

**Paper Title:**

**Impact of Environmental Regulation on Technical Efficiency: A study of Chemical Industry in and around Mumbai**

By

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***Abstract***

There is a large concentration of chemical industries around Mumbai, and the Maharashtra Pollution Control Board has been actively monitoring them. Such monitoring is likely to have an impact on the productive efficiency of these firms. However, there is a large variation in the degree of compliance among the firms measured in terms of ratio of standard to effluent quality. The factors responsible for large variations in the compliance to the pollution standards by the firms might be laxity of formal environmental regulation by the government, use of command and control instruments, and the absence of informal regulation by the communities in the neighbourhood of the firms. The objective of this paper is to find out whether these water-polluting firms in the chemical industry around Mumbai are actually unable to cope with the additional cost of pollution abatement, or they are instead, by using cleaner practices, able to improve their efficiency, and thereby support the ‘win-win’ opportunities as claimed by the Porter Hypothesis. In this paper, we have analysed the effect of environmental regulation relating to water pollution on the productive efficiency of firms, using a distance function approach. The panel data of 50 water-polluting firms for three-year period of 2004–06 was collected in a primary survey of chemical industries around Mumbai. We find that if the firms aim to be environmentally sustainable, they become more efficient. Similarly, more energy efficient a firm is, higher is the level of efficiency of their technical efficiency.

Keywords: *Technical Efficiency; Chemical Industry; Environmental regulation; Porter hypothesis; Distance functions*

JEL Classification: L60, Q53

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## 1. Introduction

Environmental regulation makes firms internalise the costs of environmental externality generated by them. It may result in firms complying with the regulation being less competitive in the market than the non-complying firms. This conventional view about the effects of regulation on the competitiveness of firms is recently subjected to scrutiny especially in the context of empirically testing the so-called Porter hypothesis (Porter, 1990a, b, 1991). Porter and van der Linde (1995) argue that properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them. Such ‘innovation offsets’, as one can call them, can not only lower the net costs of meeting environmental regulations, but even lead to absolute advantage (p. 98). The authors further contend that innovation offsets occur mainly because pollution regulation is often coincident with improved efficiency of resource usage and the inference is that stiffer environmental regulation results in greater production efficiency.

Many economists (for example Palmer et al., 1995) remain sceptical of the widespread existence of this hypothesis or such ‘win-win’ opportunities. Although, Palmer et al. clearly do not accept the basic arguments of the Porter hypothesis, they do agree that environmental regulation and production efficiency may be related. According to them, ‘we acknowledge that regulations have sometimes led to the discovery of cost saving or quality improving innovation; in other words, we do not believe that firms are ever vigilantly perched on their efficiency frontier’. However, they indicate that more systematic studies are needed to establish the extent of the effect. Indeed, the empirical literature on the relationship between environmental regulation and production efficiency is still rather scarce.

There are three major approaches used in the literature to measure the effect of environmental regulations on the production efficiency of firms:

- (i) adjusting the output of the plant to account for the marginal benefit or cost of the emission reduction or the shadow prices of pollutants (Pittman, 1981, 1983; Fare et al., 1993; Hetemaki, 1996; Coggins and Swinton, 1996; Repetto et al., 1996; Kumar, 1999; Murty and Kumar, 2000);

- (ii) accounting for the effect of pollution abatement costs on the total factor productivity (Gollop and Roberts, 1983; Barbara and McConnell, 1990; Gray and Shadbegian, 1995) and the plant cost function (Morgenstern et al., 1997); and
- (iii) directly measuring efficiency and computing the changes in inputs and outputs if pollution levels or abatement expenditures were not constrained (Fare et al., 1986, 1989; Boyd and McClelland, 1999).

All of these studies can be further classified in to two types, the first type using conventional approaches, such as production, cost, or profit functions, while a second category employs the theory of distance functions. Here the analysis is carried out using the distance functions approach. Although the theoretical framework on which the distance functions are based has been known for a long time (Shephard, 1953) it is only recently that their usefulness in empirical applications has come to be appreciated. In particular, the work of Fare and others (Fare et al., 1986, 1989, 1993, 1994; Fare and Primont, 1995) has been influential in popularising the use of distance functions. Most of the existing applications of distance functions are either non-parametric studies or based on the parametric linear programming approach. It appears that only a few econometric distance functions studies have been carried out (Lovell et al., 1990; Grosskopf and Hayes, 1993; Hetemaki, 1996; Kumar, 1999, Murty and Kumar, 2003). Probably the most important reason for the paucity of econometric applications is the fact that the stochastic estimation of distance functions is more involved than the application of linear programming models or the estimation of production, cost and profit functions. Indeed, the stochastic estimation of distance functions is still not widely common.

The linear programming approach to compute distance functions is deterministic in that random errors are absent. It has been accepted in literature, that this is rather a limitation of this approach. Of course, in some cases it may turn out that the random errors are of negligible importance for the final results, but even in these cases, this is usually not known a priori. Consequently, it is important to be able to estimate distance functions stochastically so that random errors are accounted. As it turns out, the estimation of distance functions is not as straightforward as the estimation of

conventional cost, production or profit functions. Indeed, this may be the reason for the paucity of econometric distance function studies.

There is a large concentration of chemical industries around Mumbai, and the Maharashtra Pollution Control Board has been actively monitoring them throughout the years. Hence, it is quite obvious that such monitoring will have an impact on the efficiency of these firms. An interesting thing to note however is that there is a large variation in the degree of compliance among the firms measured in terms of ratio of standard to effluent quality. The factors responsible for large variations in the compliance to the pollution standards by the firms might be laxity of formal environmental regulation by the government, use of command and control instruments, and the absence of informal regulation by the communities in the neighbourhood of the firms. The objective of this research is to find out whether these water-polluting firms in the chemical industry around Mumbai are actually unable to cope with the additional cost of pollution abatement, or they are instead, by using cleaner practices, able to improve their efficiency, and thereby support the ‘win-win’ opportunities as claimed by the Porter Hypothesis. This study will attempt to estimate the cost of water pollution abatement measures to the chemical industry using the econometric methodology of distance function in the theory of production. The objective of this paper is to study the effect of environmental regulation relating to water pollution by the manufacturing industry in India on the productive efficiency of firms. The panel (time series-cross-section) data of 50 water-polluting firms for three-year period of 2004–06 are used to test the Porter hypothesis. In the present study the output distance function and the cause and effect relationship between technical inefficiency and environmental regulation are simultaneously estimated employing the framework proposed by Battese and Coelli (1995) in a production function setting.

The next sections are planned as follows: the second section briefly deals with the review of the literature of some studies used to estimate technical efficiency; section 3 explains the methodology of this study; section 4 explains the data and the functional form of the production function; section 5 gives some descriptions of the data that was noted while collection, section 6 reports and explains both the descriptive statistics and the results that have been found in the analysis and the last section concludes.

## 2. Review of Literature

One of the first attempts to analyse producer environmental performance from an estimated bad output shadow price was made by Pittman (1981). He studied 30 pulp and paper plants in Wisconsin and Michigan in 1976. The purpose was partly to investigate whether the pollution control requirements, set by the authorities, were cost efficient. Pittman specified a restricted profit maximization problem where one of the restrictions was plant specific quotas specifying maximum allowed levels of biological oxygen demand (BOD) discharge into the waters. The Lagrange multiplier of that restriction, reflecting the shadow price, or the MAC, of BOD, was then econometrically estimated in a system of equations. This means that Pittman assumed that each plant discharged exactly as much BOD as it was allowed to. One of the findings was that the shadow price differed substantially between plants and it was interpreted such that the pollution control regulations allocated abatement resources inefficiently. A conclusion was, therefore, that either an effluent charge or a market for transferable discharge permits would potentially result in a more efficient resource allocation. A striking feature of the Pittman model is that the pollutant BOD is treated in the same way as conventional inputs. Pittman (1983) presented an alternative use of bad output shadow prices, where the estimates were used in the construction of a multi-factor productivity index. The hypothesis was that differences in conventionally measured productivity (excluding information on pollutants) among different plants could be explained by the failure to account for pollution control behaviour. However, his empirical results clearly rejected the hypothesis, but he found that productivity measures, which ignore information on pollutants, might yield misleading results from a societal point of view.

In his paper, Kumbhakar (1989) has stated that earlier papers (for e.g. Aigner, Lovell and Schmidt 1977; Meeusen and Van den Broeck 1977), technical inefficiency encompassed the efficiency of total factor employment, and not the inefficiency associated with individual inputs. These measures, he felt, treated the contribution of each factor to productive efficiency equally, and as a result, masked any differences in efficiency that might be attributed to a particular factor input. He gave an example as suggested by Kopp (1981) in his paper; that is the 'parsimonious use of fuel and

excessive use of capital can yield the same technical efficiency as the reverse pattern of factor use'. This is a very important aspect as excessive use of fuel can have environmental implications, which can affect the sustainable development of an economy. Another problem with the previous literature was that very restrictive functional forms were used to characterise the cost/production frontiers. Thirdly, efficiency estimates of earlier papers were based on specific distributional assumptions of technical efficiency for which results were usually not robust. It was pointed out by Schmidt and Sickles (1984) that the last problem can be solved if panel data was available as technical efficiency can then be estimated from firm-specific effects.

The author therefore tries an approach that represents an advance over the previous studies by combining the input specific technical inefficiency (ISTI) with techniques of estimation that reduce dependency on distributional assumptions on inefficiency by using the panel nature of the data and a flexible functional form for the cost function. He then calculates TE specific to labour and energy for 12 Finnish foundry plants over a period of eight years (1978-85) under the assumption that inefficiency is invariant over time. The results show that there is substantial variation in the efficiency of labour and energy inputs. It was found that while efficiency of labour exceeds that of energy for all plants, cost of inefficiency due to energy is higher than that due to labour. Hence, a greater cost reduction is possible by improving the efficiency of labour. This is mainly because cost of technical inefficiency depends on input prices. However, it should be noted that the findings were only relevant from the actual cost point of view. If we take into account the social cost, i.e. the impact of excessive fuel /energy use on the environment, the result is unknown as the authors did not explore this issue.

Barbara and McConnell (1990) had examined the effect of environmental regulation on productivity in five industries, which are heavily affected by environmental regulation. They measured the impact on total factor productivity by splitting up this effect into the direct effect concerning the direct costs for abatement capital and into the indirect effect into the shift in the production function. The latter measures the changes in the way conventional inputs are used to produce the manufactured good. Whereas the direct effect on productivity is negative, the indirect

effect can be positive, negative or neutral. A negative impact on total factor productivity can be expected when in conjunction with abatement capital, more energy and labour is needed, thus decreasing the productivity of the conventional output. Abatement requirements, however, could make conventional equipment obsolete and then lead to new investment and increased productivity.

The authors, in this paper, had build up a translog cost function and show that the indirect effect varies substantially with industry and it is in general smaller than the direct effect. Some industries are able to compensate for parts of the productivity loss by changes in other inputs (mainly house-keeping measures). They found that in their period of study (1961-80) the total abatement effect is negative in all the five industries, but it appears that the environmental regulation may have had a smaller effect on total factor productivity than others have predicted for the aggregate level, beginning to decrease in the early 1970s. However, this paper looks at productivity and not efficiency and these concepts are not exactly the same.

Färe et al. (1993) characterized the structure of production technology with the Shephard multi-output distance function, which is dual to the revenue function. Using this approach, duality theory is exploited and shadow prices of outputs are derived from the distance function using Shephard's dual lemma. A major difference compared to the Pittman approach is that emissions are here treated as undesirable by-products from production processes. Estimated shadow prices then reflect the trade-off between good and bad outputs. This means that information on environmental restrictions imposed on producers are not needed in this case and, consequently, there is no need to assume that producers are satisfying these requirements when estimating shadow prices. Färe et al. (1993) computed the output distance function on the Pittman (1981, 1983) data by employing a parametric linear programming technique. Their findings coincided with Pittman's in the sense that shadow prices varied between plants and, given the plants geographical proximity, this suggested that the environmental regulations in effect were not allocating resources efficiently.

Coggins and Swinton (1996) used the Färe et al. (1993) approach to calculate the shadow price, or MAC, of sulphur dioxide (SO<sub>2</sub>) for 14 Wisconsin coal-burning electric utility plants during 1990-1992. They suggested that the shadow price could

be interpreted as the market value of a SO<sub>2</sub> emission allowance to the plants in the study. Coggins and Swinton noted that the estimated sample average shadow price was close to prices at which actual trades between utilities had occurred, and that the shadow price varied widely across the sample. This variability was further confirmed by Swinton (1999), who pointed out that the variability also highlighted a dramatic difference in marginal abatement costs among plants using different abatement strategies, as installing scrubber capital or purchasing low sulphur fuel.

Reig-Martínez et al. (2001) used the Färe et al. (1993) approach on 18 Spanish ceramic pavement producers in 1995. They observed that shadow prices of watery-muds and used oil differed significantly across the sample. Due to the closely knitted geographical location of these producers, Reig-Martínez et al. (2001) found it reasonable to assume that marginal social benefits from reducing emissions were similar between the producers. Therefore, they concluded that the existing situation was not efficient in terms of allocating resources and that a market of emission permits could be developed. Reig-Martínez et al. (2001) used the calculated shadow prices to construct a labour productivity deviation index (PDI), which compares a conventional form of labour productivity to an extended form of the same. The calculated PDI showed that the conventional index overestimated labour productivity by 12 percent on average in terms of revenues per labour unit. Their major point was that producers that are less productive in conventional terms might be relatively productive when taking the environment issue into account.

Färe et al. (2002) suggest a directional output distance function approach to calculate shadow prices of bad outputs. Unlike the Shephard output distance function used in the studies discussed above, which expands both good and bad outputs to the output frontier, this function allows for a simultaneous expansion of good outputs and contraction of bad outputs. Consequently, this new approach will, in comparison with the Shephard approach, imply different shadow prices of bad outputs. Färe et al. (2002) apply the approach to the U.S. agricultural sector for the period 1960-1996. They calculate shadow prices of two indices that capture the effects on drinking water of pesticides leaching into the ground water, and of pesticide runoff into the surface water. The resulting shadow prices are then used to calculate the pollution cost for

leaching and for runoff. Their results indicate that these costs are significant, averaging about 17.5 percent of the revenues from good outputs.

The stochastic frontier production function, as known in the literature, involves an unobservable random variable associated with the technical inefficiency of production of individual firms, in addition to the random error in a traditional regression model. Different models of the technical inefficiency effects are proposed in the literature. The technical efficiency of individual sample firms can be predicted on the basis of cross-sectional or panel data on these firms. The authors Battese and Broca (1997), in this paper have considered three particular parametric models for the technical inefficiency effects in stochastic frontier production functions. They have also used two different functional forms, which are most commonly used in the literature for the stochastic frontier, namely the translogarithmic and the Cobb-Douglas production functions.

They analyse the data on wheat farmers from a district (Faisalabad) in Pakistan for four years, 1986-87, 1987-88, 1988-89 and 1990-91. The numbers of sample wheat farmers whose data are considered in this study were 87, 77, 81 and 85 for the four respective years. They use three different stochastic models, those proposed by Battese and Coelli (1992, 1995) and Huang and Liu (1994). The first two models as mentioned by the authors were proposed for the analysis of panel data, whereas the third model was originally proposed for the analysis of cross-sectional data. The authors discuss all three models assuming that data are available for a sample of  $N$  firms over  $T$  time periods. According to the authors, the panel of data need not be balanced, given the specifications of the models involved. The main difference between the three different frontier models that are considered by the authors is that they have different specifications of the technical inefficiency effects.

Their results indicate that, given the specifications of the neutral translog stochastic frontier models (Models 1 and 2), the Cobb-Douglas functional form is not an adequate representation of the data. In case of the first model, they found that the preferred frontier model is the translog frontier with no technical change, but no sub-model of the time-varying inefficiency effects was found adequate. In case of Model 2, the preferred frontier model was the frontier with no technical change but year

effects in the technical inefficiency model. In the case of the third model, the authors found that the non-neutral Cobb-Douglas frontier model with neutral technical change was accepted as an adequate representation of the data.

An interesting fact was that in case of Model 1, the all wheat farmers have predicted technical efficiencies much higher than under the specifications of Model 2 or 3. The authors suggest that these results indicate that the model specifications for the technical inefficiency effects have a significant bearing on the predicted technical efficiencies for the sample farmers.

The conventional view on environmental protection is that there is a trade-off between environmental protection and economic growth. This trade-off sets the social and ecological benefits that arise from the results of applying environmental standards against the costs of pollution prevention and cleanup. Industry often perceives this as cost-ineffective. Its response usually stems from a concern over the costs of implementation and reduction of competitiveness resulting in the fear of market loss to businesses that operate in regimes that are more lax. Generally, the response of industry to tighter regulation has been to argue that the effect of market pressures and heightened corporate social responsibility and environmental awareness are more effective spurs for ensuring environmental protection (Salter, 1992).

Porter (1991) argued that ‘strict regulations do not inevitably hinder competitive advantage against foreign rivals, indeed, they often enhance it’. Rather than regulations imposing a cost on industry, Porter and van der Linde (1995) argue that strict regulations, if properly designed, can in fact stimulate firms to discover hidden win-win opportunities. The neoclassical economic models of the firm as a profit maximiser with perfect knowledge does not exist in reality and many opportunities exist for firms to improve their environmental performance cost-effectively. Porter and van der Linde (1995) argue that strict regulation is necessary to stimulate firms into discovering opportunities, and to achieve cost-effective compliance, thus enabling firms to overcome barriers to change. However, critics of the Porter hypothesis have argued that Porter’s arguments are based on ‘inconclusive anecdotal evidence’ (Palmer and Simpson, 1993) and that there is little evidence to support the view that environmental regulation actually stimulates innovation and

improves international competitiveness (Jaffe et al., 1995). Walley and Whithead (1994) argue that win-win situations rarely exist, although the findings of Feldman et al. (1996) that improving a firm's environmental management results in a higher stock price hardly upholds this view.

In several countries environmental regulations have actually stimulated technological innovation in terms of both prevention and control measures, for example, in Japan, Germany and the US. However, from the firms' point of view, the costs of investing in developing the technology to meet a specific regulation have to be offset against future benefits from selling the technology. For example, there are a number of initiatives to encourage the use of, and therefore provide for a market for, alternative-fuelled vehicles. The potential of new fuels led the oil industry to devise new formulae for gasoline that would achieve similar emission levels as those resulting from the use of alternative fuels in the engines of existing cars (Cairncross, 1992). This kind of innovations have actually reduced the cost of compliance for the automobile industry as it was initially, thought that a new fuel to reach these emission levels, which, in turn, could be used only in cars with redesigned engines. Another example that can be observed was that in response to new fuel consumption standards, Japanese and German automobile manufactures developed lighter and more fuel-efficient cars. In contrast, the less competitive US car industry fought such standards but eventually realised that it would lose out if it did not compete through enhanced innovation.

For the more environmentally conscious firms, pollution prevention measures have resulted in cost savings. Improvement in the efficiency of energy and material use in the production process is an important part of preventive environmental management. If less material input is required to provide the same output, this will represent tangible cost savings to the company. Although the company will incur initial investment costs, the savings may, on the whole, outweigh the costs. The US company 3M was one of the first industrial corporations to adopt a preventive approach to the environmental management of process wastes (Jackson, 1996).

Despite the conflict between industry and government authorities during the negotiations of new environmental regulations, some firms have endeavoured to take

a proactive approach to environmental management, which has been driven by a strong profit motive. However, in many cases, environmental management has not been a goal in itself. The main aim has been to improve the company's public image to ensure that it remains competitive. In fact, a quantitative and detailed study (Feldman et al., 1996) concludes 'investments in environmental management and performance may be costly. Nonetheless, when appropriately evaluated, many of these investments may be shown to provide substantial, positive returns and lasting value to the firm'.

In a recent study by Murty and Kumar (2003) the "win-win" opportunities (Porter hypothesis) of environmental regulation was analysed in the context of Indian industries. This paper studied the effect of environmental regulation on the productive efficiency of water polluting industries in India. The panel data of 92 firms belonging to sugar industry of India during the period 1996–99 are used to test the Porter hypothesis of having win-win opportunities for the firms subjected to the regulation. The main empirical result that was found in this study was that the technical efficiency of firms increased with the degree of compliance of firms to the environmental regulation and the water conservation efforts thereby supporting the Porter hypothesis. The authors noted that the win-win opportunities from the environmental regulation could be found more in some industries and less in others. Similar studies for specific industries could help to identify the industries with no such opportunities so that the monitoring and enforcement could be directed to those industries in which incentives are absent. Given the very high monitoring and enforcement cost of environmental regulation, this could result in the significant cost savings.

Thus, there is a case for independent cost assessments of public policy to be undertaken that would consider the cost to the whole economy rather than a particular sector. In addition, independent technology assessment procedures and institutions could prove useful in identifying the potential of technology to meet the regulatory standards. Decision-making based on industry's estimates can in the long term be damaging to the general interest and may even be counterproductive for industrial development as in some cases there are net benefits to be gained. Environmental regulation does not necessarily generate innovation or stimulate greater

competitiveness or higher productivity for all firms; however, those firms that seize the opportunity to innovate will ultimately prevail in terms of enhanced competitiveness, which has important implications for the formulation of future environmental policy.

### 3. Methodology and Estimation

We shall now very briefly explain the methodology of estimation used in the paper.<sup>1</sup>

The stochastic output distance function for estimation is given as follows:

$$D_0 = f(X, Y, \alpha, \beta) + \varepsilon \quad (1)$$

where  $D_0$  is the distance measure,  $f(\cdot)$  is the production technology,  $X$  is a vector of inputs,  $Y$  is a vector of outputs,  $\alpha, \beta$  are vectors of parameters to be estimated, and  $\varepsilon$  is the additive error term ( $v_{it}-u_{it}$ ). The  $v_{it}$  random variables are assumed to be independent and identically distributed as  $N(0, \sigma_v^2)$  independent of the  $u_{it}$  random variables, which are assumed to be independent and identically distributed non-negative random variables, defined by the truncation (at zero) of the  $N(\mu, \sigma^2)$  distribution. In addition, it is assumed that the  $v_{it}$  and  $u_{it}$  random variables are independently distributed of the input variables in the model.

The error term  $v_{it}$  may be generated for various reasons. As described in the literature, it may include  $v_{it}$  errors introduced by measurement, data collection, functional form specification, computational procedures, or factors known to the production units but not to the econometrician.

The main problem with the econometric estimation of distance functions is that one does not observe or have data on the dependent variable. Furthermore, if we set the distance function equal to its most efficient (i.e. the frontier) value,  $D_0 = 1$ , the left-hand side of the distance function becomes invariant. As a result, the intercept cannot be estimated, and therefore the OLS parameter estimates will be biased. Further, if the distance function is expressed in logarithms, the left-hand side of the distance function will be zero for all observations (i.e.,  $D_0 = \ln(1) = 0$ ). In order to avoid these problems, the literature<sup>2</sup> utilise the property that the output distance function is homogeneous of degree one in outputs. Thus, for each observation to be

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<sup>1</sup> The methodology used primarily follows the direction of Murty and Kumar (2003).

<sup>2</sup> Lovell et al. (1990), Grosskopf et al. (1996), Grosskopf and Hayes 1993), Coelli and Perelman (1996), Kumar (1999) and Murty and Kumar (2002)

used in estimating the distance function, a value that is unique to that observation can be used to multiply all output values on the right hand-side and the value of the distance function on the left-hand side. Thus, for an output distance function the following relationship (ignoring the error term) holds:

$$D_0(X, \psi Y) = \psi D_0(X, Y), \text{ for any } \psi > 0. \quad (2)$$

In the literature, typically one of the outputs is chosen arbitrarily as a scaling variable.<sup>3</sup> For example, if we chose the M-th output, and set  $\psi = I/Y_M$ , the above equation may be written as,

$$D_0(X, Y/Y_M) = D_0(X, Y) / Y_M \quad (3)$$

Now assume that we impose some logarithmic functional form on the output distance function, in accordance with most of the empirical literature. Then, equation (3) becomes

$$\ln(D_0/Y_M) = f(X, Y/Y_M, \alpha, \beta),^4 \quad (4)$$

where  $f(\cdot)$  denotes some logarithmic functional form, such as translog and  $\alpha, \beta$  the parameters.

Alternatively, equation (4) may be expressed as,

$$\ln(D_0) - \ln(Y_M) = f(X, Y/Y_M, \alpha, \beta), \quad (5)$$

$$\text{or} \quad -\ln(Y_M) = f(X, Y/Y_M, \alpha, \beta) - \ln(D_0), \quad (6)$$

Given the data, the parameters in equation (6) can be estimated in various ways. However, the primary objective of the estimation method is to generate parameter estimates that fit the data as closely as possible while maintaining the requirement that  $0 < D_0 \leq I$ , which in the logarithmic case implies  $-\infty < \ln D_0 \leq 0$ .

Aigner et al. (1997) uses the stochastic frontier ML method in a production function context. This approach is based on the composed error term idea, in which a symmetric error term accounts for noise and an asymmetric error term accounts for production inefficiency. For the inefficiency component of the error term, one assumes a functional form and estimates simultaneously all the technology parameters and the parameter(s) of the distribution of the inefficiency term. Adding a symmetric

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<sup>3</sup> See Murty and Kumar (2002)

<sup>4</sup> Using the definition of the output distance function we get this result.

error term,  $v$ , to equation (6), and denoting the distance to frontier term,  $- \ln (D_0)$ , by  $\mu$ , the stochastic frontier output distance function is obtained as

$$- \ln(Y_M) = f(X, Y / Y_M, \alpha, \beta) + v + \mu \quad (7).$$

Typically, in the literature it has been assumed that  $v$  is distributed  $N(0, \sigma^2 v)$  and independently from  $\mu$ , while  $\mu$  is assumed to be either half-normal, truncated normal, exponential, or gamma distributed (Greene 1993 a, b). It appears that the most popular choice for application has been the half-normal distribution<sup>5</sup> and Maximum Likelihood estimation (Coelli 1995). After having estimated (7),  $E(\mu/\mu+v)$  is computed for each plant from which plant specific efficiency measures are calculated as

$$D_o(x, y) = \text{Exp}\{-E(\mu/\mu+v)\} \quad (8)$$

In order to estimate simultaneously the magnitude of inefficiency and the determinants of inefficiency, the framework proposed by Battese and Coelli (1995) in a production function setting is applied to the distance function framework. Let the equation (8) be defined as

$$\text{Exp}(-\mu) = \text{exp}(-Z\delta-w), \quad (9)$$

where the  $\mu$ 's are assumed to be independently distributed, such that  $\mu$  is obtained by truncation of the normal distribution with mean  $z\delta$  and variance  $\sigma_2^2$ ;  $Z$  is a vector of plant specific variables and  $w$  stands for the unexplained part of the efficiency.

In this model, as seen in the literature, the explanatory variables of technical inefficiency may not enter into the distance function directly but they affect technical inefficiency. We do not the exact content and term of the  $Z$  vector except for the fact that it should reflect the reason why inefficiency may arise, that is, why the plants are not operating on the output distance frontier. Here we examine some factors that may contribute to inefficiency. They are: the intensity of environmental regulation (this is an index created by Murty and Kumar (2003)), energy efficiency (energy use per unit of sales) turnover and time.

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<sup>5</sup> A detailed discussion on choice of distribution is available in Kumbhakar and Lovell (2000)

#### 4. Data and Translog Distance Function

In order to estimate the output efficiency for the chemical industry in and around Mumbai the parameters of output distance function have to be estimated. The translog functional form is chosen for estimating the output distance function [as derived in Fare (1988) and used henceforth by several others] for this industry, which is given as:

$$\ln D_0(x, y) = \alpha_0 + \sum \beta_n \ln x_n + \sum \alpha_m \ln y_m + \frac{1}{2} \sum \sum \beta_{nn'} (\ln x_n)(\ln x_{n'}) + \frac{1}{2} \sum \sum \alpha_{mm'} (\ln y_m)(\ln y_{m'}) + \sum \sum \gamma_{nm} (\ln x_n)(\ln y_m) \quad (1)$$

where,  $x$  and  $y$  are  $(N \times 1)$  and  $(M \times 1)$  vectors of inputs and outputs respectively;

Several studies that have used this translog functional form for estimating the output distance function. These include Pittman (1981), Fare *et. al.* (1990), Coggins and Swinton (1996) and Murty and Kumar (2003).

In the present study the data is collected from the primary survey of chemical industries in and around Mumbai<sup>6</sup> for three years, 2003-04, 2004-05, and 2005-06. The total number of firms for which the data is available at present is 50. The data consists of sales values, BOD, COD and SS load as outputs and the conventional inputs such as wage bill, capital stock and materials. For a calculation of the relationship between the technical inefficiency and environmental regulation, the intensity of environmental regulation is measured by a variable, the regulation index (RI). This variable was earlier used by Murty and Kumar (2002, 2003) in their analysis. The RI variable is constructed by making use of effluent concentrations of BOD, COD, and SS for all the firms. To begin an index of compliance of firms with respect to a given pollutant is constructed by scaling down each observation of effluent concentration by its maximum value (the value for the firm with least compliance) among all 150 observations. Then the regulation index is defined as the geometric mean of the three compliance indices of BOD, COD, and SS. The range of this index is from zero to one. It takes the value one for the firm with the least

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<sup>6</sup> The firms are located mainly in Thane, Mahape, Talaja, Patalganga, Roha, Khopoli, Dombivilli, Ambarnath, Saravali, Bhiwandi and Penn.

compliance and approaches zero for the firm with the maximum compliance or zero pollution. Similar type of indices had been used earlier by Gollop and Roberts (1983) and Hetemaki (1996). Another variable that has been used for the same purpose is efficiency in energy use, i.e. real energy consumption per unit of real sales. Higher the ratio, lower the conservation effort of the firm.

## **5. Data Descriptions**

As was described in the previous section, for analysis, we would need to collect data on the good output and the bad output of such industries, as well as the data of inputs required to produce these outputs. Therefore, the data required about the main plant are sales value (value of the good output), capital stock, wage bill, power and fuel cost and other material input cost. The data for the bad output or pollution that was collected was effluent quality for BOD (bio-oxygen demand), COD (chemical oxygen demand) and SS (suspended solids). For estimating the output distance function, the technology of each plant is described by joint outputs: sales value (good output) and COD, BOD and SS (bad outputs) and inputs: capital, labour, fuel and materials.

The water polluting firms in the Indian industries are supposed to meet the standards set for the pollutants (30mg/l for BOD, 250mg/l for COD, and 100mg/l for SS) by the Central Pollution Control Board (CPCB). Command and Control regulatory instruments are used to make the firms realise the standards.

For a calculation of the relationship between the technical inefficiency and environmental regulation, one can take data of any one of these three parameters as bad output. Some studies have used different means of such data to form indices and found satisfactory results. In my analysis I have used data for all three separately as discussed in the previous section.

Data for 50 firms for pH levels, BOD, COD, SS, and the amount of oil and grease concentrations of the wastewater were collected from the Maharashtra Pollution Control Board (MPCB) field offices of areas in and around Mumbai where there is high concentration of chemical industries. As I wanted to look at a water polluting industry, it was suggested by the water pollution abatement engineer of MPCB that I should look at the chemical industry as they were concentrated in the region in and around Mumbai; namely, Thane, Navi-Mumbai, Raigarh and Kalyan.

Data was finally collected for the areas Thane, Talaja, Patalganga, Roha, Khopoli, Dombivilli, Ambernath, Saravali, Bhiwandi and Pen. An interesting thing to note here was that the standards of BOD that were mentioned by the field officers of MPCB were different than those fixed by CPCB. The standard for BOD that was mentioned was 100mg/l whereas that of CPCB was 30mg/l. After visiting the field offices of these particular areas, I found that effluent samples were collected by the field officers for each month of each firm falling under their jurisdiction. Then they were coded and sent to the laboratories to be analyzed in terms of at least the 5 pollution parameters. These data was then sent back to the officials and decoded. It was then checked that which firms have maintained standards. After a firm violated the norms for a particular number of times, a warning was sent, and after that the license was cancelled.

It was noted that the method of recording such data was very poor. They were either filed haphazardly (a page for each firm for each month in a year, not in any particular order) or some columns drawn in an exercise book and hand-written in it. However, the name and address of the firms were identifiable. Hence, the firms could be approached for further data that is less sensitive in nature.

An interesting thing to note was a seasonal pattern in availability of data. Generally, for all firms and for all years, data for the month of July was missing. When enquired, it was explained that due to heavy monsoons, it was not possible for the field officers to collect the samples from the firms! Also, due to heavy water-logging in certain low-lying areas, the wastewater got mixed with the rainwater and therefore, the samples were not reliable. However, as for my analysis, I took a yearly average of the pollution parameters; the data was fairly representative of the monthly values.

Another important thing to note was that the large scale firms with multiple plants were strangely reluctant to give data than the medium or small scale firms with single plants. For single plants firms, the financial/production data was available in their annual reports. However, multi-plant firms needed to give a segregation of their data which is not in the public domain. They refused to part with information on confidentiality issues (tax purposes. i.e. evasions etc.). In my sample of 50 about 10-12 multi-plant firms had given their data willingly. Mostly notable among them were Excel industries, Roha, and RCF, Thane. Hence there might be a bias in this study with respect to size of firms.

## 6. Results

Table 1 gives the descriptive statistics of variables used in the estimation. The data shows that the standard deviation is higher than the mean values for almost all the variables. This can be attributed to the fact that the firms belonged to locations to different characteristics (for e.g. it was suggested by the field officer of Taloja that the proximity to the port had some effects on the water quality and therefore, the effluent quality of the plants) and variances in size and characteristics with respect to the size of the firms. Also, while all the firms belong to the broad category of chemical industry, there is scope of variation in the nature of the goods produced in such plants.

*Table 1  
Descriptive Statistics of the Data Used in the Study and Estimates of Technical Efficiency*

Variable	Mean	SD	Max	Min
Efficiency	0.452	0.135	0.913	0.203
Turnover (Rs. crores)	285.68	540.77	3102.09	0.93
BOD concentration (mg/l)	141.58	241.36	935	4
COD concentration (mg/l)	428.86	1003.60	3760	5
SS concentration (mg/l)	89.41	104.78	710	8.71
Materials (Rs. crores)	150.86	289.40	1645.61	0.26
Wage Bill (Rs. crores)	18.12	35.70	176.6	0.26
Capital Stock (Rs. crores)	167.52	304.74	1803.34	1.72
Regulation Index (RI)	0.075	0.119	1	0.0042
Energy Efficiency (P)	0.095	0.12	0.252	0.00045

The parameters of estimated output distance function are given in Table 2. Most of these parameters are significant at either one per cent level or 5 percent level. The value of each observation gives a measure of technical efficiency. Table 1 reports the descriptive statistics of technical efficiency for the sample, which the mean value of technical efficiency for the firms in the sample is 0.452, meaning the chemical industry in Maharashtra is 55 per cent inefficient. This is a very important fact because the analysis is primarily based on small and medium scale enterprises. It was noted by the then MPCB Member Secretary, Dr. D.B. Boralkar that the small and medium scale enterprises might be more inefficient by nature and as a result might

face dire difficulties to minimise pollution in a sustainable manner. Hence there is need of government support as well as more initiative from the part of the firms themselves to form groups so that pollution can be contained to sustainable levels.

Table 2 gives us the results of the estimation of the output distance function.

Table: 2

*Parameter Estimates of the Output Distance Function (Stochastic Estimation)*

	<i>Parameter</i>	<i>Coefficient</i>	<i>Standard-error</i>	<i>t-ratio</i>	<i>Significant</i>
<i>Constant</i>	$\beta_0$	-1.764173	.5031843	-3.51	at 1 percent
$Y_2$	$\beta_1$	-.3716301	.2066487	-1.80	at 5 percent
$Y_3$	$\beta_2$	.5060281	.2038994	2.48	at 1 percent
$Y_4$	$\beta_3$	.3406323	.161126	2.11	at 5 percent
$X_1$	$\beta_4$	.530574	.1794441	2.96	at 1 percent
$X_2$	$\beta_5$	-.5874023	.2147927	-2.73	at 1 percent
$X_3$	$\beta_6$	-.3744248	.1638544	-2.29	at 1 percent
$Y_2^2$	$\beta_7$	.1284999	.1168427	1.10	not significant
$Y_3^2$	$\beta_8$	.2729714	.0857065	3.18	at 1 percent
$Y_4^2$	$\beta_9$	-.0491169	.0663983	-0.74	at 1 percent
$X_1^2$	$\beta_{10}$	-.2108427	.036833	-5.72	at 1 percent
$X_2^2$	$\beta_{11}$	.03817	.0632187	0.60	not significant
$X_3^2$	$\beta_{12}$	-.2008579	.0355166	-5.66	at 1 percent
$Y_2Y_3$	$\beta_{13}$	-.2157537	.097422	-2.21	at 5 percent
$Y_2Y_4$	$\beta_{14}$	.0624188	.0517177	1.21	not significant
$Y_2X_1$	$\beta_{15}$	.2950312	.0767292	3.85	at 1 percent
$Y_2X_2$	$\beta_{16}$	-.2562072	.0665592	-3.85	at 1 percent
$Y_2X_3$	$\beta_{17}$	-.1004355	.0690491	-1.45	not significant
$Y_3Y_4$	$\beta_{18}$	-.0611633	.055735	-1.10	not significant
$Y_3X_1$	$\beta_{19}$	-.3935885	.0772497	-5.10	at 1 percent
$Y_3X_2$	$\beta_{20}$	.2827009	.0746817	3.79	at 1 percent
$Y_3X_3$	$\beta_{21}$	.102039	.0638009	1.60	not significant
$Y_4X_1$	$\beta_{22}$	-.006905	.0361907	-0.19	not significant
$Y_4X_2$	$\beta_{23}$	.0406057	.0399619	1.02	not significant
$Y_4X_3$	$\beta_{24}$	-.10259	.0623698	-1.64	at 10 percent
$X_1X_2$	$\beta_{25}$	-.0356616	.040445	-0.88	not significant
$X_1X_3$	$\beta_{26}$	.0602613	.0250893	2.40	at 1 percent
$X_2X_3$	$\beta_{27}$	.0274707	.053536	0.51	not significant
<i>M</i>		.8013691	.1960924	4.09	at 1 percent
<i>Log-likelihood fn.</i>		29.182			

Note:  $Y_2, Y_3, Y_4$  are BOD/Turnover, COD/Turnover, SS/ Turnover respectively, while  $X_1, X_2, X_3$  are Capital stock, Labour, and Materials respectively.

The effect of environmental regulation on technical efficiency of firms is studied by estimating a relationship between technical inefficiency and the indices of environmental regulation and energy use per unit of sales turnover, and time. The results are reported in the table below (Table 3)

*Table 3:  
Effect of Environmental Regulation on Technical Efficiency*

	<i>Parameter</i>	<i>Coefficient</i>	<i>Standard-error</i>	<i>t-ratio</i>	<i>Significant</i>
<i>Constant</i>	$\delta_0$	-.101	.2374		
<i>RI</i>	$\delta_1$	-.6885	.1328	5.19	<i>at 1 percent</i>
<i>P</i>	$\delta_2$	-.3941	.1152	-3.42	<i>at 1 percent</i>
<i>Time</i>	$\delta_3$	.0454	.0423	1.07	<i>not significant</i>
	$\gamma$	.8219	.0408	3.18	<i>at 1 percent</i>

The sign of  $\delta_i$  coefficients in the table above are of particular interest in the case of testing the Porter hypothesis as discussed in Section 2 of this paper. As discussed earlier, the Regulation Index ranges from zero to 1. Firms that have lower values are more compliant to regulation, and have lower levels of pollution. A positive sign for the estimated RI shows that higher the value of the variable, higher the value of technical efficiency. A negative sign of RI implies, higher the value of the variable, lower the value of technical efficiency. The sign of the estimated coefficients show that lower the value of the variable, more the efficiency. Or, in other words, more the industry complies with the regulation or increases its effort on conservation (i.e. value of RI decreases), more efficient it becomes. A positive sign of P implies greater the energy inefficiency (i.e. consumption of power is with respect to sales), higher the efficiency in the firm. A negative sign of P implies lesser the consumption of power is with respect to sales, higher the efficiency in the firm. This result implies that using energy in an efficient manner will increase the efficiency in the firm. This is conducive to sustainable development. Thus it can be concluded that these results do comply with the Porter hypothesis.

A positive (negative) sign of coefficient of time implies the increase (decrease) of technical efficiency over time. However, while the estimations show a positive result which implies an increase in technical efficiency over time, the values are not significant.

Thus, it can be believed that there may be potential complementarities between production of conventional output and a reduction of pollution loads. With the abatement technologies involving process changes as opposed to the end of pipe treatment, the cost of jointly producing conventional output and clean environment may be lower than the cost of producing them separately. Such complementarities might arise, for example, from cost savings associated with recovered or recycled effluents and reuse of waste water. The proponents of the Porter hypothesis argue that complementarities between environmental activities and conventional production combined with the induced innovations associated with environmental requirement can partially offset or actually exceed the direct expenditures associated with environmental protection.

## **7. Summary and Conclusions**

The aim of this paper is to look at the impact of environmental regulation on the technical efficiency of Chemical industry located in and around Mumbai. There are two views on this topic. The traditionalists feel that the only possible impact that environmental regulations can have on industries is to increase costs of production through increased abatement costs, thereby draining profits and reducing competitiveness. The revisionists on the other hand argue that such regulations will urge a firm to reduce wastes, and thus encourage them to introduce new methods of production that will increase their technical efficiency. This in turn will have a positive impact on the profit, and can even negate the impact of regulations on the cost of production, thus giving rise to a 'win-win' situation. This paper, in its study finds support to the latter view.

Theoretically, the traditional production models were also unable to explain the impact of reducing the 'bad' or polluting products, which are jointly produced with the 'good' or productive goods in a production process. The distance function approach tries to bridge that gap. It states that today, the bad outputs are not freely disposable due to environmental regulations. Hence, reducing the bad should also show a positive impact on the productivity of an industry. Let us explain it in this simple example. If the extent of harmful gases released in the atmosphere is reduced through a better technology by certain industries, it will reduce the number of people

getting affected by air-borne diseases. As a result, it will reduce the number of person-days lost due to illnesses. This will make the labour more efficient, thereby indirectly contributing to the efficiency of an industry.

In the Indian context, only a very few distance functions have been econometrically estimated, as discussed in the literature review. This is primarily because of paucity and reliability of pollution data. Through this paper, we plan to contribute to this literature as, in India, today, one of the principal concerns of the government is to minimise pollution in the industrial sector: both domestically as well as for exports. Sustainable development has become the norm and no country today can ignore the environmental impacts of a rapidly industrialising economy. Maharashtra is a state, which is rapidly growing, and there are several highly polluting industrial belts around Mumbai. The Maharashtra Pollution Control Board as was suggested by officers and plant-managers alike, were one of the most active boards in India. They are also extremely concerned about the level of pollution in the state. The focus of this study is on the chemical industry because the impact of these industries on water pollution in and around Mumbai has been quite high. Non-compliance of pollution norms in these industries was another problem faced by the MPCB. The main clusters of these industries were in the regions of Navi Mumbai, Raigarh, Thane and Kalyan. These areas were randomly chosen from a list of 15 zones of chemical industries.

From a primary survey of these firms, a panel data of firms for three financial years has been collected. We examine whether the results are compatible with the Porter Hypothesis. This is done by estimating the output distance function jointly with the equation explaining the relationship between technical inefficiency and indices of environmental regulation and efficient energy use and the time variable. The main empirical result is that the technical efficiency of firms increases with the intensity of environmental regulation and the efforts to conserve energy. This result supports the Porter hypothesis about environmental regulation.

The win-win opportunities from the environmental regulation could be found more in some industries and less in others. Similarly, different states in the country can have different results. Similar studies for specific industries that play an important

role in different states in the country could help us to identify the industries with no such opportunities so that the monitoring and enforcement could be directed to those industries in which incentives are absent. Given the very high monitoring and enforcement cost of environmental regulation, this could result in the significant cost savings.

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