 429–444.
- Chavas, J.P., 2000. Variations on invariance or some unpleasant nonparametric arithmetic: comment. *American Journal of Agricultural Economics* 79, 231–233.
- Chavas, J.P., Cox, T., 1988. A nonparametric analysis of agricultural technology. *American Journal of Agricultural Economics* 70, 303–310.
- Dinda, S., 2004. Environmental Kuznets curve hypothesis: a survey. *Ecological Economics* 49 (1), 431–455.
- Economic Survey of India, 1998–1999. Ministry of Finance, Economic Division. Government of India, New Delhi.
- Färe, R., Grosskopf, S., Lovell, C.A.K., 1985. *The Measurement of Efficiency of Production*. Kluwer–Nijhoff, Boston.
- Färe, R., Grosskopf, S., Norris, M., Zhang, Z., 1994. Productivity growth, technical progress, and efficiency change in industrialized countries. *American Economic Review* 84 (1), 66–83.
- Grossman, G.M., Krueger, A.B., 1993. Environmental impacts of a North American free trade agreement. In: Garber, Peter M. (Ed.), *The U.S.–Mexico Free Trade Agreement*. MIT Press, Cambridge, MA, pp. 13–56.
- Grossman, G.M., Krueger, A.B., 1995. Economic growth and the environment. *Quarterly Journal of Economics* 110 (2), 353–377.
- Holtz-Eakin, D., Selden, T.M., 1995. Stoking the fires? CO₂ emissions and economic growth. *Journal of Public Economics* 57, 85–101.
- Jaffe, A.B., Newell, R.G., Stavins, R.N., 2003. Technological Change and the Environment. In: Mäler, K., Vincent, J. (Eds.), *Handbook of Environmental Economics*. North-Holland. Elsevier Science, Amsterdam, 462–516.
- Kumar, S., 2006. Environmentally sensitive productivity growth: a global analysis using Malmquist–Luenberger index. *Ecological Economics* 56 (2), 280–293.
- Luenberger, D.G., 1992a. Benefit functions and duality. *Journal of Mathematical Economics* 21, 461–481.
- Luenberger, D.G., 1992b. New optimality principles for economic efficiency and equilibrium. *Journal of Optimization Theory and Applications* 75, 221–264.
- Managi, S., 2006. Are there increasing returns to pollution abatement? Empirical analytics of the environmental Kuznets curve in pesticides. *Ecological Economics* 58 (3), 617–636.
- Managi, S., Opaluch, J.J., Jin, D., Grigalunas, T.A., 2004. Technological change and depletion in offshore oil and gas. *Journal of Environmental Economics and Management* 47 (2), 388–409.
- Managi, S., Opaluch, J.J., Jin, D., Grigalunas, T.A., 2005. Environmental regulations and technological change in the offshore oil and gas industry. *Land Economics* 81 (2), 303–319.
- Ministry of Environment and Forest, 2001. *Annual Report*. Government of India, New Delhi.
- Murtya, M.N., Kumar, S., Paul, M., 2006. Environmental regulation, productive efficiency and cost of pollution abatement: a case study of sugar industry in India. *Journal of Environmental Management* 79 (1), 1–9.
- Pallikara, R., 2004. *India–National Reports*. In: Asian Productivity Organization (Eds.), *Total Factor Productivity Growth: Survey Report*. APO Survey on Total Factor Productivity, Tokyo.
- Seldon, T.M., Song, D., 1994. Environmental quality and development: is there a Kuznets curve for air pollution emissions? *Journal of Environmental Economics and Management* 27 (2), 147–162.
- Simar, L., Wilson, P.W., 2007. Estimation and inference in two-stage, semi-parametric models of production processes. *Journal of Econometrics* 136, 31–64.
- Stern, D.I., 1998. Progress on the environmental Kuznets curve? *Environment and Development Economics* 3, 173–196.
- Stern, D.I., 2004. The rise and fall of the environmental Kuznets curve. *World Development* 32, 1419–1439.
- Zaim, O., Taskin, F., 2000. A Kuznets curve in environmental efficiency: an application on OECD countries. *Environmental and Resource Economics* 17, 21–36.
- Zhengfei, G., Oude Lansink, A., 2006. A Robust Estimator for Performance Modeling. Paper presented at The 9th European Workshop on Efficiency and Productivity Analysis, Brussels, Belgium, 29 June – 2 July.