Working Paper 235

Measuring Energy Use Efficiency in Presence of Undesirable Output: An Application of Data Envelopment Analysis (DEA) to Indian Cement Industry

Sabuj Kumar Mandal
S Madheswaran

ISBN 81-7791-191-0

Institute for Social and Economic Change (ISEC) is engaged in interdisciplinary research in analytical and applied areas of the social sciences, encompassing diverse aspects of development. ISEC works with central, state and local governments as well as international agencies by undertaking systematic studies of resource potential, identifying factors influencing growth and examining measures for reducing poverty. The thrust areas of research include state and local economic policies, issues relating to sociological and demographic transition, environmental issues and fiscal, administrative and political decentralization and governance. It pursues fruitful contacts with other institutions and scholars devoted to social science research through collaborative research programmes, seminars, etc.

The Working Paper Series provides an opportunity for ISEC faculty, visiting fellows and PhD scholars to discuss their ideas and research work before publication and to get feedback from their peer group. Papers selected for publication in the series present empirical analyses and generally deal with wider issues of public policy at a sectoral, regional or national level. These working papers undergo review but typically do not present final research results, and constitute works in progress.

MEASURING ENERGY USE EFFICIENCY IN PRESENCE OF UNDESIRABLE OUTPUT: AN APPLICATION OF DATA ENVELOPMENT ANALYSIS (DEA) TO INDIAN CEMENT INDUSTRY

Sabuj Kumar Mandal[1], **S. Madheswaran**[2]

Abstract

In most cases, energy use in the production of a given desirable output results in the generation of undesirable output also as a by-product. Thus, the aim of this paper is to estimate energy use efficiency in Indian cement industry considering energy related undesirable emission. Depending on the presence and absence of undesirable output and environmental regulation, three measures of efficiency have been estimated at the state level from 2000-01 to 2004-05 by applying Data Envelopment Analysis. The first measure of energy efficiency considers both desirable and undesirable output simultaneously and assumes weak disposability of undesirable output, i.e. presence of environmental regulation aimed at reducing pollution levels, while the second measure considers only desirable output. The third measure also considers both desirable and undesirable output but it assumes strong disposability of undesirable output, i.e. absence of environmental regulation. Energy efficiency is defined as the ability of the producer to reduce the energy input to the largest extent possible, conditional on the given level of output, non-energy inputs and undesirable output. A comparison of energy efficiency estimates from the first two measures reveals that energy efficiency estimates are biased if only desirable output is considered. Results from the third measure demonstrate that environmental regulation has a reinforcing effect on energy use efficiency.

Introduction

The Indian economy exhibited an impressive growth rate of 9.0% and 9.2% during 2005-06 and 2006-07, respectively (MoF 2007). Now, Government of India aims to achieve a GDP growth rate of 10% in the Eleventh Five-year Plan and maintain an average growth rate of about 8% in the next 15 years (Planning Commission 2002). However, energy being a vital element of production, such an ambitious vision of the Indian government would inadvertently call for a rapid increase in commercial energy demand at the rate of 5.2% per year in the near future (Government of India, Planning commission). Various estimates indicate that India would have to increase its primary energy supply by at least three to four times, and its electricity generation capacity by five to six times of the 2003/2004 levels by 2031. The *Integrated Energy Policy* report brought out by the Planning Commission estimates that in a 8% GDP growth scenario, India's total energy requirements would be in the range of 1536 MTOE (million

---

[1] Ph.D Fellow, Centre for Economic Studies and Policy, Institute for Social and Economic Change, Nagarabhavi, Bangalore- 560072, E-mail: sabujecon@gmail.com

[2] Professor, Centre for Economic Studies and Policy, Institute for Social and Economic Change, Nagarabhavi, Bangalore- 560072, E-mail: madhes@isec.ac.in

We are gateful to two anonymous referees for their constructive comments on an earlier draft of this paper.

tones of oil equivalent) to 1887 MTOE by 2031, under alternative scenarios of fuel and technological diffusion. Accordingly, India faces a formidable challenge in meeting its energy needs and providing adequate and affordable energy to all sectors of the economy in a sustainable manner.

In formulating its growth strategy for the future India has placed much emphasis on the growth of its manufacturing sector. The objective of the Indian planners is to achieve accelerated growth in the industrial sector (especially manufacturing) with a view to increasing industry's share in GDP as well as India's share in the worlds industrial output (Mukherjee, 2008). This 'industry driven growth' could be achieved only through massive utilization of energy as the Indian industrial sector consumes a large proportion of primary energy, accounting for 4.5% of industrial energy use worldwide (Gielen and Tailor, 2009). This share is projected to further increase as the economy expands rapidly. Under business as usual, industrial energy use is projected to rise faster than total final energy use. In such a situation it is necessary to put in substantial effort to enhance energy use efficiency of the industrial sector so as to cope with massive demand. With this background, this chapter makes an attempt to estimate the energy use efficiency in Indian cement industry which is the highest energy intensive industry among all other manufacturing industries in India.

Indian Cement Industry: Policy Changes and Massive Growth

Indian cement industry witnessed an unprecedented growth as a sequel to government's liberalization policy initiated in the form of partial decontrol in 1982, subsequently culminating in total decontrol in 1989. India has progressed from being the world's eighth largest cement producer in 1979-80 to being the second largest producer at present. However, this huge growth in cement production has been achieved through massive utilization of energy. Among the energy intensive industries in India, cement industry happens to be highly energy-intensive with the second highest share in fuel consumption (15.60%), after Iron and Steel (18.10%), mostly in the form of coal utilization. Its expansion could not have been achieved without a substantial increase in energy uses, mostly in the form of coal.

This has resulted in severe environmental problems not only in the coal mining regions but also around the cement producing plants. In addition, India's annual emission of green house gases from the cement industry has increased from 7.32 mt in 1993 to 16.73 mt in 2003 and its share in total carbon dioxide (CO_2) emission by India has increased from 3.3% to 4.8% during this period (ICRA, 2006).

The Indian government, recognizing the potential dangers of these environmental problems, has made several policy changes over the past 25 years or so to increase the energy use efficiency of the firms and thereby reducing the CO_2 emissions, with particular emphasis on energy-intensive heavy industries such as the cement industry. These policies include (i) disclosing companies' particulars on energy efficiency; (ii) accelerated depreciation of energy efficiency and pollution control equipment; (iii) setting up the Energy Management Centre under the Ministry of Energy; (iv) deregulation to promote industrial competitiveness; (v) energy price reforms to guide energy efficiency initiatives and encourage international competitiveness; and (vi) enforcement of the Energy Conservation Act and Electricity Act (Yang, 2006). As a result, the energy intensity (measured by the ratio of energy consumption to gross value of output) of this industry declined from 0.2446 in 1989-90 to 0.2241 in 2006-07. This decline in energy intensity can be attributed to the energy efficiency policies instituted by the government over this period. Although energy intensity of Indian Cement industry declined over the study period, it is still very high as compared to other energy intensive industries, such as Glass (0.1995), Aluminum (0.1601), Paper (0.1503), Fertilizers (0.1219), Iron &steel (0.0835) and much higher than aggregate manufacturing (0.0396). *So it is necessary to examine whether there is any scope for this industry to further improve its level of energy use efficiency and how does inclusion of undesirable output in the production function affect energy efficiency scores?*

The objective of this paper is to examine the levels of energy use efficiency of the Indian cement industry at the state level by incorporating both desirable and undesirable outputs. Specifically, our aim is to examine whether exclusion of undesirable output results in biased estimates of energy use efficiency. This paper also examines whether environmental regulation, aimed at curbing energy related carbon dioxide emissions, has any significant reinforcing impact on energy use efficiency.

The rest of the paper is organized as follows. Section 2 provides a brief review of literature related to the measurement of energy use efficiency. In section 3, we discuss the model of measuring energy use efficiency. Section 4 provides an explanation for the measurement of variables and data sources, followed by a discussion of the empirical results in section 5. The final section sums up main findings and policy implications.

A Brief Review of literature

In the literature, energy intensity is defined as the quantity of energy used per unit of output/activity (Mukherjee, 2008) or energy used per unit of value added (Mongia et al., 1999). The inverse of energy intensity is traditionally used as a measure of energy efficiency or energy productivity.

A rich body of literature has emerged to examining energy intensity across various end-use sectors. The focus of this body of research has been to explain changes in energy intensity by different contributing factors. To decompose energy consumption or aggregate energy intensity, index decomposition analysis (IDA) has been applied in several countries including Canada, New Zealand and the United States (EECA, 2006; NRC, 2006; OEERE, 2007: in Zhou and Ang, 2008). In the Indian context Bhattacharya and Paul (2001) used a complete decomposition technique to decompose the sectoral changes in energy consumption and energy intensity in India during 1980-1996. Their study reveals that though there was an improvement in aggregate energy intensity, agricultural sector was lagging behind. Paul and Bhattacharya (2004) used decomposition method to decompose the observed changes in the energy-related CO_2 emissions into four factors: pollution coefficient, energy intensity, structural changes and economic activity. The results of their study show that economic growth has the largest positive effect on CO_2 emission changes in all the major economic sectors. Emissions of CO_2 in industrial and transport sectors show a decreasing trend due to improved efficiency and fuel switching. The study by Nag and Parikh (2000) also tries to analyze the impact of different factors such as activity levels, structural changes, energy intensity, and fuel mix and fuel quality on the changes in aggregate carbon intensity of the economy for the period 1970-1995.

It has been found that most of the IDA based studies concentrated on measuring energy efficiency of a specific entity, such as a country or a specific energy intensive sector and very few of them concentrated on measuring energy efficiency across sectors (Zhou and Ang, 2008). IDA based approach considers inverse of energy intensity as a proxy for energy use efficiency and tries to explain variation in energy intensity by several factors. But inverse of energy intensity is an imperfect proxy for energy use efficiency because, energy intensity may decline not only due to an improvement in energy use efficiency but also some other factors like changes in the production process from being more energy intensive to less energy intensive etc. Moreover, by concentrating on a specific entity, IDA based approach can't demonstrate the possibility of achieving higher energy use efficiency compared to other best performing counterparts. Data envelopment analysis (DEA) has gained popularity in energy efficiency analysis by serving this purpose.

DEA, originally proposed by Charnes et al. (1978), is a non-parametric frontier technique where efficiency of a particular entity is measured by its distance from the best practice frontier constructed by the best performing entities within the group. DEA measure of energy use efficiency has two major advantages as compared to the traditional definition, "the ratio of energy services to energy input". *First*, DEA accommodates multiple inputs (energy and non-energy inputs) and multiple outputs in the production process. *Secondly*, DEA can also accommodate the objectives of decision making units (DMUs) in assessing energy use efficiency. These advantages have led to wide application of DEA tools in the energy efficiency analysis in recent literature of energy economics (see Zhou et al., 2008 for a detail survey). Notable studies include Boyd and Pang (2000), where relationship between energy efficiency and productivity is established in the context of glass industry, using plant level data from the Census Bureau. Ramanathan (2000) used DEA to compare the energy efficiencies of alternative transport modes in India and Ramanathan (2005) used DEA to study efficiency in terms of energy consumption and carbon dioxide emission from 17 countries of the Middle East and North Africa. Onut and Soner (2006) applied DEA to evaluate energy use efficiencies of five-star hotels in Turkey, Hu and Kao (2007) used DEA to find energy-saving targets for 17 APEC economies, Wei et al. (2007) used DEA-based Malmquist index to examine the energy efficiency change in China's iron and steel sector, Azadeh et al.(2007) use integrated DEA approach to assessing total energy efficiency and optimization in energy intensive manufacturing sectors of OECD countries, Grosche (2008) used DEA to measure energy efficiency improvements of US single-family homes between 1997 and 2001. Recently, Mukaherjee (2008) use several DEA models for measuring energy use efficiency of the manufacturing sectors in US and India.

A common limitation found in the previously advocated DEA models in energy efficiency analysis relates to the absence of undesirable output in the production process (Zhou and Ang, 2008). Energy use, however, generates undesirable output also, e.g. CO_2 emissions as a by-product of cement. Thus, leaving out undesirable output does not seem to provide a complete spectrum of the production process. Therefore, Zhou and Ang (2008) evaluate energy use efficiency within a joint production framework of both desirable and undesirable output.

Our analysis departs from the above mentioned study in the following two aspects. *First*, while Zhou and Ang (2008) estimate energy efficiency considering both desirable and undesirable output, we estimate energy use efficiency with and without undesirable output to examine whether omitting undesirable output generates any bias in energy use efficiency or not. *Secondly*, while Zhou and Ang (2008) assume weak disposability with respect to the disposal of undesirable output, we assume both weak and strong disposability of undesirable output. Here, weak disposability of undesirable output implies presence of environmental regulation which makes disposal of undesirable output a costly activity, while strong disposability implies absence of environmental regulation inducing free disposal of undesirable output. Disposal of undesirable output, in presence of environmental regulation, becomes costly because, for controlling pollution, firms are required to divert some of their productive resources which could otherwise be used for the production of desirable output. The underlying rationale for assuming both weak and strong disposability is to examine the role of environmental regulation in reducing energy related undesirable emissions even when firms are already subjected to energy conservation regulation. If energy conservation regulation could lead to higher energy use efficiency, it would automatically lead to lower levels of emission. Now, imposition of environmental regulation, with energy conservation regulation already existing, can be justified if the new regulation could further improve firms' energy use efficiency by reinforcing the previous one; otherwise, an additional regulation would lead to increased transaction cost for the monitoring authority. The proposed models are applied to Indian cement industry to measure energy use efficiency.

We have considered Indian cement industry because it turns out to be a classic example of the scenario described earlier. Since this industry, along with others, has been notified as 'designated consumer' of energy under the Energy Conservation Act of 2001, we intend to examine the impact of introducing environmental regulation on energy use efficiency considering the fact that the industry is already under Energy Conservation Act. Moreover, cement industry produces 5% of the world's total carbon dioxide as an undesirable by-product, making the cement industry an important sector for analyzing carbon dioxide emission mitigation strategies.

Methodology

Assume a production process, in which a vector of energy input, **e,** and a vector of non-energy input, **x** is used to produce a vector of desirable output, **y** and a vector of undesirable output, **z.** Following Banker et al. (1984), we can define a output set, S, characterized by a convex hull:

$$S = \{(y, e, x, z) : x \text{ and } e \text{ can produce } y \text{ and } z\}.$$

The output set, in presence of undesirable output, is assumed to have the following properties. The first is "null-jointness" which implies that production of a positive amount of desirable output must be accompanied by some amount of undesirable one. Formally, null-jointness implies that:

$$(y, e, x, z) \in S; z = 0 \Rightarrow y = 0 \quad \text{(a)}$$

The second assumption is that desirable and undesirable outputs are jointly weakly disposable:

$$\text{If } (y, e, x, z) \in S \text{ and } 0 \le q \le 1, \text{ then } (qy, e, x, qz) \in S \quad \text{(b)}$$

This implies that a reduction in undesirable output is not possible without reducing the desirable output. The third assumption is known as strong disposability of desirable output :

If $(y, e, x, z) \in S$ and $y^0 \leq y$, then $(y^0, e, x, z) \in S$ (c)

This implies that desirable output can be reduced without reducing the undesirable one. So in our model, desirable and undesirable outputs are treated asymmetrically in terms of their disposal.

We define the best practice production frontier as the surface of S, and can define a DMU's energy use (in) efficiency by measuring the DMU's distance of the frontier. Following Shephard (1953, 1970) and *Färe* and Primont (1995), the input distance function can be defined as:

$$D(y, z, x, e) = \max\left\{q : \left(y, z, x, \frac{e}{q}\right) \in S, q \in \Re_+\right\}.$$

In other words, the value of the input distance function measures the maximum amount by which the energy input vector can be deflated by a factor q, given the non-energy input vector, desirable output vector and undesirable output vector. The reciprocal of the value of the input distance function can be defined as input oriented Farrell measure of *technical efficiency* (1957):

Technical efficiency (TE) = $\dfrac{1}{D(y, z, x, e)} = \dfrac{1}{q}$.

If we define $q = \dfrac{1}{b}$, then maximization of q is equivalent to minimization of b. The optimum value of b can be defined as a performance index in measuring energy use efficiency and can be obtained by solving the linear programming problem (1):

DEA model (1):

$$b^* = \min b$$

s.t. $\sum_{k=1}^{K} x_{nk} l_k \leq x_{n0}$, $n = 1,2,............N$ (no. of non-energy inputs) (1a)

$\sum_{k=1}^{K} e_k l_k \leq b e_0$ (1b)

$\sum_{k=1}^{K} y_{mk} l_k \geq y_{m0}$, $m = 1,2,............M$ (no. of desirable output) (1c)

$\sum_{k=1}^{K} z_{jk} l_k = z_{j0}$, $j = 1,2,...............J$ (no. of undesirable output) (1d)

$\sum_{k=1}^{K} l_k = 1$, $k = 1,2,...............K$ (no. of DMUs) (1e)

Where k is indexed as firm and the subscript "0" represents the DMU under evaluation. Model (1) attempts to proportionately contract the amounts of energy inputs to the largest extent possible. But this reduction does not ensure the reduction of quantities of other inputs also. However, inequality (1a) ensures that the other inputs are not increased at the optimal. Further, inequality (1c) ensures that the optimal output is not lower than what is actually being produced. The nature of environmental regulation is represented by inequality (1d). It represents weak disposability of undesirable output, implying that firms face environmental regulation for reducing the same. Finally, inequality (1e) indicates the technology exhibiting variable returns to scale (VRS).

In the second model, we consider only desirable output while estimating energy use efficiency. In absence of undesirable output, disposability assumption is no longer required. So if we omit (1d) from model (1), it would be a representation of model (2), providing our second measure of energy use efficiency.

Now if we assume that there is no environmental regulation, the optimization will change as follows:

DEA model (3)

$$b^* = \min b$$

s.t. $$\sum_{k=1}^{K} x_{nk} l_k \le x_{n0}, \qquad n = 1,2,\ldots\ldots N \tag{3a}$$

$$\sum_{k=1}^{K} e_k l_k \le b e_0 \tag{3b}$$

$$\sum_{k=1}^{K} y_{mk} l_k \ge y_{m0}, \qquad m = 1,2,\ldots\ldots M \tag{3c}$$

$$\sum_{k=1}^{K} z_{jk} l_k \le z_{j0}, \qquad j = 1,2,\ldots\ldots J \tag{3d}$$

$$\sum_{k=1}^{K} l_k = 1, \qquad k = 1,2,\ldots\ldots K \tag{3e}$$

The only difference between model (1) and model (3) is that we have changed the equality (1d) in model (1) into inequality (3d) in model (3). Inequality (3d) implies strong disposability of undesirable output in absence of environmental regulation. So in model (3), firms' objective is to reduce the energy input as much as possible without bothering about pollution. Model (3) provides our third measure of energy use efficiency.

Construction of the Production Frontier

Next, we need to discuss the construction of the production frontier based on which efficiency is measured. In the DEA literature, three types of frontier have been proposed to evaluate efficiency in a panel-data framework. First one is the standard *Contemporaneous Frontier* where technology in each time period t is presented by the output sets $P^t(x)$ and it is assumed that $P^t(x)$ are determined by the observations on inputs and outputs corresponding to period t only. The second type of frontier is called *Intertemporal Frontier* where $P^t(x)$ are determined by taking into account inputs and outputs of all the periods of the panel at a time. The third one is called *Sequential Frontier* which assumes all current and past observations as feasible (See Tulkens and Eeckaut, 1995 for detailed discussion about different DEA frontiers) . Then the production possibility set expands (or remain constant) from one time period to the next. Conceptually, a sequential frontier amounts to assuming that there is no technical regress, and that any technical regress will be assimilated with inefficiency by this construction (Mukherjee, 2008).[1]

In the context of manufacturing industries, in which technological regress is unlikely to occur, DEA with *Sequential Frontier* provides a more adequate measure for the possibility of technical changes than standard *Contemporaneous Frontier* (Shestalova, 2003). Therefore, in our study, we have also used the *Sequential Frontier* to accommodate the possibility of technical change that has taken place in Indian cement industry during the study period. Starting with a reference sample of 32 observations for the year 1989, we successively enlarge the reference sample by including the observations of one more year. For example, sample firms for 1990 consist of firms available in 1989 plus the existing firms in 1990. At the last period, we have considered observations of the last period and all the observations of the previous periods, making total number of observations 887 at the last period. To provide robustness of our result, we have estimated efficiency scores from the *Contemporaneous Frontier* also and compared the efficiency scores obtained from *Sequential Frontier.* Theoretically, contemporaneous efficiency scores should be higher than sequential efficiency scores, because in case of sequential frontier, sample size increases in every successive period and as a result probability of being efficient decreases for an entity.

Data Consolidation

We have attempted to evaluate energy use efficiency performance of Indian cement industry at the state level. The state- level data for the period 2000-01 to 2004-05 has been extracted from the Annual Survey of Industries (3 digit 98 NIC code 269). The study covers 20 major cement producing states for the analysis. We conceptualize a two output, four input production function for the cement industry in India. Desirable output is measured by value of ex-factory products and by- products, deflated by the whole sale price index for cement and undesirable output by CO_2 emissions (in tonnes). The inputs include (i) capital, (ii) energy, (iii) labor, (iv) raw materials. The capital input is measured as a stock by taking the value of gross fixed capital, deflated by the wholesale price index for machinery and machine tools. Labor is measured by total number of persons employed. Energy is measured in terms of expenditure on fuels deflated by the wholesale price index for fuel, power, light and lubricants.

Similarly, the material input is measured by the expenditure on materials, deflated by wholesale price index for non-metallic mineral products. Then, all inputs and outputs are divided by the total number of factories in a particular state so that we can examine environmental efficiency of a 'typical firm' within each state.[2] Descriptive statistics of the variables are presented in Table 1.

Table 1: Descriptive statistics of the variables

Variable	Mean	Std. Dev.	Min	Max
Output	3.46	4.74	0.19	23.09
CO_2	0.24	0.45	0.0025	1.84
Capital	3.82	9.05	0.12	72.62
Energy	0.62	1.02	0.0035	4.34
Labor	41.00	22.00	15.00	87.00
Material	1.33	1.13	0.049	5.23

Note: All nominal variables are converted into real variables with 1993-94 as the base. Output, capital, energy and material are in Rs.Lakh INR (1 USD =45.317 in 2004); labor is in number; CO_2 is in tonnes.

Calculation of CO_2 emissions[3]

In the cement industry, two types of carbon-dioxide emissions can be observed: one is process related emission and the other energy related emission. In the absence of information regarding process related CO_2 emissions, in the present study, we have considered CO_2 emissions generated by the fuel combustion, particularly coal because it constitutes the major share in the total fuel consumption by the cement industry besides being a major source of energy related CO_2 emissions. Contribution of other fuels to CO_2 emissions is negligible. CO_2 emission is estimated by taking into account the carbon emission factor of coal (25.8), the fraction of oxidized carbon of coal (0.98) and molecular weight ratio of carbon dioxide to carbon (44/12). Following the method of the IPCC[4] (1995), the sectoral CO_2 emission of the i th fuel is obtained from the following relationship:

$$EC_i(t) = C_i(t) \times O_i \times N_i \times M,$$

where $EC_i(t)$ is the carbon dioxide emission of the ith fuel at time t; $C_i(t)$ is the consumption of ith fuel at time t; O_i is the carbon emission factor of the ith fuel; N_i is the fraction of carbon oxidized of the ith fuel and M is the molecular weight ratio of carbon dioxide to carbon (44/12)

According to IPCC (1995) guidelines, the following steps have been carried out to calculate CO_2 emissions from particular fuel consumption.

(A) Energy consumption data in million tones of oil equivalent (MTOE) is converted into tera joules (TJ) unit using standard conversion factors.

(B) Total carbon emission (tones of carbon), TC, is estimated by multiplying fuel the fuel consumption (tera joules) by the carbon emission factor (TC/TJ) of the corresponding fuel.

(C) Total carbon emission is then multiplied by the fraction of carbon oxidized and the molecular weight ratio of carbon dioxide to carbon to arrive at the total carbon dioxide emitted from fuel combustion.

Empirical Results

We have first estimated energy use efficiency from model (1) which considers both desirable and undesirable output and assumes weak disposability regarding the disposal of undesirable output. Results are presented in Table 2. The average energy efficiency of the states under study during the sample period was 0.8777 implying that it would be possible to reduce the energy input by a maximum amount of 12.23% and still produce the given level of output, without using more of any other inputs. However, efficiency level varies across states. While Chattisgarh Gujarat, Kerala, Punjab, Uttaranchal, Uttar Pradesh, Himachal Pradesh, and West Bengal demonstrated 100% technical efficiency each year, Tamil Nadu, Haryana, and Jammu& Kashmir achieved technical efficiency close to 100%. On the other hand, states like Andhra Pradesh, Karnataka, Maharastra, Madhya Pradesh and Rajasthan were found with the lowest measure of technical efficiency.

Table 2: Energy use efficiency based on weak disposability assumption of undesirable output

State	2000-01	2001-02	2002-03	2003-04	2004-05	Annual average
AP	0.8367	0.0853	0.1156	0.1622	0.2434	0.2886
AS	1.0000	0.8342	0.6312	0.6561	1.0000	0.8243
BI	1.0000	1.0000	0.8276	0.8065	1.0000	0.9268
CT	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
GU	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
HA	1.0000	0.6663	1.0000	1.0000	1.0000	0.9333
H.P	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
JK	1.0000	1.0000	1.0000	1.0000	0.9471	0.9894
JH	0.7412	0.4850	0.7896	0.9222	1.0000	0.7876
KA	0.7571	0.5670	0.5671	0.7361	0.9067	0.7068
KE	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
MP	0.8224	1.0000	0.8441	0.8481	0.9848	0.8999
MA	1.0000	0.4939	0.7568	1.0000	0.7878	0.8077
OR	1.0000	0.5247	0.8915	0.9932	0.7780	0.8375
PU	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
RA	0.7200	1.0000	0.5205	0.3688	0.5658	0.6350
TN	1.0000	0.9462	1.0000	1.0000	0.6359	0.9164
UP	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
UT	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
WB	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
State Average	0.9439	0.8301	0.8472	0.8747	0.8925	0.8777

Note: (a) AP- Andhra Pradesh, AS- Assam, BI- Bihar, CT- Chattisgarh, GU- Gujarat, HA - Haryana, HP- Himachal Pradesh, JK- Jammu & Kashmir, JH- Jharkhand, KA - Karnataka, KE- Kerala, MP- Madhya Pradesh, MA- Maharashtra, OR- Orissa, PU-Punjab, RA-Rajasthan, TA - Tamil Nadu, UP- Uttar Pradesh, UT-Uttaranchal, WB-West Bengal.
(b) State average is the average efficiency of the 20 states for a given year. Annual average is the average for a given state over 5 years.

Average energy efficiency was 0.9439 in 2000-01 but declined to 0.8925 in 2004-05. Next we have estimated energy use efficiency without considering undesirable output and estimates are presented in Table 3.

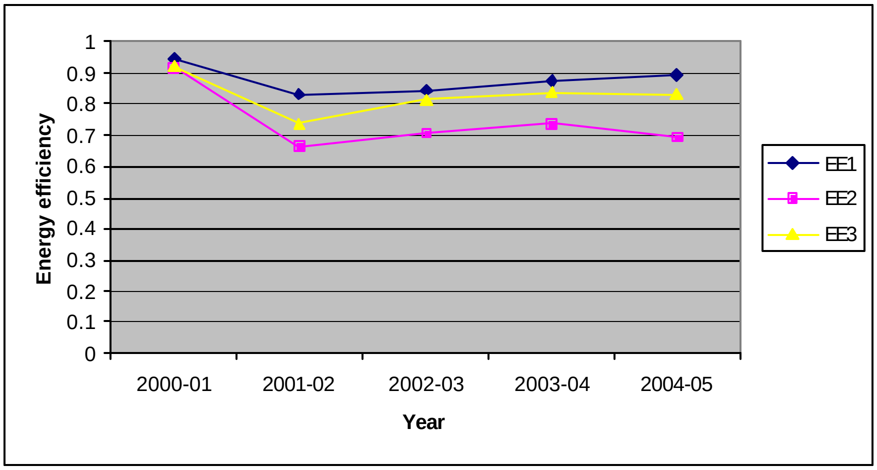
Table 3: Energy use efficiency without considering undesirable output

State	2000 -01	2001-02	2002-03	2003-04	2004-05	Annual average
AP	0.8177	0.0847	0.0674	0.0928	0.1368	0.2399
AS	1.0000	0.694	0.6291	0.6474	0.9576	0.7856
BI	1.0000	0.8184	0.6792	0.8013	1.0000	0.8598
CT	0.9317	0.6842	0.7784	0.7942	0.8209	0.8019
GU	1.0000	1.0000	0.2262	0.5391	0.4382	0.6407
HA	0.8724	0.3556	0.5067	0.536	0.2526	0.5046
HP	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
JK	1.0000	1.0000	1.0000	1.0000	0.6819	0.9364
JH	0.7072	0.4846	0.7372	0.8242	1.0000	0.7507
KA	0.7003	0.2071	0.4782	0.5682	0.6127	0.5133
KE	1.0000	0.8771	0.6639	0.609	0.6542	0.7608
MP	0.7081	0.6444	0.7791	0.7574	0.7339	0.7246
MA	0.8246	0.1678	0.7232	0.9619	0.5069	0.6369
OR	1.0000	0.3752	0.8327	0.9186	0.705	0.7663
PU	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
RA	0.7146	1.0000	0.5152	0.3549	0.4116	0.5993
TN	1.0000	0.2388	1.0000	1.0000	0.4669	0.7412
UP	1.0000	0.8123	0.8241	0.7428	1.0000	0.8758
UT	1.0000	0.8677	0.6727	0.5626	0.5329	0.7272
WB	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
State average	0.9138	0.6656	0.7057	0.7355	0.6956	0.7432

While comparing the efficiency scores presented in Table 2 and Table 3, it can be seen that average energy efficiency measure based on both desirable and undesirable output is substantially higher than that obtained from the model that considers only desirable output and leave out the undesirable output. In order to verify whether omitting undesirable output results in biased estimates of energy efficiency, the Wilcoxon Rank Sum test[5] has been conducted. The null hypothesis is that efficiency scores obtained from the two models contain the same population of relative frequency distribution, whereas, alternative hypothesis is that mean energy efficiency score obtained from with undesirable model is significantly different from the one obtained without considering undesirable output. The value of Wilcoxon statistic is 153 and the value of two tailed 'p' statistic is less than 0.0001. Therefore, the null hypothesis can be rejected at 1% level, implying that omitting undesirable output results in biased energy efficiency estimates and this bias is statistically significant.

While model (1) represents energy input minimization in the presence of environmental regulation, model (3) represents absence of environmental regulation implying strong disposability of undesirable output. The estimates of energy efficiency obtained from model (3) are presented in Table 4. The average energy use efficiency achieved by the states under strong disposability is 0.8280.

Fig. 1: Change in the average energy efficiency performance for the 18 Indian states over time.



Note: EE1, EE2 and EE3 are the first, second and third measure of energy use efficiency respectively.

It can be seen from Fig.1 that India's cement industry experienced a sharp decline in energy use efficiency in 2001-02 compared to the initial period. After that, efficiency performance shows an increasing trend but ends up with a lower value at 2004-05 compared to the initial period 2000-01. This observed trend is similar for all three measures of energy use efficiency.

In order to verify whether energy efficiency scores, based on weak disposability assumption, are significantly different from those obtained from strong disposability assumption, the Wilcoxon Rank Sum test has been conducted again. The null hypothesis is that efficiency scores obtained from the two models contain the same population of relative frequency distribution, whereas, alternative hypothesis is that mean efficiency score obtained from weak disposability assumption is higher than that obtained from strong disposability assumption. The value of Wilcoxon statistic is 2 and the value of one tailed 'p' statistic is 0.0007.

Table 4: Energy efficiency based on strong disposability assumption

State	2000-01	2001-02	2002-03	2003-04	2004-05	Annual average
AP	0.8177	0.0847	0.0674	0.0928	0.1368	0.2399
AS	1.0000	0.6940	0.6312	0.6561	0.9576	0.7878
BI	1.0000	0.8184	0.6792	0.8013	1.0000	0.8598
CT	0.9317	0.6842	0.7784	0.7942	0.8209	0.8019
GU	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
HA	1.0000	0.6663	1.0000	1.0000	1.0000	0.9333
HP	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
JK	1.0000	1.0000	1.0000	1.0000	0.9471	0.9894
JH	0.7072	0.4850	0.7372	0.8242	1.0000	0.7507
KA	0.7003	0.2071	0.4782	0.5682	0.6127	0.5133
KE	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
MP	0.7081	0.6444	0.7791	0.7574	0.7339	0.7246
MA	0.8246	0.1678	0.7568	0.9619	0.5069	0.6436
OR	1.0000	0.3752	0.8327	0.9186	0.7050	0.7663
PU	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
RA	0.7146	1.0000	0.5152	0.3688	0.5658	0.6329
TN	1.0000	0.9462	1.0000	1.0000	0.6359	0.9164
UP	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
UT	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
WB	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
State Average	0.9202	0.7387	0.8128	0.8372	0.8311	0.8280

Therefore, the null hypothesis can be rejected at 1% level, implying that average energy use efficiency in presence of environmental regulation is higher than that obtained in absence of it. So, environment al regulation may yield double dividends here, one in terms of lower pollution level and the other higher energy use efficiency.

Although at the aggregate level, environmental regulation yields higher average energy efficiency, impact of regulation is not the same across the states. Table 5 presents energy use efficiency under strong disposability, weak disposability, and improvement in energy use efficiency, if any, under weak disposability assumption. States like Gujarat, Kerala, Punjab, Uttaranchal, Uttar Pradesh, Himachal Pradesh, and West Bengal are found operating on the best-practice frontier through out the study period irrespective of the existence of environmental regulation or otherwise. Average efficiency remains the same in both the situations for Haryana and Tamil Nadu also, implying that environmental regulation is non-binding for these states. For all other remaining states, environmental regulation has been found to bring about significant improvement in terms of energy use efficiency.

Table 5: Differences in mean energy efficiency under strong and weak disposability

State	Strong	Weak	Improvement
AP	0.2399	0.2886	0.0488
AS	0.7878	0.8243	0.0365
BI	0.8598	0.9268	0.0670
CT	0.8019	1.0000	0.1981
GU	1.0000	1.0000	0.0000
HA	0.9333	0.9333	0.0000
HP	1.0000	1.0000	0.0000
JK	0.9894	0.9894	0.0000
JH	0.7507	0.7876	0.0369
KA	0.5133	0.7068	0.1935
KE	1.0000	1.0000	0.0000
MP	0.7246	0.8999	0.1753
MA	0.6436	0.8077	0.1641
OR	0.7663	0.8375	0.0712
PU	1.0000	1.0000	0.0000
RA	0.6329	0.6350	0.0022
TN	0.9164	0.9164	0.0000
UP	1.0000	1.0000	0.0000
UT	1.0000	1.0000	0.0000
WB	1.0000	1.0000	0.0000

Note: Improvement in efficiency has been calculated by taking the difference between weak and strong efficiency scores.

Conclusion

This paper makes an attempt to estimate energy use efficiency of the Indian cement industry at the state level for the period 2000-01 to 2005-05, using Data Envelopment Analysis (DEA). Since, cement industry is a major producer of environmentally detrimental carbon dioxide gas as an undesirable by-product, a special emphasis is given to that undesirable output while evaluating energy use efficiency. The major focus of the study has been to answer two empirical questions. First, whether exclusion of undesirable output from the analysis results in biased estimates of energy use efficiency. Secondly, whether environmental regulation has any reinforcing impact on energy use efficiency or not. To answer the first question, we have estimated energy use efficiency considering both desirable and undesirable output in the first case and only desirable output in the other to examine whether omitting undesirable output results in biased estimates of energy use efficiency. To answer the second question we have assumed both weak and strong disposability with respect to disposal of undesirable output to examine whether environmental regulation aimed at reducing energy related emissions is able to bring about further improvement in energy use efficiency also. Empirical results demonstrate that energy efficiency measures are biased if only desirable output is considered, implying that undesirable output indeed matters while evaluating energy use efficiency Moreover, average energy use efficiency is higher in presence environmental regulation than that obtained in absence of it. Therefore, we conclude by claiming that environmental regulation has the potential in terms of positively impacting energy use efficiency in addition to reducing higher pollution levels, implying that if we formulate our model correctly with introduction of environmental regulation it will result in higher efficiency scores. Higher energy use efficiency in presence environmental regulation suggests that the government can introduce environmental regulation in the form of institutional instruments such as pollution taxes which would induce the firms to internalize the external costs (including environmental) of energy consumption.

End Notes

[1] The assumption of no technical regress seems to make sense for the sample years under study during which most of the cement companies did experienced significant technological improvement.

[2] This approximation of firm level data from of the industry is not absolutely perfect because, here we assume that all firms in a particular state produce equally using equal amount of inputs. In the absence of firm level data within the states, we have used this kind of approximation. Mukherjee (2008), in the context of Indian manufacturing, also used the same approximation.

[3] This section draws heavily on Paul and Bhattacharya (2004).

[4] Intergovernmental Panel for Climate Change.

[5] Wilcoxon Rank-Sum test is a nonparametric alternative to the two sample t-test. This test is based solely on the order in which the observations from the two samples fall. Since DEA efficiency scores are obtained from nonparametric linear programming model, we have used this nonparametric alternative for t-test.

References

Azadeh, A., Amalnick, M.S., Ghaderi, S.F., Asadzadeh, S.M., 2007. An integrated DEA PCA numerical taxonomy approach for energy efficiency assessment and consumption optimization in energy intensive manufacturing sectors. *Energy Policy* 35, 3792-806.

Bhattacharya, R.N., Paul, S., 2001. Sectoral changes in consumption and intensity of energy in India. *Indian Economic Review* 36(2), 381-92.

Boyd, G.A.,Pang, J.X., 2000. Estimating the linkage between energy efficiency and productivity. *Energy Policy* 28, 289-96.

Charnes,A., Cooper, W.W., Rhodes,E., 1978. Measuring the efficiency of decision making units. *European journal of Operational Research* 3, 392-444.

Energy Efficiency and Conservation Authority (EECA), 2006. Energy Efficiency and Renewable Energy in New Zealand, Year Four Report: March 2001 to 2005.

Fare, R., Primont, D., 1995. Multi-output production and duality: theory and applications. Kluwer Academic publisher, Norwell, MA.

Farrell, M.J., 1957. The measurement of productive efficiency. Journal of Royal Statistical Society Series A 120 (III): 253-81.

Gielen,D., Tailor,P.,2009. Indicators for industrial energy efficiency in India. *Energy* 34, 962-69.

Government of India, Planning Commission, Ninth and Tenth Five Year Plan Documents.

Grösche, P., 2008. Measuring Residential Energy Efficiency Improvements with DEA. Ruhr Economic Paper No. 60. Available at SSRN: http://ssrn.com/abstract=1280878.

Hu, J.L., Kao, C.H., 2007. Efficient energy-saving targets for APEC economies. *Energy Policy* 35, 373-82.

ICRA Sector Analysis (2006). The Cement Industry in India.

IPCC, 1995. Greenhouse gas inventory: IPCC Guidelines for National Greenhouse Gas Inventories, United Kingdom Meteorological Office, Bracknell, England.

MoF, 2007. Ministry of Finance, Economic Survey 2006/07. New Delhi: MoF, Government of India.

Mongia,P., Sathaye,J., 1998. Productivity Growth and Technical Change in India's Energy Intensive industries: A Survey. Energy Analysis Program, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory Berkeley, CA 94720.

Mukherjee, K., 2008. Energy use efficiency in the Indian manufacturing sector: An interstate analysis. *Energy Policy* 36, 662-72.

Mukherjee, K., 2008. Energy use efficiency in U.S. manufacturing: A nonparametric analysis. *Energy Economics* 30, 76-97.

Natural Resource Canada (NRC), 2006. Energy Efficiency Trends in Canada: 1990 to 2004. Office of Energy Efficiency, Ottawa.

Office of Energy Efficiency and Renewable Energy (OEERE), 2007. Indicators of Energy Intensities in the United States.

Onut, S., Soner, S., 2006. Energy efficiency assessment for the Antalya Region hotels in Turkey. *Energy and Buildings* 38, 964-71.

Paul, S., Bhattacharya, R.N., 2004. CO_2 emission from energy use in India : a decomposition analysis. *Energy Policy* 32, 585-93.

Ramanathan, R., 2000. A holistic approach to compare energy efficiencies of different transport modes. *Energy Policy* 28, 743-47.

Ramanathan, R., 2005. An analysis of energy consumption and carbon dioxide emissions in countries of the Middle East and North Africa. Energy 30, 2831-42.

Shephard, R.W., 1953. Cost and production functions. Princeton University Press, Princeton.

Shephard, R.W., 1970. Theory of cost and production functions. Princeton University Press, Princeton.

Shestalova, V., 2003. Sequential Malmquist Indices of Productivity Growth: An Application to OECD Industrial Activities. *Journal of Productivity Analysis* 19, 211-26.

Tulkens, H. and P. V. Eeckaut. (1995). "Non-Parametric Efficiency, Progress and Regress Measure for Panel Data: Methodological Aspects." *European Journal of Operational Research* 80, 474-99.

Wei, Y.M., Liao,H., Fan, Y., 2007. An empirical analysis of energy efficiency in China's iron and steel sector. Energy 32, 2262-70.

Yang, M., 2006. Energy efficiency policy impact in India: case study of investment in industrial energy efficiency. *Energy Policy* 34, 3104-14.

Zhou, P., Ang, B.W., 2008. Linear programming models for measuring economy-wide energy efficiency performance. *Energy Policy* 38, 2911-16.

Zhou, P., Ang, B.W., Poh, K.L., 2008. A survey of data envelopment analysis in energy and environmental studies. *European Journal of Operational Research* 189, 1-18.

Recent Working Papers

171 **Community Contribution for Enviornmental Sanitation: Myth or Reality?**
Veerashekharappa

172 **Does Repayment Indicate the Success of Micro-Finance Programme?**
Emil Mathew

173 **Community Participation in Rural Water Supply: An Analysis Using Household Data from North Kerala**
Nisha K R

174 **Urbanisation in a Forward Looking Statpe of India: Patterns Issues and Policy**
G S Sastry

175 **Contract Labour Act in India: A Pragmatic View**
Meenakshi Rajeev

176 **Issues of Unaccounted for Water in the Urban Water Sector**
G S Sastry

177 **Liberalisation and Efficiency of Indian Commercial Banks: A Stochastic Frontier Analysis**
H P Mahesh

178 **Power Sharing in the Panchayats of Orissa**
Pratyusna Patnaik

179 **Can Career-Minded Young Women Reverse Gender Discrimination?**
Alice W Clark and T V Sekher

180 **People's Participation in Environmental Protection: A Case Study of Patancheru**
Geetanjoy Sahu

181 **Efficiency and Bureaucracy**
Anitha V

182 **Reproductive and Child Health Programmes in the Urban Slums of Bangalore City: A Study on Unmet Needs fro Family Welfare Services**
C S Veeramatha

183 **Demographic Change and Gender Inequality: A Comparative Study of Madhya Pradesh and Karnataka**
C M Lakshmana

184 **Increasing Ground Water Dependency and Declinin Water Quality in Urban Water Supply: A Comparative Analysis of Four South Indian Cities**
K V Raju, N Latha and S Manasi

185 **Impact of Land Use Regulations on Suburbanisation: Evidence from India's Cities**
Kala Seetharam Sridhar

186 **Socio-Economic Determinants of Women Leadeship at the Grass - Roots**
K C Smitha

187 **Groundwater for Agriculural Use in India: An Institutional Perspective**
Sarbani Mukherjee

188 **Comparative Study of Traditional Vs. Scientific Shrimp Farming in West Bengal: A Technical Efficiency Analysis**
Poulomi Bhattacharya

189 **Urban and Service Delivery in Bangalore: Public-Private Partnership**
Smitha K C and Sangita S N

190 **Social Capital in Forest Governance Regimes**
Sangita S N

191 **Agriculture in Karnataka: A Historical View After the Fall of Serirangapatana**
R S Deshpande and Malini Tantri

192 **Personality Traits and Administrators**
Anitha V

193 **Sustainability of Indian Agriculture: Towards an Assessment**
V M Rao

194 **Emerging Development Issues of Greater Bangalore**
G S Sastry

195 **Rural Infrastructure Development Fund: Need for a Track Change**
Meenakshi Rajeev

196 **Emerging Ground Water Crisis in Urban Areas — A Case Study of Ward No. 39, Bangalore City**
K V Raju, S Manasi and N Latha

197 **In Pursuit of India's Export earning advantage: An Assessment of IT-Enabled Services Industry**
Meenakshi Rajeev

198 **A Patriarchal Link to HIV/AIDS in India**
Skylab Sahu

199 **Collective Action and Property Rights: Some Critical Issues in the Context of Karnataka**
K G Gayathri Devi

200 **State, Society and Inclusive Governance: Community Forests in Andhra Pradesh, Karnataka and Orissa**
S N Sangita

201 **Urban Poverty and Links with the Environment: An Exploration**
K G Gayathri Devi

202 **Groundwater Over-exploitation, Costs and Adoption Measures in the Central Dry Zone of Karnataka**
Anantha K H and K V Raju

203 **Changing Child Population: Growth, Trends and Levels in Karnataka**
C M Lakshmana

204 **Awareness About HIV/AIDS Among Karnataka Woment: An Analysis of RCH 2002-04 Data**
K S Umamani

205 **The Microfinance Promise in Financial Inclusion and Welfare of the Poor: Evidence from Karnataka, India**
Naveen K Shetty

206 **Structure of Central Himalayan Forests Under Different Management Regimes: An Empirical Study**
Sunil Nautiyal

207 **Poverty and Natural Resources: Measuring the Links (Some Issues in the Context of Karnataka)**
K G Gayathri Devi

208 Federalism and Decentralisation in India: Andhra Pradesh and Tamil Nadu
V Anil Kumar

209 Capital, 'Development' and Canal Irrigation in Colonial India
Patric McGinn

210 Gender, Ecology and Development in Karnataka: Situation and Tasks Ahead
K G Gayathri Devi

211 Greenhouse Gases Emission and Potential Corbon Sequestration: A Case Study of Semi-Arid Area in South India
Lenin Babu and K V Raju

212 Emerging Trends in Managing Drinking Water – Case Studies of Coastal Villages in Karnataka
Manasi S, Latha N and K V Raju

213 Spatio-Temporal Analysis of Forests Under Different Management Regimes Using Landsat and IRS Images
Sunil Nautiyal

214 Traditional Knowledge System (Medicine): A Case Study of Arakalgud Taluk, Karnataka, India
B K Harish, K Lenin Babu

215 Tribal Movement in Orissa: A Struggle Against Modernisation?
Patibandla Srikant

216 Technological Progress, Scale Effect and Total Factor Productivity Growth in Indian Cement Industry: Panel Estimation of Stochastic Production Frontier
Sabuj Kumar Mandal and S Madheswaran

217 Fisheries and Livelihoods in Tungabhadra Basin, India: Current Status and Future Possibilities
Manasi S, Latha N and K V Raju

218 Economics of Shrimp Farming: A Comparative Study of Traditional Vs. Scientific Shrimp Farming in West Bengal
Poulomi Bhattacharya

219 Output and Input Efficiency of Manufacturing Firms in India: A Case of the Indian Pharmaceutical Sector
Mainak Mazumdar, Meenakshi Rajeev and Subhash C Ray

220 Panchayats, Hariyali Guidelines and Watershed Development: Lessons from Karnataka
N Sivanna

221 Gender Differential in Disease Burden: It's Role to Explain Gender Differential in Mortality
Biplab Dhak and Mutharayappa R

222 Sanitation Strategies in Karnataka: A Review
Veerashekharappa and Shashanka Bhide

223 A Comparative Analysis of Efficiency and productivity of the Indian Pharmaceutical Firms: A Malmquist-Meta-Frontier Approach
Mainak Mazumdar and Meenakshi Rajeev

224 Local Governance, Patronage and Accountability in Karnataka and Kerala
Anand Inbanathan

225 Downward Dividends of Groundwater Irrigation in Hard Rock Areas of Southern Peninsular India
Anantha K H

226 Trends and Patterns of Private Investment in India
Jagannath Mallick

227 Environmental Efficiency of the Indian Cement Industry: An Interstate Analysis
Sabuj Kumar Mandal and S Madheswaran

228 Determinants of Living Arrangements of Elderly in Orissa: An Analysis
Akshaya Kumar Panigrahi

229 Fiscal Empowerment of Panchayats in India: Real or Rhetoric?
M Devendra Babu

230 Energy Use Efficiency in Indian Cement Industry: Application of Data Envelopment Analysis and Directional Distance Function
Sabuj Kumar Mandaland S Madheswaran

231 Ethnicity, Caste and Community in a Disaster Prone Area of Orissa
Priya Gupta

232 Koodankulam Anti-Nuclear Movement: A Struggle for Alternative Development?
Patibandla Srikant

233 History Revisited: Narratives on Political and Constitutional Changes in Kashmir (1947-1990)
Khalid Wasim Hassan

234 Spatial Heterogeneity and Population Mobility in India
Jajati Keshari Parida and S Madheswaran

Price: Rs. 30.00 ISBN 81-7791-191-0

INSTITUTE FOR SOCIAL AND ECONOMIC CHANGE
Dr V K R V Rao Road, Nagarabhavi P.O., Bangalore - 560 072, India
Phone: 0091-80-23215468, 23215519, 23215592; Fax: 0091-80-23217008
E-mail: lekha@isec.ac.in; Web: www.isec.ac.in