VOLUNTARY ENVIRONMENTAL PROGRAMS AND TECHNICAL EFFICIENCY: ANOTHER EXAMINATION OF THE PORTER HYPOTHESIS

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TABLE OF CONTENTS

Chapter Page

Chapter Page

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The significance of environmental costs is often understated. Under conventional cost accounting, environmental costs are treated as general overhead costs and assigned arbitrarily to all products. This practice leads to inaccurate product costing and obscures improvement opportunities, especially when environmental costs are significant to a firm. For example, polluting products may appear more profitable than they actually are because their pollution costs are hidden in overhead costs. According to the Environmental Protection Agency (EPA), environmental costs have increased significantly in the past twenty years with increasingly stringent environmental standards. Given the political and economic pressures to improve environmental performance and the potential magnitude of environmental costs, firms need to establish an environmental cost management system (ECMS) to identify and control their environmental costs. However, few firms have yet established such systems. Based on telephone interviews and site visits, Epstein (1996) finds that most firms do not attempt to identify and measure environmental costs.

One compelling reason for not establishing an ECMS is that managers are not convinced of its value. Complying with traditional command-and-control environmental regulations has been very costly for firms. If improving environmental quality inevitably leads to high environmental costs, then managers may feel that an ECMS would be probably costly. Investing in an ECMS demands some evidence of its potential value.

Porter (1991) and Porter and van der Linde (1995) suggest that it is possible to improve environmental quality while reducing environmental costs simultaneously when environmental standards are properly designed. Properly designed regulations are defined as those that emphasize desired environmental outcomes without specifying means of achievements. Under such regulations, firms are given maximum opportunities to discover how to solve their own problems. Such regulations can trigger innovations that allow compliance and, at the same time, reduce costs. The above reasoning has become known as the Porter Hypothesis. The Porter Hypothesis is controversial, since much of the supportive evidence remains anecdotal, relying on individual success stories to support a relationship between environmental performance and economic performance of a firm. The empirical evidence on the Porter Hypothesis is still rather scarce.

To empirically test the Porter hypothesis, properly designed regulations that emphasize desired outcomes without specifying means of achievement must be present. Two voluntary environmental programs (the EPA’s 33/50 Program and the Canadian ARET Program) provide opportunities to perform a validity test of the Porter Hypothesis, since they fit the condition of properly designed regulations. Both programs encourage firms to participate voluntarily and reduce pollution without specifying means of achievement.

1.1 Significance of the Study

The purpose of this study is to empirically test the validity of the Porter Hypothesis by investigating the impact of complying with properly designed environmental programs (EPA’s 33/50 Program and Canadian ARET Program) on a firm’s technical efficiency. The results from this study should be of significant interest to managers, regulators and investors. If the Porter Hypothesis is valid, then it will provide a strong incentive for management to invest in an environmental cost management system. An ECMS can assist managers in obtaining the correct costing of products, which is a pre-condition for making sound business decisions. In addition, such systems can help managers justify their cleaner production projects, and aid companies in the design of more environmentally preferable products, processes and services for the future. To regulators, evidence supporting the Porter Hypothesis would also encourage them to introduce more properly designed regulations that create maximum opportunity for innovation. Properly designed environmental regulations can not only improve our living conditions but also motivate firms to find ways to reduce their environmental costs. To individual investors, evidence supporting the Porter Hypothesis would encourage them to invest in ‘greener’ firms, since ‘greener’ firms may have more competitive advantages over their competitors.

1.2 Organization of the Study

The remainder of the study is organized as follows: the next chapter reviews related literatures; Chapter 3 presents the statement of hypothesis, and research design is presented in Chapter 4. Chapter 5 describes the data collection and variable selection, and empirical results are presented in Chapter 6. Chapter 7 summarizes the study.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Literature on competing theories

Competing theories of the impact of complying with environmental regulation/program on a firm's economic performance can be classified into three categories: (1) the Traditional Economics View, (2) Ecoefficiency and (3) the Porter Hypothesis.

(1) the Traditional Economics View

The Traditional Economics View holds that mandated expenditures on reducing pollution represent costs that generally confer no corresponding benefits to the firm. Rational managers should choose the level of pollution that balances the costs and benefits. Beyond the balanced level, additional pollution reduction will increase costs and reduce profits. Economists suggest that complying with environmental regulations often leads to high costs that hurt a firm's competitiveness. Joshi et al. (2001) estimate the hidden costs of environmental regulations. By using plant level data from 55 steel mills from 1979-1988, Joshi et al. (2001) document that "a $1 increase in the visible cost of environmental regulation is associated with an increase in total cost of $10-$11, of which $9-$10 are hidden". Based on this empirical evidence, Joshi et al. (2001) conclude that environmental regulations can cause large (hidden) environmental costs, which may hurt a firm's competitive advantage.

Joshi et al. (2001) fail to investigate the nature of those environmental regulations. The majority of those environmental regulations before the early 1990s are command-and-control in nature. Command-and-control regulations are defined as those that tell the polluter how much pollution can be emitted and how pollution should be controlled. Under command-and-control regulations, companies are not allowed to find innovative ways to improve environmental performance and reduce environmental costs at the same time. Command-and-control environmental regulations lead to increased environmental costs. According to Damon and Khanna (1999), a major factor that caused the EPA to introduce innovation-friendly regulations/programs after the late 1980s was the realization of the escalating cost of command-and-control regulations.

(2) Ecoefficiency

Contrary to the Traditional View, ecoefficiency suggests that improving environmental performance can be compatible with improving economic performance. A large number of success stories support the existence of this phenomenon. Ecoefficiency maintains that "companies can produce more useful goods and services while simultaneously reducing negative environmental impact, resource consumption, and costs". This concept contains three important messages. First, improving environmental and economic performance can be complementary. Second, improving environmental performance should not be viewed as a matter of goodwill but as a matter of competitive advantage. Third, ecoefficiency is complementary and supportive of sustainable development (Hansen and Mowen 2004). Under ecoefficiency, managers are fully rational and voluntarily engage in ecoefficient behavior and it seems unnecessary for the regulatory agency (e.g., EPA) to establish any environmental standards.

(3) the Porter Hypothesis

While agreeing with ecoefficiency, Porter (1991) and Porter and van der Linde (1995) are skeptical that mangers will voluntarily engage in ecoefficient behavior (Burnett 2003, Burnett and Hansen 2004). Instead, Porter points out that regulatory intervention is necessary since mangers have bounded rationality relative to ecoefficiency. Williamson (1981) defines the bounded rationality as 'the property of an agent that behaves in a matter that is nearly optimal with respect to its goals as its resources will allow'. In other words, the agent may experience limits in formulating and solving complex problems. The bounded rationality is caused by the fact that firms are "currently in a transitional phase of industrial history where companies are still inexperienced in dealing creatively with environmental issues (Porter and van der Linde 1995, 99-100)". Porter states that in such a situation properly designed regulation can have a positive impact on the direction of innovation. In Porter's view, regulation intervention refers to properly designed environmental regulations, which emphasize desired environmental outcomes without specifying means of achievement. The purpose of such regulations is to "create maximum opportunities for innovations by letting companies discover how to solve their own problems".

Porter proposes that properly designed environmental regulation can trigger innovations that may partially or more than fully offset the costs of complying with them. Such innovation offsets can not only reduce the compliance costs but also lead to absolute advantage (Porter and van der Linde 1995, 98). Porter lists six explanations to support his hypothesis:

1) Environmental regulation signals companies about likely resource inefficiencies and potential technological improvements, since companies are not very aware of potential cost savings. This also implies that managers have bounded rationality.

2) Environmental regulation focused on information gathering can achieve major benefits by raising corporate awareness.

3) Environmental regulation reduces the uncertainty that investments to address the environment will be valuable. This encourages more investments in this area.

4) Environmental regulation creates pressure that promotes innovation and progress.

5) Environmental regulation levels the transitional playing field. It ensures that one company cannot gain a competitive advantage by ignoring the environment during the transition period to innovation-based solutions.

6) Environmental regulation is needed in the case of incomplete offsets. This means that innovations may not always completely offset the compliance cost, especially in the short term. In such cases, regulation is necessary to improve environmental performance.

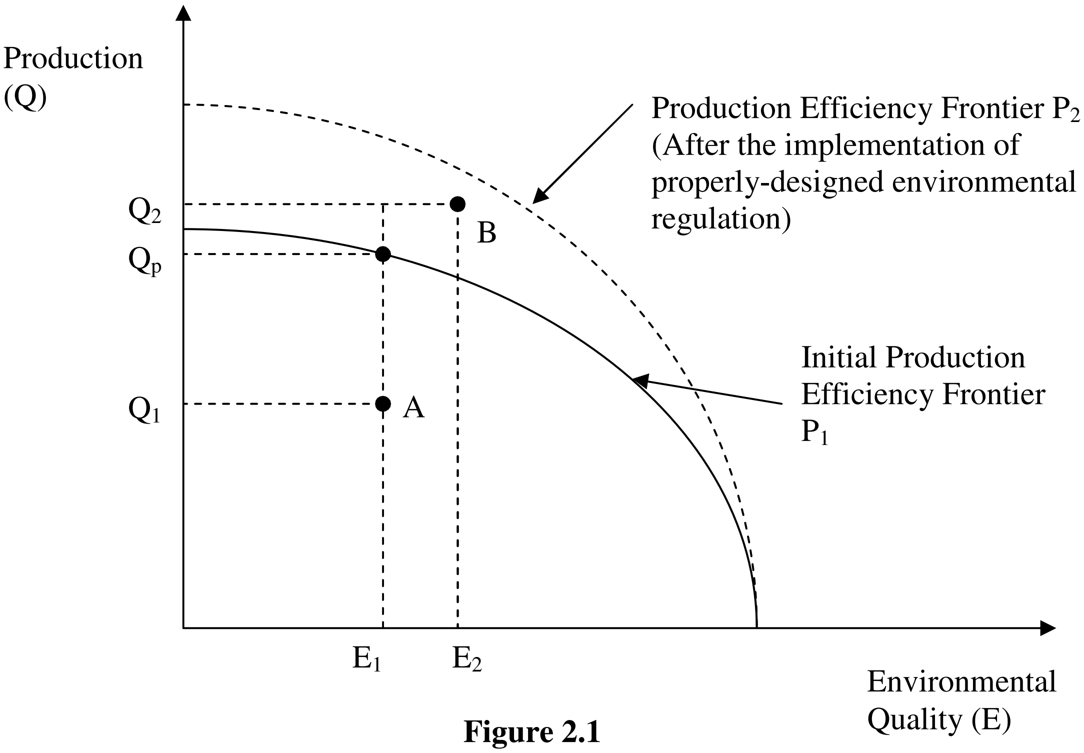

Figure 2.1
The Porter Hypothesis

Figure 2.1 can be used as a simple example to illustrate the Porter Hypothesis. The x axis denotes the level of environmental quality, while the y axis stands for the productivity level of firms. Suppose the firm produces only a single output (Q). The initial production efficiency frontier is defined as $P_{1.}$ Given an environmental regulation that demands an environmental quality of (at least) E_1, thus the production possibility set will be limited to the area that is to the right of the vertical line E_1 and within the bold curve P_1. Suppose a firm operates at point A. At point A, it is possible for the firm to produce more goods without hurting the environmental quality, since it operates beneath the efficiency frontier P_1. Now suppose that the government introduces a properly designed environmental regulation, which increases the level of environmental quality from E_1 to E_2. According to the Porter Hypothesis, such a regulation can make firms aware of their own performance and inefficiencies, and give firms an incentive to improve their performance. In Figure 2.1, this is illustrated by a movement from point A to point B. At point B, productivity is higher than point A, as the production has increased from Q_1 to Q_2. In addition, the Porter Hypothesis suggests that a properly designed regulation can improve current technology, encourage innovations, and thus help firms produce better products that are less costly. This is indicated as an outward shift from P_1 to P_2 in Figure 2.1. This shift suggests that it is possible to produce more goods without worsening the environmental quality. The total effect on output from the movement (E_1 to E_2) is the sum of the efficiency increase (Q_p-Q_1) and the gain from advances in technology (Q_2-Q_p).

Figure 2.2 explains the Porter Hypothesis from another perspective.

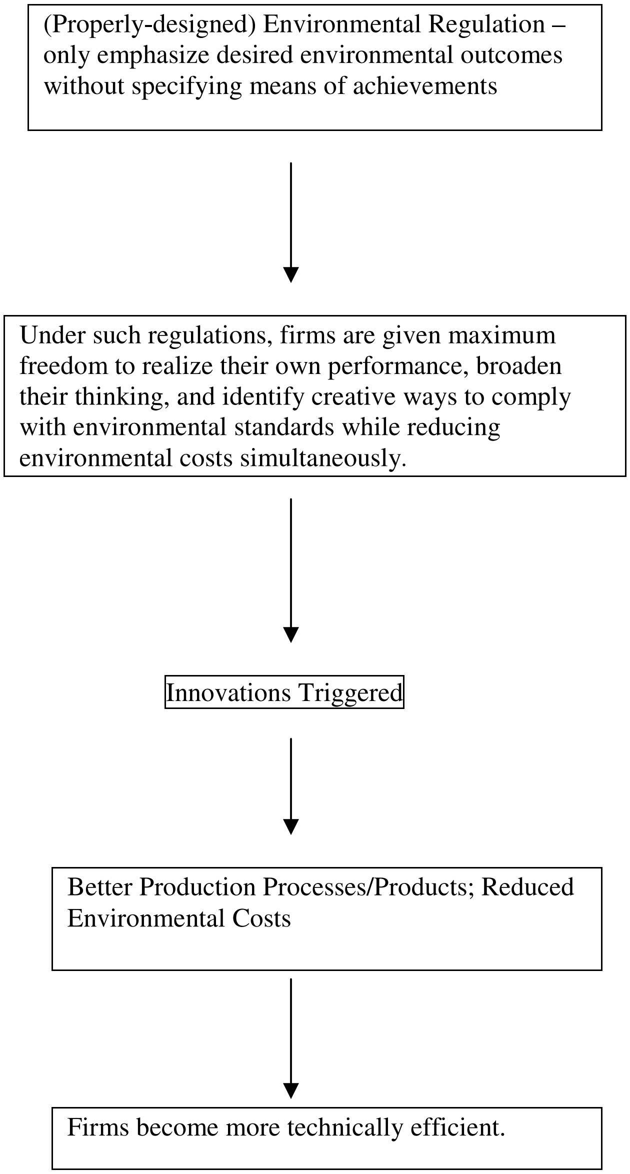

Figure 2.2
Another Perspective of
The Porter Hypothesis

Jaffe and Palmer (1997) identity three versions of the Porter Hypothesis. The first version of the hypothesis is that properly environmental regulations stimulate innovation. The second version states that properly designed environmental regulations place constraints on the profit opportunities of firms, and that firms subject to those environmental regulations will do things differently. The third version, also called the strong version of the Porter hypothesis, rejects the profit-maximizing paradigm and states that firms under normal operating circumstances do not necessarily find or pursue all profit-maximizing opportunities for new products or processes. Thus, properly designed environmental regulations may induce them to broaden their thinking and to find new products or processes that both comply with regulations and increase profits. In this strong version view, properly designed environmental regulation can be regarded as a free lunch to firms. Under the Porter Hypothesis, environmental regulation can lead to "win-win" situations, since firms not only reduce pollution but also reduce their environmental costs. From this perspective, environmental regulation act as free money or courtesy of a suggestion from the government.

One criticism of the Porter Hypothesis is that much of the supporting evidence remains anecdotal, relying on individual success stories to support a relationship between environmental performance and economic performance of a company. For instance, Porter and van der Linde (1995) only cite several case studies as evidence for the validity of the Porter Hypothesis. These case studies include the cell battery, electronic manufacturing, printing ink, paper and pulp, and refrigerator industries. Due to the lack of empirical evidence, the Porter Hypothesis has been, and still is, very controversial. Many economists (e.g., Palmer et al. 1995) do not accept the basic arguments of the

Porter Hypothesis. For example, after reviewing those case studies in Porter and van der Linde (1995), Jaffe et al. (1995) are skeptical that “continually higher regulatory standards would lead firms to discover new clean and profitable technologies” (p.156) and note that “…there is relatively little evidence to support the hypothesis…systematic empirical evidence in this area is only beginning” (p.157). Indeed, the empirical literature on the relationship between environmental regulation and a firm’s technical efficiency is still scarce.

To empirically test the Porter Hypothesis, properly designed regulations that attempt to promote innovations must be present. A good example of such regulations is the 1990 Clean Air Act Amendments (1990 CAAA), which required power plants to reduce their sulfur dioxide (SO2) emissions to a predetermined level and granted power plants complete freedom in how they achieved compliance. By testing the 1990 CAAA, Burnett (2003) became the first empirical study that provides a direct test of the Porter Hypothesis[1]. Burnett (2003) argues that if the Porter Hypothesis is true, then utilities subject to the 1990 CAAA should exhibit an increase in production efficiency relative to performance prior to the Act. By applying a nonparametric method (Data Envelopment Analysis) to measure the relative efficiencies of 84 electric utility plants from 1990 to 1995, Burnett (2003) finds that complying with the 1990 CAAA does have a positive impact on a plant’s technical efficiency. Results from Burnett (2003) support the Porter Hypothesis. However, there are still a few limitations in Burnett (2003). First, results in Burnett (2003) are confined to a single industry. Whether these findings can be generalized to other industries is still questionable. Second, the focus of Burnett (2003) is limited to firms in the United States. Last, Burnett (2003) only investigates the impact of

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[1] Please see Appendix D for similarities and differences between Burnett (2003) and this study.

complying with 1990 CAAA at the plant level. A potential avenue for future research in this area would be to explore the impact of environmental regulation at the firm level.

Another empirical study is Murty and Kumar (2003), which examines the effect of environmental regulation on the productive efficiency of water polluting industries by using panel data of 92 Indian firms during the period 1996-1999.This paper employs a parametric method – translog function to measure a firm’s efficiency. Empirical results support the Porter Hypothesis. However, there are still a few limitations. Murty and Kumar (2003) fail to identify the nature of these environmental regulations. Whether these regulations are properly designed remains unknown. In addition, results are only confined to a single industry in India.

Both Burnett (2003) and Murty and Kumar (2003) provide empirical evidence supporting the Porter Hypothesis, and call for more empirical testing.

2.2 Literature on U.S. EPA's 33/50 Program

There are some empirical studies on the U.S. EPA's 33/50 Program[2], however the majority of these studies merely investigate factors that cause firms to participate. Arora and Cason (1995) find that firms with high toxics releases are more likely to participate in the 33/50 Program in the following industries: chemical (SIC 28), petroleum refining (SIC 29), rubber and plastics (SIC 30), primary metals (SIC 33), fabricated metals (SIC 34), electrical equipment (SIC 36), and transportation (SIC 37). Alberini and Videras (2000) also investigate factors leading to participating in the 33/50 Program by studying manufacturing firms from S&P 500. They find that firms with significant environmental impacts are more likely to participate. In addition, publicity is an important component of participation. The above studies reveal factors that may lead to participation, but they fail to investigate the impact of the 33/50 Program on a participant's environmental and economic performance.

Only one study (Damon and Khanna 1999) examines the impact of the 33/50 Program on a firm's environmental and economic performance in the U.S. chemical industry. Damon and Khanna (1999) find that program participation led to a significant decline in toxic releases over the period 1991-1993. Also, results indicate that larger reduction in 33/50 chemicals achieved before the participation did not have a significant effect on participation. This suggests that firms did not get a free ride on reductions achieved before the 33/50 Program was initiated. By using Return on Investment (ROI) as a proxy for the short-term economic performance and Excess Value per unit Sales

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[2] EPA's 33/50 Program was launched in 1991 to encourage firms to voluntarily reduce their emissions of 17 high-priority toxic chemicals. The goal was to reduce the aggregate releases of these chemicals by 33% by 1992 and by 50% by 1995.

(EV/S) as a proxy for the long-term economic performance for a firm, Damon and Khanna (1999) find that the effect of the 33/50 Program on the ROI of firms is significantly negative, but the impact on EV/S is significantly positive[3].

There are a few limitations in Damon and Khanna (1999). First, results obtained from one single industry may not be convincing. Second, Damon and Khanna (1999) point out that a positive impact on EV/S indicates that 'investors expect the cost of participating and improving environmental performance to be offset in the future by lower environmental liabilities, lower abatement expenditures, increased consumer goodwill, and savings in inputs costs due to increased efficiency in production'. The above reasoning seems to support the Porter Hypothesis. But Damon and Khanna (1999) fail to empirically examine the above statement. Third, using ROI and EV/S as proxies for economic performance may produce inaccurate results, since there could be factors besides the pollution reduction that can have an impact on these two proxies. Last, Damon and Khanna (1999) study changes in environmental and economic performance of a participant over the period of 1991-1993, which is only the first three years of the 33/50 Program. Thus, results may not describe the entire story of the program.

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[3] EV/S = [Market value of a firm – Book value of assets]/Sales

CHAPTER 3

STATEMENT OF HYPOTHESES

Arora and Cason (1995) suggest that participating in the 33/50 Program may generate economic benefits for firms. For example, voluntarily reducing chemicals releases typically requires firms to reformulate production processes and redesign products. A redesigned production process may help firms realize future cost savings. Also, reducing more chemicals may improve a firm's public image, and investors may perceive that a firm that commits to reducing its chemical pollution ahead of time as gaining competitive advantages over its competitors. Thus, participating firms theoretically could realize future cost savings and possibly increased revenues. The above reasoning is consistent with either the Porter Hypothesis or ecoefficiency. Furthermore, Daman and Khanna (1999) point out that 'the 33/50 Program provides technical assistance to firms to help them identify and adopt innovative waste minimization practices, through nationally held workshops and computer bulletin boards'. Such assistance is expected to help firms become more cost-effective. Alberini and Videras (2000) also suggest that there is a possibility that cost savings can be realized through the 33/50 Program. Finally, one interesting finding from Daman and Khanna (1999) is that firms with old equipments are more likely to participate in the 33/50 Program. This suggests that participants may experience an increase in production efficiency after they replace old equipment with new and innovative equipment. The above reasoning also applies to the ARET participants, since the ARET expands on the 33/50 Program.

Both the 33/50 Program and the ARET Program are good candidates for testing the Porter Hypothesis, since they represent a form of government intervention that emphasizes desired environmental outcomes without specifying means. This hypothesis argues that properly designed environmental regulation not only increases environmental quality but also helps firms discover innovations that can offset the compliance costs. Porter and van der Linde (1995) further contend that innovation offsets occur mainly because (properly designed) environmental regulation leads to improved efficiency of resource usage. This implies that complying with such regulations may result in greater technical efficiency. If the Porter Hypothesis is valid, then participants should experience an increase in technical efficiency relative to performance prior to the program. Based on the Porter Hypothesis, the theory suggests an increase in the technical efficiency of participating firms under EPA's 33/50 Program and Canadian ARET Program.

H1 (alternative form): U.S. Companies that participated in the EPA's 33/50 Program will be at least as technically efficient after the participation as before the participation.

H2 (alternative form): Canadian companies that participated in the ARET Program will be at least as technically efficient after the participation as before the participation.

CHAPTER 4

RESEARCH DESIGN

Before attempting to measure efficiency, this study needs to clearly define the term ‘efficiency’. According to Farrel (1957), productive efficiency can be decomposed into two components – technical efficiency (TE) and allocative efficiency (AE). Technical efficiency refers to the physical relation between inputs and outputs. Thus technical efficiency addresses the issue of using given inputs to maximize outputs. Allocative efficiency addresses the issue of achieving the right mixture of inputs to maximize the given output.

The efficiency in this study refers to technical efficiency. This study uses the technical efficiency for the following reasons. First, technical inefficiency is clearly incorporated into the specification of the stochastic frontier analysis. Second, it may be difficult to measure the allocative efficiency in this study, since the prices for inputs are not available. Also compared to technical efficiency, it may be difficult to interpret allcoative efficiency. Last, the efficiency in the Porter Hypothesis refers to technical efficiency.

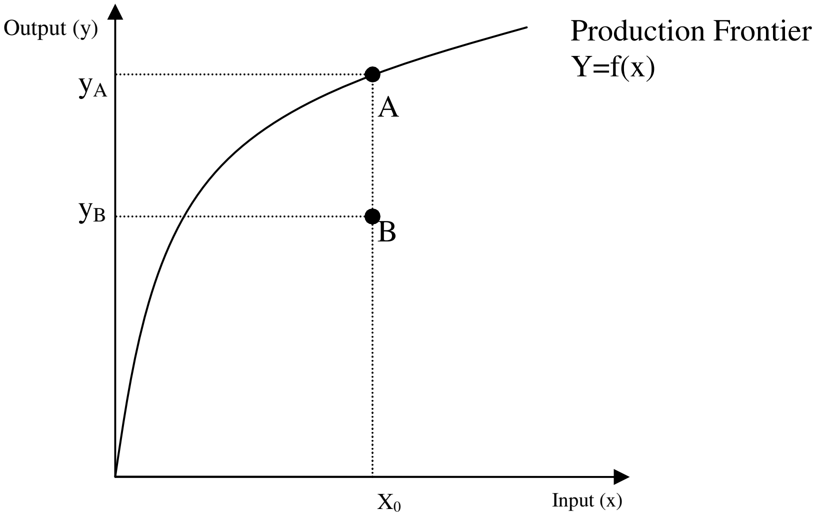

Figure 4.1
An Example of Technical Efficiency

Assume there is one input (x) and one output (y). The production frontier Y=f(x) denotes the maximum output attainable from each level of input, with the current state of technology. If a firm operates on the frontier, then the firm is technically efficient. If a firm operates beneath the production frontier, then the firm is not technically efficient. For example, a firm at point B is technically inefficient because it can operate at point A which produces a higher output level ($y_A > y_B$) with the same level of input (x_0).

4.1 The Idea of Methodology Cross-checking

In terms of methodology, this study falls into the third category described in Murty and Kumar (2003) and applies the technique of distance function to measure production efficiency[4]. The existing applications of distance functions include parametric and nonparametric studies. Both parametric and nonparametric methods are good tools to

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[4] Please see Appendix E for more information.

estimate frontier efficiency. However, despite intense research efforts, there is really no consensus on the preferred method. Berger and Humphrey (1997) suggest that it is not possible to determine which of the two major approaches dominates the other. The majority of empirical function analyses use only one of the above two methods to estimate their distance functions.

Charnes et al. (1988) propose an idea of 'methodology cross-checking', which advocates applying both parametric and nonparametric methods to the same data set for estimating efficiency. Charnes et al. (1988) argue that methodology cross-checking will help to guard against one-sided inferences from undue reliance on only one methodology, because applying a different methodology to the same data set may arrive at dramatically opposite conclusions. Berger and Humphrey (1997) also state the importance of 'methodology cross-checking': " Policies and research issues that rely upon firm-level efficiency estimated may be more convincingly addressed if more than one frontier efficiency technique is applied to the same set of data to demonstrate the robustness of explanatory results obtained". In addition, Bauer et al. (1998) suggest that if efficiency estimates are consistent across different methodologies then these measures will be convincing and valid estimates. Currier (2002) performs both parametric and nonparametric methods to evaluate the efficiency of schools in Oklahoma. Both methods produce relatively consistent results. Thus, Currier (2002) concludes that the robustness of her study is significantly increased, and the results are more convincing. In fact, the two major methods can be and should be used to complement each other. Consistent with Charnes et al. (1988), this study applies both parametric and nonparametric methods.

4.2 Model Specification

In order to define an output distance function, this study defines the production function of the firm using the output set as $P(x)$, which represents the set of all output vectors, $y \in R^M$, which can be produced using the input vector, $x \in R^K$[5]. That is,

$$P(x) = \{y \in R^M : x \to y\}$$

The output distance function is then defined on the output set, $P(x)$, as

$$D_0(x, y) = \min\{\theta : (y/\theta) \in P(x)\}$$

The distance function, $D_0(x, y)$, will take a value which is less than or equal to one if the output vector, y, is an element of the feasible production set, $P(x)$. That is, $D_0(x, y) \leq 1$ when $y \in P(x)$. The distance function will take a value of one if y is located on the efficient frontier. That is, $D_0(x, y) = 1$ when $y \in IsoqP(x)$.

Here is an example of an output distance function. Suppose a single input x_1 can produce two outputs y_1, y_2.

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[5] The output distance function describes how 'far' an output vector is from the boundary of the representative output set, given the fixed input vector.

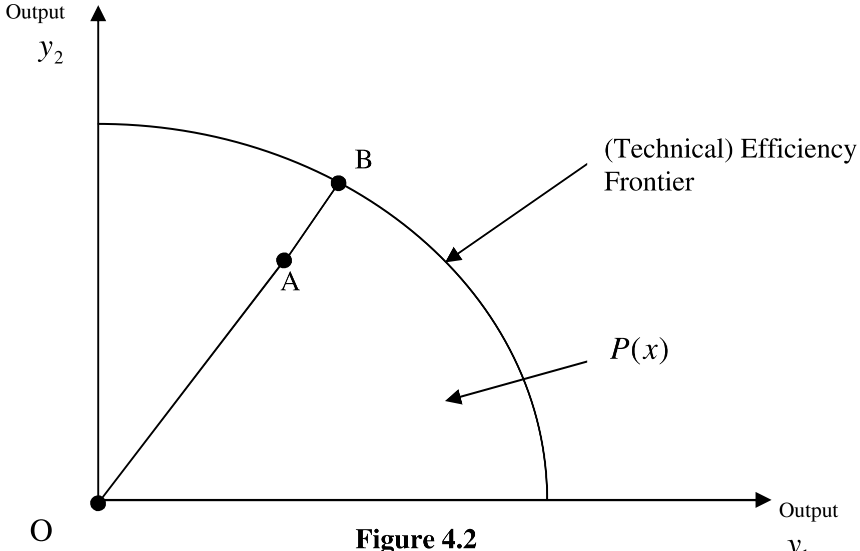

Figure 4.2
An Example of Output Distance Function

The production possibility set, $p(x)$, is the area bounded by the efficiency frontier curve and the y_1 and y_2 axes. For a firm operating at point A in figure 4.1, the value of the distance function for the firm is the ratio $D = \frac{OA}{OB}$. If the firm can operate at point B, which is on the efficiency frontier, then the value of distance function for operating at point B is equal to 1.

4.2.1 The Parametric Model – Stochastic Frontier Analysis (SFA)

This study uses the stochastic frontier analysis (SFA), one of the most widely used parametric models, to estimate the efficiency of the firm. Introduced by Aigner et al. (1977), SFA assumes that the production of a firm is bounded by the sum of a parametric function of known inputs and a random error for a given combination of input levels. The greater the realized production falls below the production frontier, the greater the level of inefficiency. SFA involves specifying a parametric form for the production technology and using linear programming to select parameter values that provide the closest possible envelopment of the observed data. A typical SFA model is given as:

$$\ln(y_{it}) = x_{it}\beta + \nu_{it} - \mu_{it} \qquad \text{[Equation 1]}$$

where y_{it} = the output of i^{th} firm in t^{th} period

x_{it} = a vector of inputs of i^{th} firm in t^{th} period.

β = the vector of unknown parameters be estimated.

ν_{it} = random error. This term captures random variation in output due to factors beyond the control of firms, such as market crash, weather, etc. $\nu_{it} \sim N(0, \sigma_\nu^2)$.

μ_{it} = technical inefficiency of i^{th} firm in t^{th} period, The common assumption is that this term is firm-specific and non-negative. The condition that $\mu_{it} \geq 0$ guarantees that all observations either lie on, or are beneath, the stochastic efficiency frontier. $\mu_{it} \sim N(0, \sigma^2)$.

The technical efficiency of the i-th firm is defined by Aigner et al (1977) as below

$$\text{Technical Efficiency (TE)} = \exp(-\mu_{it}) \qquad \text{[Equation 2]}$$

TE_{it} is a function of $e^{-\mu_{it}}$. Given that μ_{it} is a non-negative value, the lower the value of μ_{it} is, the higher the value of technical efficiency.

A stochastic frontier model can be illustrated in Figure 4.3.

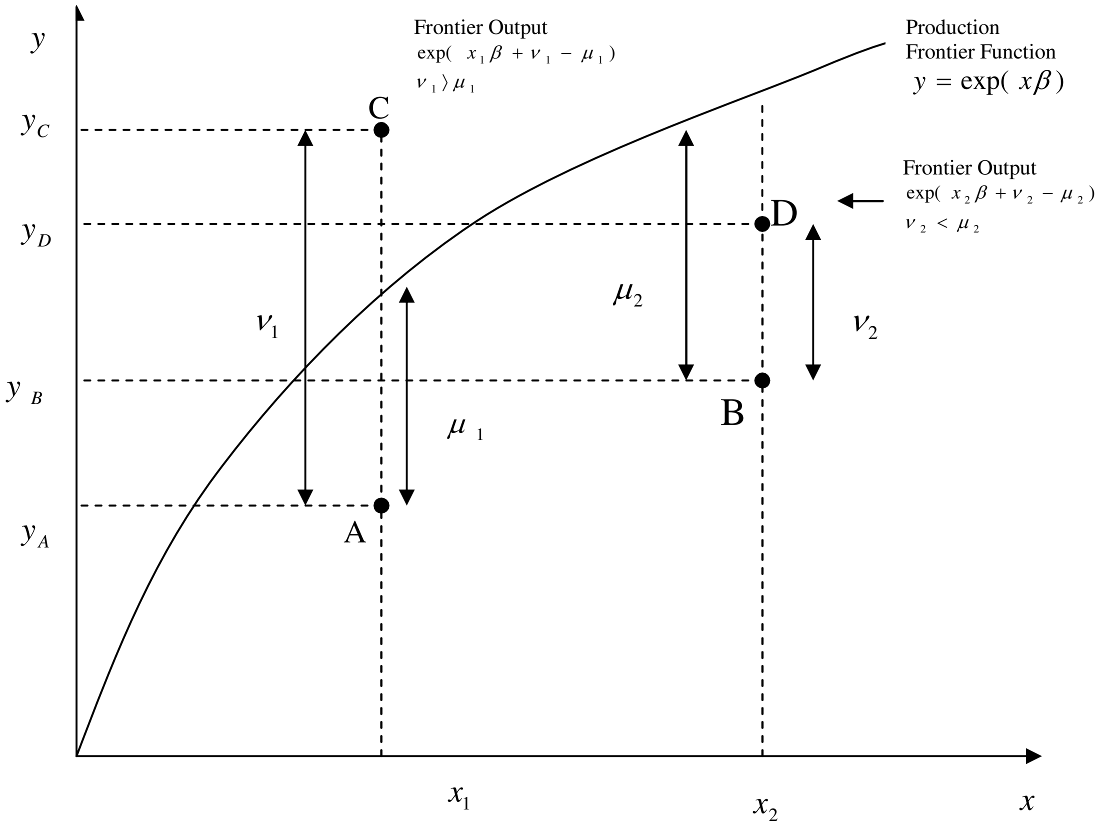

Figure 4.3
Stochastic Frontier Model

The model, defined by Equation 1, is called the stochastic frontier production function because the output values are bounded by the stochastic (random) variables. The random error, v_i, can be positive or negative and so the stochastic frontier outputs vary about the deterministic part of the frontier model, $\exp(x_i\beta)$. Suppose the observed value for firms 1 and 2 are denoted by points A and B, respectively. If $v_1 > \mu_1$, the value of stochastic frontier output for firm 1 is shown by point C. If $v_2 < \mu_2$, the value of stochastic frontier output is shown by point D. Thus, the stochastic output will be above the frontier if $v_i > \mu_i$ and below the frontier if $v_i < \mu_i$.

The parameters of the stochastic frontier function can be estimated using the Maximum-likelihood (ML) method. Battese and Corra (1977) suggest that the parameters, $\gamma = \frac{\sigma^2}{\sigma_s^2}$, be used because it has a value between zero and one.

The log-likelihood function is then defined in Battese and Corra (1977) as:

$$Ln(L) = -\frac{N}{2}\ln(\frac{\pi}{2}) - \frac{N}{2}\ln(\sigma_s^2) + \sum_{i=1}^{N}\ln\left[1-\Phi(z_i)\right] - \frac{1}{2\sigma_s^2}\sum_{i=1}^{N}\left(\ln y_i - x_i\beta\right)^2 \quad \text{[Equation 3]}$$

Where $z_i = \frac{\ln y_i - x_i\beta}{\sigma_s}\sqrt{\frac{\gamma}{1-\gamma}}$

$\Phi(*)$ is the distribution function of the standard normal random variable.

$$\gamma = \frac{\sigma^2}{\sigma_s^2}$$

$$\sigma_s^2 = \sigma^2 + \sigma_v^2$$

The Maximum-likelihood estimates of β, σ_s^2 and γ are obtained by finding the maximum of the log-likelihood function, defined in Equation 3.

The technical efficiency of the i-th firm is defined as $TE = \exp(-\mu_i)$. This involves the technical inefficiency effect, μ_i, which is unobservable. Even if the true value of parameter vector, β, in the stochastic frontier model (Equation 1) was known, only the difference (residual), $e_i = v_i - \mu_i$, could be observed. Battese and Coelli (1988) point out that the best predictor of $\exp(-\mu_i)$ can be estimated by using:

$$E\left[\exp(-\mu_i)\right] = \frac{1-\Phi\left(\sigma_A + \gamma e_i / \sigma_A\right)}{1-\Phi\left(\gamma e_i / \sigma_A\right)}\exp\left(\gamma e_i + \sigma_A^2/2\right) \quad \text{[Equation 4]}$$

Where $\sigma_A = \sqrt{\gamma(1-\gamma)\sigma_s^2}$

$$e_i = \ln(y_i) - x_i\beta$$

$$\gamma = \frac{\sigma^2}{\sigma_s^2}$$

$\Phi(*)$ is the distribution function of the standard normal random variable.

SFA can take various functional forms. There are several important criteria for designing functional forms that are to be estimated. According to Currier (2002), a suitable functional form should satisfy:

(1) Basic axioms on the nature of technology, (e.g., concavity[6], symmetry[7], etc)

(2) Technological and behavioral assumption, (e.g., profit maximization or cost minimization)

(3) Some simplifying assumptions that may facilitate the analysis, (e.g. the independence of error terms)

In addition, there are some practical considerations:

(1) The functional forms should only contain the parameters that are necessary. Excess parameters may create multicollinearity.

(2) The functional forms should be clear and easy to interpret.

(3) The functional forms should be chosen with computational ease in mind.

This study selects the Cobb-Douglas functional form, which has been commonly used in the empirical estimation of frontier models[8]. Its simplicity is a very attractive feature. The Cobb-Douglas function is easy to estimate, and it also functions well with small samples.

A Cobb-Douglas function is $Y = AX_1^{\alpha} X_2^{\beta}$

Where

Y = output

X_1 = input 1

X_2 = input 2

A, α, β are constants determined by technology

---

[6] A shape that curves or bends inward.

[7] A design (or composition) with identical or nearly identical form on opposite sides of a dividing line or central axis.

[8] The Cobb-Douglas function was proposed by Knut Wichsell, and tested against statistical evidence by Paul Douglas and Charles Cobb in 1928.

If $\alpha + \beta = 1$, then the function has constant returns to scale. If $\alpha + \beta < 1$, then the function has decreasing returns to scale, and if $\alpha + \beta > 1$ returns to scale are increasing.

4.2.2 The Non-Parametric Model – Data Envelopment Analysis (DEA)

As the most widely used nonparametric approach, DEA was introduced by Charnes et al. (1978) as "a mathematical programming model applied to observational data that provides a new way of obtaining empirical estimates of relations that are cornerstones of modern economics". Unlike the typical parametric approach that evaluates DMUs to an average DMU, DEA is an extreme point method that compares each DMU with only the 'best' DMU[9].

For each DMU, DEA forms the input and output by weights (v_i) and (u_i):

Input = $v_1 x_{10} + \ldots + v_m x_{m0}$

Output = $u_1 y_{10} + \ldots + u_s y_{s0}$

By using linear programming techniques, DEA attempts to determine the weights so as to maximize the ratio $\frac{output}{input}$. The weights may vary from one DMU to another. Each DMU is assigned a 'best' set of weights with values that may vary from one DMU to another. The term 'best' is used here to mean that the $\frac{output}{input}$ ratio for each DMU is maximized relative to all other DMUs.

Figure 4.4 shows an example of DEA. Assume one input and one output. The production function of each DMU is variable-return-to-scale. Suppose there are only 7 DMUs, (A, B, C, D, E, F, and G).

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[9] In efficiencies studies, the organization under study is called a DMU (Decision Making Unit). In general, a DMU is an entity that is responsible for converting inputs into outputs. DMUs may include schools, firms, banks, hospitals and so forth.

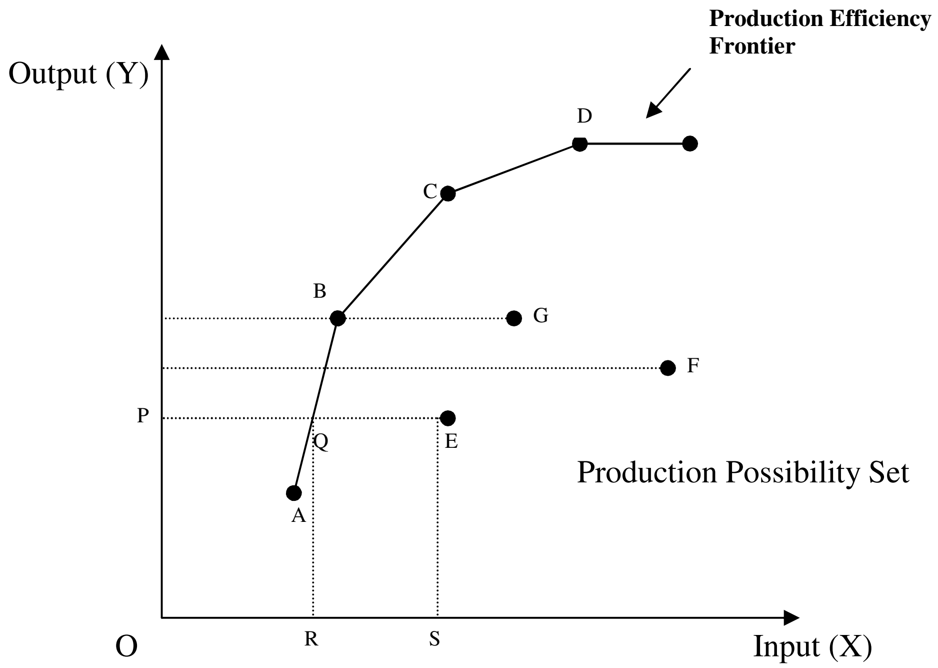

Figure 4.4
An Example of Data Envelopment Analysis

DMUs (A, B, C, D) are on the efficiency frontier, and thus their values of the $\frac{output}{input}$ ratio are one. The values of the $\frac{output}{input}$ ratio for DMUs, which operate beneath the efficiency frontier, are between zero and one. For instance, the efficiency of DMU (point) E is $\frac{PQ}{PE}$. [$\frac{output}{input}$ ratio for point Q is $\frac{QR}{PQ}$, while $\frac{output}{input}$ ratio for point E is $\frac{ES}{PE}$. Thus the relative efficiency of point E $= \frac{\frac{ES}{PE}}{\frac{QR}{PQ}} = \frac{PQ}{PE}$, since $QR = ES$]

This study applies the variable-return-to-scale DEA model, also known as the BCC model. [Banker et al. 1984]. This model estimates the efficiency of DMUs by solving the following linear program:

Max $z = u \cdot y_0 - u_0$

Subject to $v \cdot x_0 = 1$

$-v \cdot x + u \cdot y - u_0 e \leq 0$

$v \geq 0$, $u \geq 0$, u_0 free in sign

Where

x, y represent vectors of inputs and outputs respectively.

z and u_0 are scalars.

u_0 may be positive or negative.

e denotes a row vector in which all elements are equal to 1.

v and u denote weights associated with a particular DMU.

4.3 An Investigation of Efficiency Changes – Malmquist Productivity Index (MPI)

In order to test the hypotheses, the proposed study needs to investigate the changes of a firm's production efficiency. The MPI is an index number that enables a productivity comparison between two periods. To start with, suppose we have an output possibility set:

P(x) = {y: x can produce y}

The output distance function with technology at time s, (the initial time period), can be written as:

$d^s(x,y) = \min \{Q: \frac{y}{Q} \in P(x)\}$

This distance function measures the maximum output that a given amount of inputs can produce.

Similarly, the output distance function with technology at time t, (the final time period), can be written as:

$$d^t(x,y) = \min\{Q: \frac{y}{Q} \in P(x)\}$$

The Malmquist Productivity Index in relation to the technology of the initial period (s) can be defined as:

$$M^s = \frac{d^s(x^t, y^t)}{d^s(x^s, y^s)}$$

The Malmquist Productivity Index in relation to the technology of the final period (t) can be defined as:

$$M^t = \frac{d^t(x^t, y^t)}{d^t(x^s, y^s)}$$

Figure 4.5 illustrates M^s and M^t by using a simple example. Suppose one-input (x) and one-output (y) with a constant return to scales.

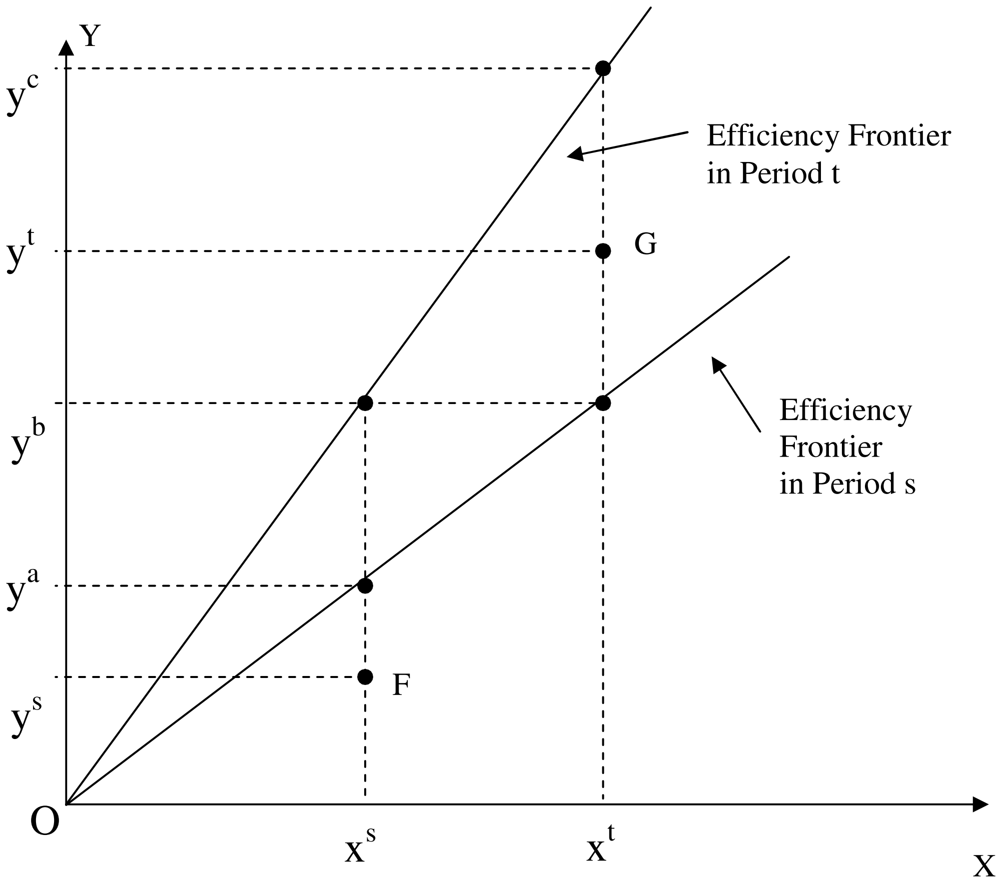

Figure 4.5
An Example of
Malmquist Productivity Index

Point F and G in Figure 4.4 represent the performance of a DMU in period S and period T respectively. In both case, it operates beneath the efficiency frontier. A productivity index in period S can be calculated as $(Y^t/Y^s)/(Y^b/Y^a)$, where (Y^t/Y^s) denotes the output growth and (Y^b/Y^a) represents a movement along the efficiency frontier in period S. The index can be rewritten as $(Y^t/Y^b)/(Y^s/Y^a)$. This is consistent with the definition of Malmquist Index for period s.

$$M^s = \frac{d^s(x^t, y^t)}{d^s(x^s, y^s)} = \frac{(Y^t / Y^b)}{(Y^s / Y^a)}$$

A productivity index in period T can be calculated as $(Y^t/Y^s)/(Y^c/Y^b)$, where (Y^t/Y^s) represents the output growth and (Y^c/Y^b) denotes a movement along the efficiency frontier in period T. The index can be rewritten as $(Y^t/Y^c)/(Y^s/Y^b)$. This is consistent with the definition of Malmquist Index for period t.

$$M^t = \frac{d^t(x^t, y^t)}{d^t(x^s, y^s)} = \frac{(Y^t / Y^c)}{(Y^s / Y^b)}$$

Fare et al. (1992, 1994) define the Malmquist Productivity Index between period s and period t as the geometric mean of the above two indices:

$$\mathrm{M}(x^t, y^t, x^s, y^s) = \left[\frac{d^s(x^t, y^t)}{d^s(x^s, y^s)} \times \frac{d^t(x^t, y^t)}{d^t(x^s, y^s)} \right]^{\frac{1}{2}} \qquad \text{[Equation 5]}$$

If the value of a MPI is greater than one, this indicates that there has been an increase in a firm's productivity from period s to period t. If the value of a MPI is smaller than one, this suggests that the firm's productivity has decreased from period s to period t. A value equals to one indicates no change between two periods.

Equation 5 is also equivalent to:

$$M(x^t, y^t, x^s, y^s) = \frac{d^t(x^t, y^t)}{d^s(x^s, y^s)} \times \left[\frac{d^s(x^t, y^t)}{d^t(x^t, y^t)} \times \frac{d^s(x^s, y^s)}{d^t(x^s, y^s)} \right]^{\frac{1}{2}} \qquad \text{[Equation 6]}$$

where

--- $\dfrac{d^t(x^t, y^t)}{d^s(x^t, y^t)}$ is known as the catch-up effect, which measures the change in technical efficiency between year s and year t. The catch-up effect represents the better or worse of the firm's performance over time.

--- $\left[\frac{d^s(x^t, y^t)}{d^t(x^t, y^t)} \times \frac{d^s(x^s, y^s)}{d^t(x^s, y^s)}\right]^{\frac{1}{2}}$ is known as the frontier shift effect, which measures the shift (advance) in technology between year s and year t.

Equation 6 indicates that the improvement in firms' productivity may not come from only the pure improvement in efficiency. Instead, it might be a combination of the pure improvement in efficiency (the catch-up effect) and the advance in technology (the frontier shift effect).

4.4 Investigating Frontier Shift by using Grosskopf and Valdmanis (1987)

DEA assumes that all firms use the same technology and have the same production frontier, and inefficiency is measured as variation from the production frontier. Before-participation and after-participation firms may have different production functions and use different technology, which may result in different production frontier. To test this possibility, this study uses the procedures described in Grosskopf and Valdmanis (1987). First, the pooled sample is divided into subsamples of before-participation and after-participation firms. Then, this study calculates indices of within-group efficiency for each of the subsamples. At last, the overall efficiency index (EI) and the within-group index (EI*) are combined to compute a between-group efficiency index, which can be used to see if the frontier of one subsample differs from that of the other subsample.

Figure 4.6 demonstrates the relationship between overall, within-group, and between-group efficiency indices. Suppose that Z represent the frontier for the pooled sample (including before-participation and after-participation firms). Assume that points A-D represent firms in one subsample and points E-H represent firms in the remaining subsample. The frontier for the latter group is Z*. The efficiency for point F relative to the total sample frontier Z is measured as EI, where

$$EI = \frac{OF^{\prime}}{OF}$$

The efficiency score for point F relative to its own subsample frontier, the within-group efficiency index (EI*), is calculated as the ratio of $OF^{\prime\prime}$ to OF

$$EI^{*} = \frac{OF^{\prime\prime}}{OF}$$

A between-group index is used to identify differences in the position of frontiers of different groups of firms. The between-group efficiency index (EI**) is calculated as the ratio of the overall efficiency index (EI) to the within-group efficiency index (EI*).

$$EI^{**} = \frac{EI}{EI^{*}} = \frac{(OF^{\prime} / OF)}{(OF^{\prime\prime} / OF)} = \frac{OF^{\prime}}{OF^{\prime\prime}}$$

A test of difference in means for EI** (A) vs. EI**(B) can be used to see which group (A or B) is the most right shifted. A difference in means tells us that one subsample is more efficient than the other.

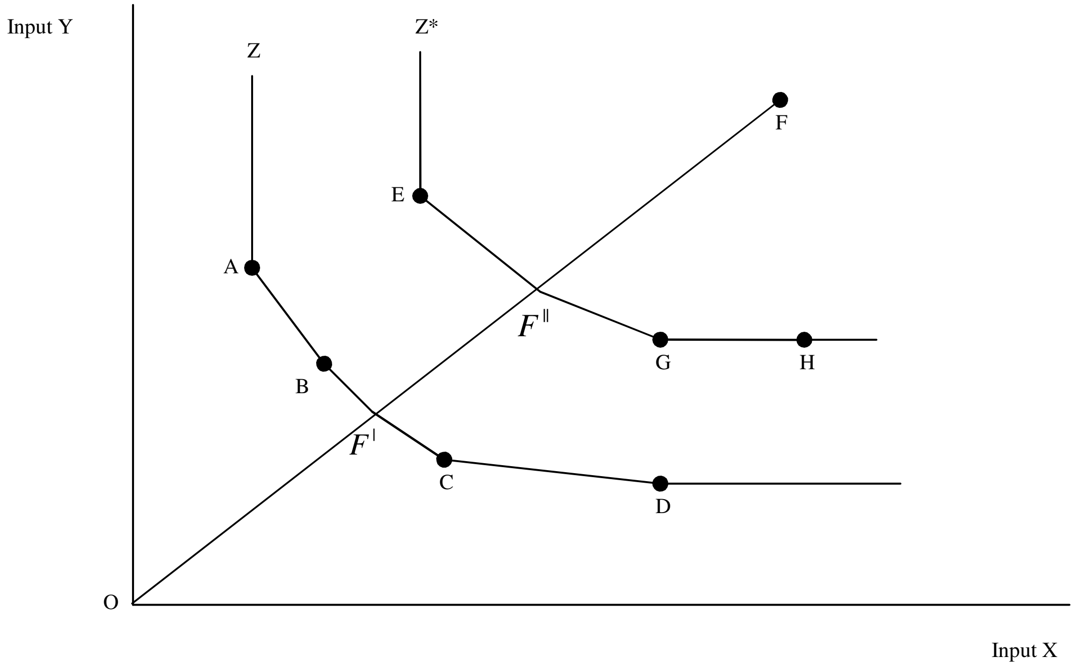

Figure 4.6
Methodology in Grosskopf and Valdmanis (1987)

CHAPTER 5

DATA AND VARIABLES

5.1 Sample Selection

Table 1 describes the sample selection procedures. For testing Hypothesis 1, this study begins with a sample of 1300 firm-year observations[10]. Next this study excludes 994 observations, because they are not public companies. Another 89 observations without 7 years of data available on Compustat (1990-1996) are also deleted. This study further removes firms in industries 26 (Paper and allied products), 30/31 (Rubber and leather products) and 38 (Measurement instrument), since the number of firms in such industries is less than 20. The final sample consists of 179 firm-year observations from 1990 to 1996.

For testing Hypothesis 2, the study begins with a sample of 127 firm-year observations[11]. Next this study excludes 64 observations, because they are not public companies. Another 4 observations without 8 years of data available on Compustat (1993-2000) are also deleted. This study further removes firms in industries 10 (Metal mining), 26 (Paper and allied products) and 33 (Metal), since the number of firms in such

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[11] Contact information: Mr. Brad Fisher, acting manager for environmental performance agreement, Environment Canada, phone: (819) 953 – 5235, email: brad.fisher@ec.gc.ca

industries is less than 20. The final sample consists of 24 firm-year observations from 1993 to 2000.

TABLE 1
Sample Selection and Screening

Panel A: EPA's 33/50 Program

	Sample Size
Original sample[a]	1,300
Non-Public Firms	- 994
Firms without 7 years of data available on Compustat (1990-96)	- 89
Participating firms in industry (SIC=26)	- 14
Participating firms in industry (SIC=30/31)	- 9
Participating firms in industry (SIC=38)	- 15
Final Sample	179

Panel B: Canadian ARET Program

	Sample Size
Original sample[b]	127
Non-Public Firms	- 64
Firms without 8 years of data available on Compustat (1993-00)	- 4
Participating firms in industry (SIC=10)	- 11
Participating firms in industry (SIC=26)	- 14
Participating firms in industry (SIC=33)	- 10
Final Sample	24

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[a] provided by the Environmental Protection Agency of the United States

[b] provided by Canadian Environment

5.2 Variables Selection

In the past some studies have used physical measures for input/output variables, while others have instead used monetary measures (dollar amount). For the majority of the variables, this study uses monetary measures for the following three reasons. First, it is difficult to obtain variable information in physical units; second, Battese and Coelli (1995) suggest that it is preferable to use monetary measures to measure efficiencies at the firm level, since a firm is often engaged in many different activities. Using monetary measures may capture more information and account for all the resources; and third, in a multiple-industry setting, monetary measures may outperform physical measures, since different industries have different physical (input/output) measures.

Table 2 summarizes these variables. This study selects conventional input/output variables to measure technical efficiency. The output variables consist of Sales and Pollution. The input variables consist of Cost of Goods Sold, Selling, General, and Administrative Expenses, and Capital Expenditures.

TABLE 2
Variable Selection for Efficiency Model

Panel A: Output Variables

Output Variables	Measurement	Description
Sales [CompuStat Item Number: A12]	in million of dollars	This variable represents gross sales reduced by cash discounts, trade discounts, and returned sales and allowances for which credit is given to customers.
Pollution [U.S. EPA & Environment Canada]	in pounds of chemicals releases[12]	This variable measures the aggregated releases of targeted chemicals.

Panel B: Input Variables

Input Variable	Measurement	Description
Cost of Goods Sold (COGS) [CompuStat Item Number: A41]	in millions of dollars	This item represents all costs directly allocated by the company to production, such as materials, labor and overhead.
Selling, General, and Administrative Expenses (XSGA) [CompuStat Item Number: A189]	in millions of dollars	This item represents all commercial expenses of operation incurred in the regular course of business pertaining to the securing the operating income.
Capital Expenditures (CAPX) [CompuStat Item Number: A128]	in millions of dollars	This item represents cash outflow or the funds used for additions to the company's property, plant and equipment.

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[12] For EPA's 33/50 program, this item represents the total amount (in pounds) of releases of 17 targeted chemicals. For ARET program, this item represents the total amount (in pounds) of releases of 117 targeted chemicals.

5.3 Sample Descriptive Statistics

Table 3, Panel A, reports the two-digit industry distribution for the EPA's 33/50 participating firms. Thirty-four percent of the sample firms are in industries 28 and 29 (Chemical and Petroleum). Table 3, Panel B, provides means and medians of five attributes for EPA's 33/50 participants. Those five attributes are Sales, Pollution, Cost of goods sold, Selling, general and administrative expenses, and Capital expenditures. Statistical tests indicate that sales, cost of goods sold and selling, general and administrative expenses have increased significantly from 1990 to 1996, while pollution has decreased significantly during that period. Panel C reports the percentage changes in mean and median for each of these five attributes. All variables, except pollution, have increased from 1990 to 1996. Results indicate that participating firms have reduced 60% of targeted chemicals, relative to 1990.

The goal of EPA's 33/50 Program was to reduce the aggregate releases of targeted chemicals by 33% by 1992 and by 50% by 1995. Empirical results (60% reduction in targeted chemicals) suggest that the goal has been achieved. On average, firms have reduced more than 50% of targeted chemical releases since 1990. The evidence supports EPA's conclusion that 33/50 Program was a huge success.

TABLE 3
Descriptive Statistics of EPA's 33/50 Participating Firms

Panel A: Distribution of Two-Digit Industry Classifications

Two-digit SIC	Industry Description	Number of Firms	%
28/29	Chemical/Petroleum	61	34.08%
33/34	Metal	37	20.67%
35	Industrial/Commercial Machinery	28	15.64%
36	Electronic Equipment	30	16.76%
37	Transportation Equipment	23	12.85%
		179	100.00%

Panel B: Financial and Non-financial Attributes of EPA's 33/50 Participants

	1990		1996		Diff. in mean[a]	
Attributes	Mean	Median	Mean	Median	t-stat.	p-value
Sales	6,780.41	1,598.82	8,788.28	1,784.43	-4.78	<0.0001
Pollution[b]	1,609,532	563,638	645,444.20	126,619.30	5.59	<0.0001
Cost of Goods Sold	4,878.23	1,113.90	6,251.35	1,217.70	-4.16	<0.0001
Selling, General Expenses	1,018.53	171	1,349.48	234	-5.03	<0.0001
Capital Expenditures	631.01	78.2	850.59	98.7	-1.14	0.2562

Panel C: Changes in Means and Medians

	Changes in Mean (1990 - 1996)	Changes in Median (1990 - 1996)
Sales	29.61%	11.61%
Pollution	-59.90%	-77.54%
Cost of Goods Sold	28.15%	9.32%
Selling, General and Administrative Expenses	32.49%	36.84%
Capital Expenditures	34.80%	26.21%

---

[a] Difference = Mean value of 1990 – Mean value of 1996

[b] in pounds

Table 4, Panel A, reports means and medians of five attributes for 33/50 firms in industry 28/29 (Chemical and Petroleum). Statistical tests indicate that sales, cost of goods sold, and selling, general and administrative expenses have increased significantly from 1990 to 1996, while pollution has decreased significantly during that period from 2,065,972 to 904,660 pounds. Although capital expenditure has increased from 1990 to 1996, this increase is not statistically significant. Table 4, Panel B, presents the percentage changes in mean and median for each of these five attributes. Participating firms have reduced about 56% of targeted chemicals, relative to 1990. The goal of EPA's 33/50 Program was to reduce at least 50% targeted chemicals. It appears that participating firms in chemical and petroleum industry have achieved the pollution reduction requirement of EPA's 33/50 Program.

TABLE 4
Descriptive Statistics of EPA's 33/50 Participating Firms: Chemical and Petroleum Industry

Two-digit SIC: 28/29
Industry: Chemical/Petroleum
Observation: 61

Panel A: Financial and Non-financial Attributes of Firms in Industry 28/29

	1990		1996		Diff. in mean[a]	
Attributes	Mean	Median	Mean	Median	t-stat.	p-value
Sales	11,069.79	3,722.20	12,950.57	5,101.52	-3.75	0.0004
Pollution[b]	2,065,972	807,979	904,660	496,706.7	4.92	<0.0001
Cost of Goods Sold	7,579.78	2,059.50	8,637.19	2,404.90	-3.15	0.0025
Selling, General Expenses	1,779.05	745.7	2,151.33	882.1	-2.79	0.007
Capital Expenditures	969.68	389	1,210.01	324.3	-0.77	0.445

Panel B: Changes in Means and Medians

	Changes in Mean (1990 - 1996)	Changes in Median (1990 - 1996)
Sales	16.99%	37.06%
Pollution	-56.21%	-38.52%
Cost of Goods Sold	13.95%	16.77%
Selling, General and Administrative Expenses	20.93%	18.29%
Capital Expenditures	24.78%	-16.63%

---

[a] Difference = Mean value of 1990 – Mean value of 1996
[b] in pounds

Table 5, Panel A, reports means and medians of five attributes for EPA’s 33/50 firms in industry 33/34 (Metal). Statistical tests show that sales and cost of goods sold have increased significantly from 1990 to 1996. However, the increases in selling, general and administrative expense and capital expenditure are not statistically different.

Although those participating firms reduced pollution as required by EPA’s 33/50 Program, the amount of pollution reduced is not statistically significant. In fact, those firms reduced about 29% of targeted chemicals, relative to 1990. It appears that firms in industries 33 and 34 (Metal Firms) have failed to satisfy the pollution reduction requirement of EPA’s 33/50 Program.

TABLE 5
Descriptive Statistics of EPA's 33/50 Participating Firms: Metal Industry

Two-digit SIC: 33/34
Industry: Metal
Observation: 37

Panel A: Financial and Non-financial Attributes of Firms in Industry 33/34

	1990		1996		Diff. in mean[a]	
Attributes	Mean	Median	Mean	Median	t-stat.	p-value
Sales	1,193.68	517.01	1,522.04	699.84	-2.00	0.0534
Pollution[b]	775,344.8	269,215	551,356	74,079	1.15	0.2561
Cost of Goods Sold	922.08	403.6	1,087.32	592	-1.89	0.0663
Selling, General Expenses	134.71	53.5	207.66	73.1	-1.21	0.2344
Capital Expenditures	93.7	22.2	98.73	33.6	-0.25	0.8028

Panel B: Changes in Means and Medians

	Changes in Mean (1990 - 1996)	Changes in Median (1990 - 1996)
Sales	27.51%	35.36%
Pollution	-28.89%	-72.48%
Cost of Goods Sold	17.92%	46.68%
Selling, General and Administrative Expenses	54.15%	36.64%
Capital Expenditures	5.37%	51.35%

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[a] Difference = Mean value of 1990 – Mean value of 1996
[b] in pounds

Table 6, Panel A, presents means and medians of five attributes for EPA's 33/50 firms in industry 35 (Industrial and Commercial Machinery). Statistical tests indicate that cost of goods sold and selling, general and administrative expenses have increased significantly from 1990 to 1996, while pollution has decreased significantly during that period from 503,429 to 122,648 pounds. Although sales and capital expenditure have experienced increases, these increases are not statistically significant. Furthermore, results in Panel B suggest that firms in industry 35 have reduced 76% of targeted chemicals, relative to 1990. It appears that machinery firms have achieved the pollution reduction requirement of EPA's 33/50 Program.

TABLE 6
Descriptive Statistics of EPA's 33/50 Participating Firms: Industrial and Commercial Machinery Industry

Two-digit SIC: 35
Industry: Industrial and Commercial Machinery
Observation: 28

Panel A: Financial and Non-financial Attributes of Firms in Industry 35

	1990		1996		Diff. in mean[a]	
Attributes	Mean	Median	Mean	Median	t-stat.	p-value
Sales	2,392.22	835.15	3,839.27	683.99	-1.48	0.1504
Pollution[b]	503,429.1	225,953.2	122,648.4	32,430.2	3.01	0.0056
Cost of Goods Sold	1,431.73	466.8	2,655.61	526.95	-1.89	0.0699
Selling, General Expenses	628.07	155.75	1,008.68	213.35	-2.08	0.0468
Capital Expenditures	129.41	33.3	193.12	36.8	-1.06	0.2974

Panel B: Changes in Means and Medians

	Changes in Mean (1990 – 1996)	Changes in Median (1990 - 1996)
Sales	60.49%	-18.10%
Pollution	-75.64%	-85.65%
Cost of Goods Sold	85.48%	12.89%
Selling, General and Administrative Expenses	60.60%	36.98%
Capital Expenditures	49.23%	10.51%

---

[a] Difference = Mean value of 1990 – Mean value of 1996
[b] in pounds

Table 7, Panel A, reports means and medians of five attributes for 33/50 firms in industry 36 (Electronic Equipment). Statistical tests indicate that sales, cost of goods sold, capital expenditures and selling, general and administrative expenses have increased significantly from 1990 to 1996, while pollution has decreased significantly during that period from 531,605 to 156,968. Table 7, Panel B, presents the percentage changes in mean and median for each of these five attributes. Participating firms have reduced about 70% of targeted chemicals, relative to 1990. It appears that those firms have achieved the pollution reduction requirement of EPA’s 33/50 Program.

TABLE 7
Descriptive Statistics of EPA's 33/50 Participating Firms: Electronic Equipment Industry

Two-digit SIC: 36
Industry: Electronic Equipment
Observation: 30

Panel A: Financial and Non-financial Attributes of Firms in Industry 36

	1990		1996		Diff. in mean[a]	
Attributes	Mean	Median	Mean	Median	t-stat.	p-value
Sales	2,746.51	376.97	5,416.73	745.13	-2.65	0.013
Pollution[b]	531,605.8	214,089.1	156,968.8	9,827.2	2.81	0.0088
Cost of Goods Sold	1,715.76	266.4	3,309.05	367.3	-2.41	0.0223
Selling, General Expenses	644.38	85.5	1,170.55	153.2	-3.01	0.0054
Capital Expenditures	254.65	18.65	473.99	54.9	-2.15	0.0396

Panel B: Changes in Means and Medians

	Changes in Mean (1990 - 1996)	Changes in Median (1990 - 1996)
Sales	97.22%	97.66%
Pollution	-70.47%	-95.41%
Cost of Goods Sold	92.86%	37.88%
Selling, General and Administrative Expenses	81.66%	79.18%
Capital Expenditures	86.13%	194.37%

---

[a] Difference = Mean value of 1990 – Mean value of 1996

[b] in pounds

Table 8, Panel A, reports means and medians of five attributes of EPA’s 33/50 firms in industry 37 (Transportation Equipment). Statistical tests indicate that sales, cost of goods sold, and selling, general and administrative expenses have increased significantly from 1990 to 1996, while pollution has decreased significantly during that period from 4,4934,480 to 1,382,906 pounds. Although capital expenditure has experienced an increase from 1990 to 1996, this increase is not statistically significant. Table 8, Panel B, presents the percentage changes in mean and median for each of these five attributes. Firms in transportation equipment industry have reduced 69% of targeted chemicals, relative to 1990. It appears that participating firms have achieved the pollution reduction requirement of EPA’s 33/50 Program.

TABLE 8
Descriptive Statistics of EPA's 33/50 Participating Firms: Transportation Equipment Industry

Two-digit SIC: 37
Industry: Transportation Equipment
Observation: 23

Panel A: Financial and Non-financial Attributes of Firms in Industry 37

Attributes	1990 Mean	Median	1996 Mean	Median	Diff. in mean[a] t-stat.	p-value
Sales	14,995.37	3,639.15	19,860.93	3,611.60	-2.09	0.0481
Pollution[b]	4,493,480	1,551,672	1,382,906	299,295	3.07	0.0056
Cost of Goods Sold	12,398.21	3,310	16,446.29	3,161	-1.97	0.0611
Selling, General Expenses	1,386.68	476.4	1,708.01	448	-2.05	0.052
Capital Expenditures	1,061.35	191.2	2,138.51	117	-1.30	0.2064

Panel B: Changes in Means and Medians

	Changes in Mean (1990 - 1996)	Changes in Median (1990 - 1996)
Sales	32.45%	-0.76%
Pollution	-69.22%	-80.71%
Cost of Goods Sold	32.65%	-4.50%
Selling, General and Administrative Expenses	23.17%	-5.96%
Capital Expenditures	101.49%	-38.81%

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[a] Difference = Mean value of 1990 – Mean value of 1996
[b] in pounds

Table 9 reports descriptive statistics for Canadian ARET firms. Panel A indicates that only one industry – Chemical and Petroleum is involved in this study. Panel B reports means and medians of five attributes for ARET firms in industry 28/29 (Chemical and Petroleum). Statistical tests indicate that sales, cost of goods sold, and capital expenditures have increased significantly from 1993 to 2000, while pollution has decreased significantly during that period from 200,993 to 58,451 pounds. Panel C presents the percentage changes in mean and median for each of those five attributes. The participating firms have reduced about 71% of targeted chemicals, relative to 1993. The goal of Canadian ARET Program was to reduce 30 chemicals by 90% and other 87 chemicals by 50%. It appears that firms have achieved the pollution reduction requirement of ARET Program.

TABLE 9
Descriptive Statistics of Canadian ARET Participating Firms

Panel A: Distribution of Two-Digit Industry Classifications

Two-digit SIC	Industry Description	Number of Firms	%
28/29	Chemical/Petroleum	24	100.00%

Panel B: Financial and Non-financial Attributes of Canadian ARET Participants

	1993		2000		Diff. in mean[a]	
Attributes	Mean	Median	Mean	Median	t-stat.	p-value
Sales	5,548.26	3,023.74	7,750.60	4,512.14	-5.00	<0.0001
Pollution[b]	200,993.4	17,090	58,451.8	1,400	2.65	0.0143
Cost of Goods Sold	3,433.45	1859.75	4,818.30	2,438.20	-3.70	0.0012
Selling, General Expenses	1295.47	388.9	1,553.43	474.5	-1.50	0.15
Capital Expenditures	490.36	388.5	716.72	465.6	-2.50	0.022

Panel C: Changes in Means and Medians

	Changes in Mean (1993 - 2000)	Changes in Median (1993 - 2000)
Sales	39.69%	49.22%
Pollution	-70.92%	-91.81%
Cost of Goods Sold	40.33%	31.10%
Selling, General and Administrative Expenses	19.91%	22.01%
Capital Expenditures	46.16%	19.85%

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[a] Difference = Mean value of 1993 – Mean value of 2000

[b] in pounds

CHAPTER 6

EMPIRICAL RESULTS

6.1 “Pollution” Included in the Efficiency Model

Table 10, Panel A, reports the mean efficiency distribution for EPA’s 33/50 participants. Firm efficiencies in 1990 and 1996 are calculated by using Stochastic Frontier Analysis (SFA). Output variables are Sales and Pollution, while input variables are Cost of goods sold, Selling, general and administrative expenses, and Capital expenditures. The last two columns of Panel A are t-statistics and significance levels (p-value) for paired differences between mean efficiency in 1990 and in 1996. Results suggest that firm efficiencies have increased significantly from 1990 to 1996 in industries 28/29 (Chemical and Petroleum), 33/34 (Metal), 35 (Machinery), 36 (Electronic Equipment), and 37 (Transportation). It appears that participating firms have improved their technical efficiencies since participation. Empirical evidence supports the Porter Hypothesis.

Table 10, Panel B, provides the mean efficiency distribution for Canadian ARET participants. Firm efficiencies in 1993 and 2000 are calculated by using Stochastic Frontier Analysis (SFA). The last two columns of Panel B are t-statistics and significance levels (p-value) for paired differences between mean efficiency in 1993 and in 2000. Results suggest that firm efficiencies have increased significantly from 1993 to 2000 in industry 28/29 (Chemical and Petroleum). It appears that participating firms have improved their efficiencies since participation. Empirical evidence supports the Porter Hypothesis.

TABLE 10
Mean Efficiency of Participating Firms under SFA

Model: Stochastic Frontier Analysis (SFA)
Output Variables: Sales
Pollution
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: EPA 3350 Program

SIC	Description	Obs.	Efficiency 1990	Efficiency 1996	Difference in Mean[a] T-Value (5%)	P-Value
28/29	Chemical/Petroleum	61	0.6540	0.6883	1.9284	0.0293*
33/34	Metal	37	0.7040	0.7944	3.7782	0.0003*
35	Industrial/Commercial Machinery	28	0.6431	0.7239	1.7684	0.0442*
36	Electronic Equipment	30	0.5139	0.5900	2.3309	0.0135*
37	Transportation Equipment	23	0.6114	0.6740	1.7578	0.0463*
		179				

Panel B: Canadian ARET Program

SIC	Description	Obs.	Efficiency 1993	Efficiency 2000	Difference in Mean T-Value (5%)	P-Value
28/29	Chemical/Petroleum	24	0.6696	0.7352	2.6851	0.0066*

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* significant at 90% probability level

[a] Difference = Mean efficiency scores in 1996 - Mean efficiency scores in 1990

Table 11, Panel A, reports the mean efficiency distribution for EPA's 33/50 participants. Firm efficiencies in 1990 and 1996 are calculated by using Data Envelopment Analysis (DEA). Output variables are Sales and Pollution, while input variables are Cost of goods sold, Selling, general and administrative expenses, and Capital expenditures. The last two columns of Panel A are t-statistics and significance levels (p-value) for paired differences between mean efficiency in 1990 and in 1996. Results suggest that firm efficiencies have increased significantly from 1990 to 1996 in industries 28/29 (Chemical and Petroleum), 33/34 (Metal), 35 (Machinery), 36 (Electronic Equipment), and 37 (Transportation). It appears that participating firms have improved their efficiencies since participation. The evidence supports the Porter Hypothesis.

Table 11, Panel B, provides the mean efficiency distribution for Canadian ARET participants. Firm efficiencies in 1993 and 2000 are calculated by using Data Envelopment Analysis (DEA). Results suggest that firm efficiencies have increased significantly from 1993 to 2000 in industry 28/29 (Chemical and Petroleum). Participating firms improved their efficiencies. The evidence supports the Porter Hypothesis.

The fact that Table 10 and 11 produced relatively similar results suggests that both Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are good tools to model the technical efficiency of a firm. Also, relatively consistent efficiency estimates from different methodologies may lead to improved robustness of this study. Empirical results of this study may be more convincing and valid.

TABLE 11
Mean Efficiency of Participating Firms under DEA

Model: Data Envelopment Analysis (DEA)
Output Variables: Sales
Pollution
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: EPA's 33/50 Program

SIC	Description	Obs.	Efficiency 1990	Efficiency 1996	Difference in Mean[a] T-Value (5%)	P-Value
28/29	Chemical/Petroleum	61	0.7189	0.7931	2.9748	0.0021*
33/34	Metal	37	0.6039	0.7499	2.5741	0.0072*
35	Industrial/Commercial Machinery	28	0.6574	0.7977	2.0593	0.0025*
36	Electronic Equipment	30	0.7584	0.8452	2.1683	0.0192*
37	Transportation Equipment	23	0.6958	0.8338	2.3138	0.0152*
		179				

Panel B: Canadian ARET Program

SIC	Description	Obs.	Efficiency 1993	Efficiency 2000	Difference in Mean T-Value (5%)	P-Value
28/29	Chemical/Petroleum	24	0.7549	0.8982	3.2348	0.0018*
		24				

---

* significant at 90% probability level

[a] Difference = Mean efficiency scores in 1996 - Mean efficiency scores in 1990

The MPI is an index number that enables a productivity comparison between two periods. If the value of a MPI is greater than one, this indicates that there has been an increase in a firm's productivity from period 1 to period 2. If the value of a MPI is smaller than one, this suggests that the firm's productivity has decreased from period 1 to period 2. A value equals to one indicates no change between two periods.

Table 12, Panel A, provides the mean MPI values for EPA's 33/50 participants. The last two columns of Panel A are t-statistics and significance levels (p-value) to test if the MPI values are significantly different from one. Results indicate that there have been significant increases in productivities of firms in industries 28/29 (Chemical and petroleum), 33/34 (Metal), 35 (Machinery), and 36 (Electronic equipment). An attractive feature of MPI is that it is just an index number, thus it is feasible to combine MPI values from all industries. Cross-sectional results indicate that the MPI values are significantly different from one. It appears that productivities of EPA's 33/50 participants have significantly increased from 1990 to 1996. This evidence is consistent with the Porter Hypothesis.

Table 12, Panel B, provides the mean MPI values for Canadian ARET participants. Results indicate that there have been significant increases in productivity of firms in industry 28/29 (Chemical and petroleum). This evidence is also consistent with the Porter Hypothesis.

TABLE 12
Malmquist Productivity Index (MPI) of Participating Firms

Output Variables: Sales
Pollution
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: EPA's 33/50 Program

SIC	Industry	Obs.	MPI	T-Stat.	P-Value
28/29	Chemical/Petroleum	61	1.1007	2.7064	0.0044*
33/34	Metal	37	1.1972	3.5187	0.0006*
35	Industrial/Commercial Machinery	28	1.1129	2.6016	0.0071*
36	Electronic Equipment	30	1.8692	3.3286	0.0012*
37	Transportation Equipment	23	1.4797	1.2405	0.1139
	Cross-Sectional	179	1.3065	4.3362	<0.0001*

Panel B: Canadian ARET Program

SIC	Industry	Obs.	MPI	T-Stat.	P-Value
28/29	Chemical/Petroleum	24	1.3498	2.3835	0.0129*

---

* significant at 90% probability level

This study further decomposes the MPI values into the catch-up effect and the frontier-shift effect components. Table 13, Panel A, provides the values of catch-up and frontier-shift components for EPA's 33/50 participants. T-tests are performed to see if those values are significantly different from one. Cross-sectional results indicate that both catch-up and frontier-shift effects are significant. On average, EPA's 33/50 participants not only improved their efficiencies over time but also experienced a shift in their production frontier due to improved technology. Furthermore, the fact that the frontier-shift effect is significant in each industry indicates that participating firms in each industry have experienced a significant shift (improvement) in their production frontiers (technology). This shift suggests that there may have been innovations among participating firms, which led to improved technology. The above evidence is consistent with the Porter Hypothesis.

Table 13, Panel B, provides the mean values of catch-up and frontier-shift components for Canadian ARET participants. Results indicate that frontier-shift effects are significant. It appears that firms in the chemical and petroleum industry have experienced a significant shift in their production frontier.

TABLE 13
Catch-up and Frontier-shift Effect of Participating Firms

Output Variables: Sales
Pollution
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: EPA's 33/50 Program

SIC	Obs.	Catch-up[a]	T-Stat.	P-Value	Frontier-shift[b]	T-Stat.	P-Value
28/29	61	1.0712	1.2123	0.1151	1.0522	4.2437	<0.0001*
33/34	37	1.1272	1.9982	0.0266*	1.0979	2.9313	0.0026*
35	28	1.0949	1.2754	0.1059	1.0605	2.2007	0.0178*
36	30	0.8343	-4.2817	<0.0001*	2.2043	4.6071	<0.0001*
37	23	1.4519	1.2298	0.1159	1.0507	1.3772	0.0912*
	179	1.1015	1.8392	0.0337*	1.2537	4.6383	<0.0001*

Panel B: Canadian ARET Program

SIC	Obs.	Catch-up	T-Stat.	P-Value	Frontier-shift	T-Stat.	P-Value
28/29	24	1.0917	0.7377	0.234	1.276	3.7841	<0.0001*

---

* significant at 90% probability level

[a] Catch-up effect measures the better or worse of a firm's performance over time.

[b] Frontier-shift effect measures the advance or shift in technology between year s and year t.

6.2 "Pollution" Excluded from Efficiency Model

Under both programs (EPA's 33/50 Program and Canadian ARET Program), participating firms are required to report their targeted chemical releases to certain government agency, while non-participating firms have no such obligations. Thus, obtaining information on those chemical releases for non-participating firms may be difficult. In order to establish a performance comparison between participating firms and non-participating (matched) firms, this study removes the output variables, Pollution, from the efficiency model. The new model includes one output (Sales) and three inputs (COGS, General Selling and Administrative Expense, and Capital Expenditure).

Data then can be collected for a control sample made up of non-participating firms for the same period. In most studies, control firms are selected by matching the industry and size of the sample firms (the traditional I/S method). That is, for each sample firm, a matching firm with the closest firm size within the same industry is selected. The traditional I/S method has been widely accepted for the following two reasons: (1) matching industry can isolate any industry-specific factors, since firms in the same industry are likely to be subject to the same industry conditions, and (2) matching firm size can isolate any factors that can affect companies of certain size. The study attempts to match on net assets in the year preceding the participation at the two-digit industry level.

Table 14, Panel A, reports the mean efficiency distribution for EPA's 33/50 participants. Firm efficiencies are calculated by using Stochastic Frontier Analysis (SFA). Output variable is Sales, while input variables are Cost of goods sold, Selling, general and administrative expenses, and Capital expenditures. The last two columns of Panel A are t-statistics and significance levels (p-value) for paired differences between mean efficiency in 1990 and in 1996. Results suggest that firm efficiencies have increased significantly from 1990 to 1996 in industries 28/29 (Chemical and Petroleum), 33/34 (Metal), 35 (Machinery), 36 (Electronic Equipment), and 37 (Transportation Equipment). It appears that participating firms have improved their efficiencies from 1990 to 1996 since participation. Empirical evidence supports the Porter Hypothesis.

Table 14, Panel B, reports the mean efficiency distribution for the matched firms. Although firm efficiencies have increased in industries 30/31 (Rubber and Leather Products), 33/34 (Metal), 35 (Machinery), 36 (Electronic Equipment), and 37 (Transportation Equipment), those increases are not statistically significant. Results suggest that matched firms have not experienced a significant improvement in their efficiencies from 1990 to 1996.

TABLE 14
Mean Efficiency of U.S. Participating and Matched Firms under SFA

Model: Stochastic Frontier Analysis (SFA)
Output Variable: Sales
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: EPA 33/50 Participants

SIC	Description	Obs.	Efficiency 1990	Efficiency 1996	Difference in Mean[a] T-Value	P-Value
28/29	Chemical/Petroleum	61	0.6682	0.6889	1.988	0.0257*
33/34	Metal	37	0.692	0.758	3.3569	0.0009*
35	Industrial/Commercial Machinery	28	0.6345	0.6925	1.8657	0.0365*
36	Electronic Equipment	30	0.5074	0.5963	2.1062	0.0220*
37	Transportation Equipment	23	0.5942	0.6902	2.5426	0.0093*
		179				

Panel B: Matched Firms

SIC	Description	Obs.	Efficiency 1990	Efficiency 1996	Difference in Mean T-Value	P-Value
28/29	Chemical/Petroleum	61	0.7205	0.7136	0.4031	0.3441
33/34	Metal	37	0.7717	0.7819	0.4233	0.3373
35	Industrial/Commercial Machinery	28	0.816	0.8253	0.6281	0.2676
36	Electronic Equipment	30	0.5589	0.5731	0.481	0.317
37	Transportation Equipment	23	0.8255	0.8352	0.5824	0.2831
		179				

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* significant at 90% probability level

[a] Difference = Mean efficiency scores in 1996 - Mean efficiency scores in 1990

Table 15, Panel A, reports the mean efficiency distribution for Canadian ARET participants. Firm efficiencies are calculated by using Stochastic Frontier Analysis (SFA). Output variable is Sales, while input variables are Cost of goods sold, Selling, general and administrative expenses, and Capital expenditures. The last two columns of Panel A are t-statistics and significance levels (p-value) for paired differences between mean efficiency in 1993 and in 2000. Results suggest that firm efficiencies have increased significantly from 1993 to 2000 in industriy28/29 (Chemical and Petroleum). Participating firms have improved their efficiencies since participation. It appears that the evidence supports the Porter Hypothesis.

Table 15, Panel B, presents the mean efficiency distribution for the matched firms. Although firm efficiencies have increased in industry 28/29 (Chemical and Petroleum), those increases are not statistically significant. Results indicate that matched firms have not experienced a significant improvement in their efficiencies from 1993 to 2000.

TABLE 15
Mean Efficiency of Canadian Participating and Matched Firms under SFA

Model: Stochastic Frontier Analysis (SFA)
Output Variable: Sales
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: Canadian ARET Participants

SIC	Description	Obs.	Efficiency	Efficiency	Difference in Mean[a]	
			1993	2000	T-Value	P-Value
28/29	Chemical/Petroleum	24 24	0.6588	0.7233	2.5566	0.0088*

Panel B: Matched Firms

SIC	Description	Obs.	Efficiency	Efficiency	Difference in Mean	
			1993	2000	T-Value	P-Value
28/29	Chemical/Petroleum	24 24	0.8628	0.8848	1.2262	0.1163

---

* significant at 90% probability level

[a] Difference = Mean efficiency scores in 2000 - Mean efficiency scores in 1993

Table 16, Panel A, reports the mean efficiency distribution for EPA's 33/50 participants. Firm efficiencies are calculated by using Data Envelopment Analysis (DEA). Output variable is Sales, while input variables are Cost of goods sold, Selling, general and administrative expenses, and Capital expenditures. The last two columns of Panel A are t-statistics and significance levels (p-value) for paired differences between mean efficiency in 1990 and in 1996. Results suggest that firm efficiencies have increased significantly in industries 28/29 (Chemical and Petroleum), 33/34 (Metal), 35 (Machinery), 36 (Electronic Equipment), and 37 (Transportation Equipment). Participating firms have improved their efficiencies from 1990 to 1996. Empirical evidence supports the Porter Hypothesis.

Table 16, Panel B, reports the mean efficiency distribution for the matched firms. Although firm efficiencies have increased in industries 26 (Paper and Allied Products), 28/29 (Chemical and Petroleum), 33/34 (Metal), 35 (Machinery), and 37 (Transportation Equipment), those increases are not statistically significant except for industry 37. Only firms in the industry 37 (Transportation Equipment) have experienced a significant increase in their efficiencies. The majority of matched firms have not experienced significant increases in their technical efficiencies for the period of 1990 and 1996.

TABLE 16
Mean Efficiency of U.S. Participating and Matched Firms under DEA

Model: Data Envelopment Analysis (DEA)
Output Variable: Sales
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: EPA 33/50 Participants

SIC	Description	Obs.	Efficiency 1990	Efficiency 1996	Difference in Mean[a] T-Value	P-Value
28/29	Chemical/Petroleum	61	0.9071	0.9509	4.2032	<0.0001*
33/34	Metal	37	0.7842	0.9258	3.3034	0.0011*
35	Industrial/Commercial Machinery	28	0.5715	0.8938	3.5189	0.0008*
36	Electronic Equipment	30	0.7693	0.8791	2.6362	0.0067*
37	Transportation Equipment	23	0.7717	0.9184	2.602	0.0081*
		179				

Panel B: Matched Firms

SIC	Description	Obs.	Efficiency 1990	Efficiency 1996	Difference in Mean T-Value	P-Value
28/29	Chemical/Petroleum	61	0.5205	0.5299	0.3289	0.3717
33/34	Metal	37	0.4411	0.4779	0.7352	0.2335
35	Industrial/Commercial Machinery	28	0.6102	0.6537	0.8409	0.2039
36	Electronic Equipment	30	0.4849	0.4608	-0.766	0.2249
37	Transportation Equipment	23	0.7097	0.7572	1.4829	0.0760*
		179				

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* --- significant at 90% probability level

[a] Difference = Mean efficiency scores in 1996 - Mean efficiency scores in 1990

Table 17, Panel A, reports the mean efficiency distribution for Canadian ARET participants. Firm efficiencies are calculated by using Data Envelopment Analysis (DEA). Output variable is Sales, while input variables are Cost of goods sold, Selling, general and administrative expenses, and Capital expenditures. The last two columns of Panel A are t-statistics and significance levels (p-value) for paired differences between mean efficiency in 1993 and in 2000. Results indicate that firm efficiencies have increased significantly in industry 28/29 (Chemical and Petroleum). It appears that participating firms have improved their efficiencies since participation. Empirical evidence supports the Porter Hypothesis.

Table 17, Panel B, reports the mean efficiency distribution for the matched firms. Although firm efficiencies have increased in industry 28/29 (Chemical and Petroleum), those increases are not statistically significant. Matched firms have not experienced significant increases in their technical efficiencies for the period of 1993 and 2000.

TABLE 17
Mean Efficiency of Canadian Participating and Matched Firms under DEA

Model: Data Envelopment Analysis (DEA)
Output Variable: Sales
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: Canadian ARET Participants

SIC	Description	Obs.	Efficiency 1993	Efficiency 2000	Difference in Mean[a] T-Value (5%)	P-Value
28/29	Chemical/Petroleum	24	0.775	0.8882	2.6569	0.0070*

Panel B: Matched Firms

SIC	Description	Obs.	Efficiency 1993	Efficiency 2000	Difference in Mean T-Value (5%)	P-Value
28/29	Chemical/Petroleum	24	0.7743	0.7854	0.382	0.3529

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* significant at 90% probability level
[a] Difference = Mean efficiency scores in 2000 - Mean efficiency scores in 1993

Table 18, Panel A, provides the mean MPI values for EPA's 33/50 participants. The last two columns of Panel A are t-statistics and significance levels (p-value) to test if the MPI values are significantly different from one. Results indicate that there have been significant increases in the efficiency of firms in industries 28/29 (Chemical and petroleum), 30/31 (Rubber and leather products), 33/34 (Metal), 35 (Machinery), and 36 (Electronic equipment). An attractive feature of MPI is that it is an index number, thus it is feasible to combine MPI values from all industries. Cross-sectional results also indicate that the MPI values are significantly different from one. It appears that productivities of EPA's 33/50 participants have significantly increased from 1990 to 1996.

Table 18, Panel B, reports the mean MPI values for the matched firms. Although firm productivities have increased in industries 28/29 (Chemical and Petroleum), 33/34 (Metal), 35 (Machinery), 36 (Electronic Equipment), those increases are not statistically significant. Furthermore, cross-sectional results indicate that the mean value of MPI for matched firms is not significant from one. Empirical evidence suggests matched firms have not experience a significant increase in their productivities for the period of 1990 and 1996.

TABLE 18
Malmquist Productivity Index (MPI) of EPA 33/50 Participants and Matched Firms

Output Variable: Sales
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: EPA 33/50 Participants

SIC	Industry	Obs.	MPI	T-Stat.	P-Value
28/29	Chemical/Petroleum	61	1.079	3.0565	0.0016*
33/34	Metal	37	1.2378	2.544	0.0077*
35	Industrial/Commercial Machinery	28	1.0953	2.0821	0.0229*
36	Electronic Equipment	30	1.0973	1.5317	0.0680*
37	Transportation Equipment	23	1.3966	1.0294	0.1572
	Cross-Sectional	179	1.16423	2.9857	0.0016*

Panel B: Matched Firms

SIC	Industry	Obs.	MPI	T-Stat.	P-Value
28/29	Chemical/Petroleum	61	1.0094	0.2592	0.3982
33/34	Metal	37	1.0587	0.4799	0.3171
35	Industrial/Commercial Machinery	28	1.0352	1.1544	0.1292
36	Electronic Equipment	30	1.0483	0.6731	0.2531
37	Transportation Equipment	23	0.9948	0.1438	0.4435
	Cross-Sectional	179	1.0283	0.9115	0.1816

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* significant at 90% probability level

The MPI values from Table 18 are further decomposed into the catch-up effect and the frontier-shift effect components. Table 19, Panel A, provides the values of catch-up and frontier-shift components for EPA’s 33/50 participants. T-tests are performed to see if those values are significantly different from one. Cross-sectional results indicate that both catch-up and frontier-shift effects are significant. On average, EPA’s 33/50 participants not only improved their efficiencies over time but also experienced a shift in their production frontier due to improved technology. Furthermore, the fact that the frontier-shift effect is significant in each industry indicates that participating firms in each industry have experienced a significant shift (improvement) in their production frontiers (technology). This shift suggests that there may have been innovations among participating firms, which led to improved technology. The above evidence is consistent with the Porter Hypothesis.

Table 19, Panel B, provides the values of catch-up and frontier-shift components for matched firms. Cross-sectional results indicate that the catch-up effects are not statistically significant, but the frontier-shift effects are significant for matched firms. This evidence suggests that EPA’s 33/50 participating firms, as pioneers in their industries, may have created an improvement in production frontier (technology), which then might benefit non-participating firms. The significant shift in technology of matched firms might be brought by the significant shift in frontier of EPA’s 33/50 participants. In other words, non-participating firms learned from the innovations created by 33/50 participants.

TABLE 19
Catch-up and Frontier-shift Effect of EPA's 33/50 Participants and Matched Firms

Output Variable: Sales
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: EPA 33/50 Participants

SIC	Obs.	Catch-up[a]	T-Stat.	P-Value	Frontier-shift[b]	T-Stat.	P-Value
28/29	61	1.0253	0.9722	0.1674	1.0577	5.5603	<0.0001*
33/34	37	1.0464	0.1932	0.4239	1.8383	1.0011	0.0001*
35	28	1.0346	0.6567	0.2582	1.0749	3.8588	0.0002*
36	30	1.0767	1.0045	0.1617	1.0371	2.4329	0.0110*
37	23	1.266	2.8013	0.2269	1.1544	2.5037	0.0101*
	179	1.0755	1.1033	0.1357	1.2304	4.6357	<0.0001*

Panel B: Matched Firms

SIC	Obs.	Catch-up	T-Stat.	P-Value	Frontier-shift	T-Stat.	P-Value
28/29	61	0.9886	0.3394	0.3677	1.0188	2.2183	0.0151*
33/34	37	1.0135	0.1517	0.4401	1.1386	1.3241	0.0969*
35	28	1.0172	0.6191	0.2705	1.0184	1.5526	0.0660*
36	30	1.1229	1.1824	0.1233	0.9825	0.5699	0.2865
37	23	0.9446	1.8026	0.0425*	1.0523	3.6375	0.0007*
	179	1.01511	0.5321	0.2976	1.0417	1.8404	0.0337*

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* significant at 90% probability level

[a] Catch-up effect measures the better or worse of a firm's performance over time.

[b] Frontier-shift effect measures the advance or shift in technology between year s and year t.

Table 20, Panel A, provides the MPI values for Canadian ARET participants. The last two columns of Panel A are t-statistics and significance levels (p-value) to test if the MPI values are significantly different from one. Results indicate that there have been significant increases in the productivities of firms in industry 28/29 (Chemical and petroleum). Overall productivities of sample firms have significantly increased from 1993 to 2000.

Table 20, Panel B, provides the MPI values for matched firms. The MPI values of matched firms in industry 28/29 (Chemical and petroleum) are also statistically significant. It seems that these results in Table 20 are mixed.

TABLE 20
Malmquist Productivity Index (MPI)
of Canadian ARET Participants and Matched Firms

Output Variable: Sales
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: Canadian ARET Participants

SIC	Industry	Obs.	MPI	T-Stat.	P-Value
28/29	Chemical/Petroleum	24	1.1841	2.0476	0.0261*

Panel B: Matched Firms

SIC	Industry	Obs.	MPI	T-Stat.	P-Value
28/29	Chemical/Petroleum	24	1.081	1.7071	0.0560*

---

* --- significant at 90% probability level

Table 21, Panel A, provides the values of catch-up and frontier-shift components for Canadian ARET participants. The cross-sectional results indicate that both catch-up effect and frontier-shift effects are statistically significant. This implies that Canadian ARET participants not only improved their efficiencies over time but also experienced a shift in their production frontier due to improved technology.

Table 21, Panel B, reports the values of catch-up and frontier-shift components for the matched sample. Cross-sectional results indicate that the catch-up effects are not statistically significant, but the frontier-shift effects are significant for matched firms. This evidence is similar to that in Table 15, Panel B. That is, participating firms, as pioneers in their industries, may have created an improvement in production frontier (advance in technology), which then might benefit non-participating firms. The significant shift in technology of matched firms might be brought by the significant shift in frontier of Canadian ARET Participants. In other words, non-participating firms learned from the innovations created by Canadian ARET participants.

The combined results from Table 19 and 21 suggest that participating firms have experienced innovations though reducing pollution, and non-participating firms may then benefited from those innovations, which also caused a significant frontier-shift effect among nonparticipating firms.

Table 21
Catch-up Effect and Frontier-shift Effect of Canadian ARET Participants and Matched Firms

Output Variable: Sales
Input Variables: Cost of Goods Sold (COGS)
Selling, General, and Administrative Expenses (XSGA)
Capital Expenditures (CAPX)

Panel A: Canadian ARET Participants

SIC	Obs.	Catch-up[a]	T-Stat.	P-Value	Frontier-shift[b]	T-Stat.	P-Value
28/29	24	1.0748	0.9761	0.1695	1.1038	3.6348	0.0006*

Panel B: Matched Firms

SIC	Obs.	Catch-up	T-Stat.	P-Value	Frontier-shift	T-Stat.	P-Value
28/29	24	0.9986	0.0358	0.4858	1.0815	5.3892	<0.0001*

---

* significant at 90% probability level

[a] Catch-up effect measures the better or worse of a firm's performance over time.

[b] Frontier-shift effect measures the advance or shift in technology between year s and year t.

6.3 Regression Analysis

Previous studies have examined factors that cause firms to participate in voluntary environmental programs. Daman and Khanna (1999) suggest that companies with old equipment are more likely to participate in programs like EPA's 33/50. Arora and Cason (1995) and Alberini and Videras (2000) suggest that bigger firms are more likely to participate in such programs. Based on previous studies, this study identifies the following three control variables:

<u>Age of Assets (AGE)</u>: Age of Assets can be estimated in percentage terms, which equals accumulated depreciation divided by the total assets. This percentage represents the proportion of the assets that have been depreciated. A value closer to one indicates that the assets get older.

<u>Research and Development Expenses (RD)</u>: This variable represents all costs incurred during the year that relate to the development of new products or services. The reason to select this variable is that participation in programs such as EPA's 33/50 and ARET may encourage firms to conduct more research and find innovative ways to reduce pollution.

<u>Assets (AT)</u>: This variable represents current assets plus net property, plant, and equipment plus other concurrent assets, and attempts to control for the firm size.

A regression model is specified to test the relation between MPI and the above three control variables:

$$MPI = \partial_0 + \partial_1 AGE + \partial_2 RD + \partial_3 AT + \varepsilon \qquad \text{[Equation 7]}$$

$$Catchup = \beta_0 + \beta_1 AGE + \beta_2 RD + \beta_3 AT + \gamma \qquad \text{[Equation 8]}$$

$$Frontier = \lambda_0 + \lambda_1 AGE + \lambda_2 RD + \lambda_3 AT + \nu \qquad \text{[Equation 9]}$$

By using MPI as the dependent variable, Table 22 reports the cross-sectional results of regression analysis for EPA's 33/50 participating firms. Although MPI is positively related to RD and AT and negatively related to AGE, these relations are not statistically significant.

TABLE 22
Regression Analysis for EPA's 33/50 Participants: MPI and Control Variable

Model:

$$MPI^{a} = \partial_0 + \partial_1 AGE + \partial_2 RD + \partial_3 AT + \varepsilon \qquad \text{[Equation 7]}$$

Results:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3.68763	1.22921	1.38	0.2503
Error	175	155.79296	0.89025		
Corrected Total	178	159.48059			

Root MSE	0.94353	R-Square	0.0231
Dependent Mean	1.30440	Adj R-Sq	0.0064
Coeff Var	72.33410		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.07868	0.26929	4.01	<.0001
AGE[b]	1	-0.25716	0.33414	-0.77	0.4426
RD[c]	1	0.04889	0.05959	0.82	0.4131
AT[d]	1	0.00914	0.06643	0.14	0.8908

---

[a] MPI = Malmquist Productivity Index value for the period of 1990 -1996 .Values of MPI are obtained from Section 6.1, in which Pollution variable is involved in calculating MPI and its components.

[b] AGE = Accumulated Depreciation in 1990 / Assets in 1990

[c] RD = LOG (R&D in 1991 + ... + R&D in 1995)

[d] AT = LOG (Assets in 1990)

MPI can be decomposed into catch-up effect and frontier-shift effect. This study further investigates whether the catch-up effect or frontier-shift effect component has any significant relation with control variables. Table 23 presents the regression analysis results, by using catch-up effect component as the dependent variable. Results suggest that control variables have no significant relation with the catch-up effect component.

Contrary to those in Table 23, the results in Table 24 indicate that the frontier-shift effect component has a significantly positive relation with RD, and a significantly negative relation with AT. This evidence suggests that research and development activities play an important role in the shift in production frontier or the advances in technology among EPA’s 33/50 participants. Indeed, research and development activities lead to innovations that cause a shift in production frontier. This is consistent with the Porter Hypothesis. The significantly negative association between the frontier-shift effect and AT suggests that it may be easier and faster for small firms to adopt and implement newly improved technology relative to large firms.

TABLE 23
Regression Analysis for EPA's 33/50 Participants: Catch-up Effect and Control Variable

Model:

$$Catchup^{a} = \beta_0 + \beta_1 AGE + \beta_2 RD + \beta_3 AT + \gamma \qquad \text{[Equation 8]}$$

Results:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.97838	0.32613	0.59	0.6203
Error	175	96.21929	0.54982		
Corrected Total	178	97.19767			

Root MSE	0.74150	R-Square	0.0101
Dependent Mean	1.10158	Adj R-Sq	-0.0069
Coeff Var	67.31226		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.00646	0.21163	4.76	<.0001
AGE[b]	1	-0.03344	0.26259	-0.13	0.8988
RD[c]	1	-0.06243	0.04683	-1.33	0.1843
AT[d]	1	0.06023	0.05220	1.15	0.2502

---

[a] catch-up effect component of MPI from Table 22

[b] AGE = Accumulated Depreciation in 1990 / Assets in 1990

[c] RD = LOG (R&D in 1991 + ... + R&D in 1995)

[d] AT = LOG (Assets in 1990)

TABLE 24
Regression Analysis for EPA's 33/50 Participants: Frontier-shift Effect and Control Variable

Model:

$$Frontier^{a} = \lambda_0 + \lambda_1 AGE + \lambda_2 RD + \lambda_3 AT + v \qquad \text{[Equation 9]}$$

Results:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	5.66619	1.88873	3.69	0.0132
Error	175	89.69144	0.51252		
Corrected Total	178	95.35763			

Root MSE	0.71591	R-Square	0.0594
Dependent Mean	1.25375	Adj R-Sq	0.0433
Coeff Var	57.10127		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.26690	0.20433	6.20	<.0001
AGE[b]	1	-0.22487	0.25353	-0.89	0.3763
RD[c]	1	0.14814	0.05004	2.96	0.0035*
AT[d]	1	-0.09959	0.05361	-1.86	0.0649*

---

[a] frontier-shift effect component of MPI from Table 22

[b] AGE = Accumulated Depreciation in 1990 / Assets in 1990

[c] RD = LOG (R&D in 1991 + ... + R&D in 1995)

[d] AT = LOG (Assets in 1990)

* significant at 90% probability level

Table 25 reports the cross-sectional results of regression analysis for Canadian ARET participating firms. Although MPI is positively related to RD and negatively related to AGE and AT, these relations are not statistically significant.

Table 26, Panel A, presents the regression analysis results, by using catch-up effect component as the dependent variable. No significant relation is founded between the catch-up effect and control variables. By using frontier-shift effect component as the dependent variable, Table 25, Panel B, does not find any significant relation between the frontier-shift effect and control variables. It appears that Canadian firms did not put a lot effort into research and development activities.

The above evidence is not surprising. Environment Canada has been very active in learning and absorbing any newly developed technology from the United States. After realizing and learning from the success of the U.S. EPA's 33/50 Program, Canada launched its ARET Program, which expands on the 33/50 Program. In fact, ARET is very similar to 33/50 in many aspects. It is possible that Canadian firms that participated in ARET have already exposed to innovations generated by 33/50 firms in U.S. That is, Canadian firms could just adopt those innovations in the United States without conducting much research and development on their own. Since the U.S. EPA is the leading environmental agency in the world, it is probably sufficient for Canadian firms to just learn and adopt any new innovations or breakthroughs in technologies in environmental protection from the United States. The above statement justifies the insignificant association between the frontier-shift effect and research and development activities for Canadian ARET participants.

TABLE 25
Regression Analysis for Canadian ARET Participants: MPI and Control Variable

Model:

$$MPI^{a} = \partial_0 + \partial_1 AGE + \partial_2 RD + \partial_3 AT + \varepsilon \text{ [Equation 7]}$$

Results:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	4.38084	1.46028	3.89	0.0243
Error	20	7.50536	0.37527		
Corrected Total	23	11.88621			

Root MSE	0.61259	R-Square	0.3686
Dependent Mean	1.34975	Adj R-Sq	0.2739
Coeff Var	45.38539		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.75100	0.74691	2.34	0.0295
AGE[b]	1	0.62430	0.73008	0.86	0.4026
RD[c]	1	0.01703	0.10881	0.16	0.8774
AT[d]	1	0.04173	0.10566	0.39	0.6971

---

[a] MPI = Malmquist Productivity Index value for the period of 1993 -2000 .Values of MPI are obtained from Section 6.1, in which Pollution variable is involved in calculating MPI and its components.
[b] AGE = Accumulated Depreciation in 1994 / Assets in 1994
[c] RD = LOG (R&D in 1994 + ... + R&D in 1999)
[d] AT = LOG (Assets in 1994)

TABLE 26
Regression Analysis for Canadian ARET Participants: Catch-up Effect and Control Variable

Panel A: Catch-up effect component of MPI

Model:

$$Catchup^{a} = \beta_0 + \beta_1 AGE + \beta_2 RD + \beta_3 AT + \gamma \qquad \text{[Equation 8]}$$

Results:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.98440	0.66147	2.02	0.1435
Error	20	6.54903	0.32745		
Corrected Total	23	8.53343			

Root MSE	0.57223	R-Square	0.2325
Dependent Mean	1.09173	Adj R-Sq	0.1174
Coeff Var	52.41535		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.23601	0.69771	1.77	0.0917
AGE[b]	1	0.42484	0.68198	0.62	0.5404
RD[c]	1	-0.03451	0.09542	-0.36	0.7218
AT[d]	1	0.05073	0.09870	0.51	0.6129

---

[a] catch-up effect component of MPI from Table 25

[b] AGE = Accumulated Depreciation in 1994 / Assets in 1994

[c] RD = LOG (R&D in 1994 + ... + R&D in 1999)

[d] AT = LOG (Assets in 1994)

TABLE 27
Regression Analysis for Canadian ARET Participants: Frontier-shift Effect and Control Variable

Model:

$$Frontier^{a} = \lambda_0 + \lambda_1 AGE + \lambda_2 RD + \lambda_3 AT + \nu \qquad \text{[Equation 9]}$$

Results:

```
                           Sum of         Mean
Source               DF     Squares       Square     F Value    Pr > F

Model                 3     0.22077      0.07359      0.54      0.6592
Error                20     2.71627      0.13581
Corrected Total      23     2.93704


        Root MSE            0.36853        R-Square    0.0752
        Dependent Mean      1.27602        Adj R-Sq   -0.0636
        Coeff Var          28.88099


                      Parameter     Standard
Variable     DF       Estimate      Error         t Value    Pr > |t|

Intercept     1        1.50528      0.44934        3.35      0.0032
AGE^b         1        0.02254      0.43921        0.05      0.9596
RD^c          1       -0.03966      0.04667       -0.85      0.4056
AT^d          1       -0.00199      0.06356       -0.03      0.9754
```

---

[a] frontier-shift effect component of MPI from Table 25

[b] AGE = Accumulated Depreciation in 1994 / Assets in 1994

[c] RD = LOG (R&D in 1994 + ... + R&D in 1999)

[d] AT = LOG (Assets in 1994)

This study further examines the industry effect on the changes in efficiency, which is measured by MPI. The regression model is $MPI^a = \partial_0 + \partial_1 AGE + \partial_2 RD + \partial_3 AT + \partial_4 IND + \varepsilon$, where IND stands for industry. This paper runs the above model five times, since five industries are involved in the sample of EPA's 33/50 Program.

In Table 28, if the industry is chemical (SIC = 28/29), then the value of the industry variable – 'IND' is one, otherwise the value is zero. Results indicate that there is a statistically significant (positive) relation between MPI and IND. This implies that chemical firms are more likely to improve their technical efficiencies through reducing pollution.

In Table 29, if the industry is metal (SIC=33/34), then the value of the industry variable – 'IND' is one, otherwise the value is zero. Results indicate that there is a negative relation between MPI and IND, however this relation is not statically significant.

In Table 30, if the industry is industrial and commercial machinery (SIC=35), then the value of the industry variable – 'IND' is one, otherwise the value is zero. Results indicate that there is a negative relation between MPI and IND, however this relation is not statically significant.

In Table 31, if the industry is electronic equipment (SIC = 36), then the value of the industry variable – 'IND' is one, otherwise the value is zero. Results indicate that there is a statistically significant (positive) relation between MPI and IND. This implies that electronic equipment firms are more likely to improve their technical efficiencies through reducing pollution.

In Table 32, if the industry is transportation equipment (SIC=37), then the value of the industry variable – ‘IND’ is one, otherwise the value is zero. Results indicate that there is a positive relation between MPI and IND, however this relation is not statistically significant.

TABLE 28
MPI and Industry Effect: Chemical and Petroleum Industry

Model:

$$MPI^{a} = \partial_0 + \partial_1 AGE + \partial_2 RD + \partial_3 AT + \partial_4 IND + \varepsilon$$

Results:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	10.87940	2.71985	3.18	0.0148
Error	174	148.60119	0.85403		
Corrected Total	178	159.48059			

Root MSE	0.92414	R-Square	0.0682
Dependent Mean	1.30440	Adj R-Sq	0.0468
Coeff Var	70.84752		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	0.98378	0.26578	3.70	0.0003
AGE[b]	1	-0.05102	0.33489	-0.15	0.8791
RD[c]	1	0.07164	0.05889	1.22	0.2254
AT[d]	1	0.01901	0.06515	0.29	0.7708
IND[e]	1	0.46372	0.15980	2.90	0.0042*

---

[a] MPI = Malmquist Productivity Index value for the period of 1990 -1996 .Values of MPI are obtained from Section 6.1, in which Pollution variable is involved in calculating MPI and its components.

[b] AGE = Accumulated Depreciation in 1990 / Assets in 1990

[c] RD = LOG (R&D in 1991 + ... + R&D in 1995)

[d] AT = LOG (Assets in 1990)

[e] if Industry = chemical (SIC=28/29), then IND =1, otherwise IND=0

* significant at 90% probability level

TABLE 29
MPI and Industry Effect: Metal Industry

Model:

$$MPI^{a} = \partial_0 + \partial_1 AGE + \partial_2 RD + \partial_3 AT + \partial_4 IND + \varepsilon$$

Results:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	3.68782	0.92195	1.03	0.3934
Error	174	155.79277	0.89536		
Corrected Total	178	159.48059			

Root MSE	0.94624	R-Square	0.0231
Dependent Mean	1.30440	Adj R-Sq	0.0007
Coeff Var	72.54161		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.07941	0.27473	3.93	0.0001
AGE[b]	1	-0.25703	0.33522	-0.77	0.4443
RD[c]	1	0.04848	0.06580	0.74	0.4622
AT[d]	1	0.00940	0.06903	0.14	0.8918
IND[e]	1	-0.00289	0.19800	-0.01	0.9884

---

[a] MPI = Malmquist Productivity Index value for the period of 1990 -1996 .Values of MPI are obtained from Section 6.1, in which Pollution variable is involved in calculating MPI and its components.
[b] AGE = Accumulated Depreciation in 1990 / Assets in 1990
[c] RD = LOG (R&D in 1991 + ... + R&D in 1995)
[d] AT = LOG (Assets in 1990)
[e] if Industry = metal (SIC=33/34), then IND =1, otherwise IND=0

TABLE 30
MPI and Industry Effect:
Industrial and Commercial Machinery Industry

Model:

$$MPI^{a} = \partial_0 + \partial_1 AGE + \partial_2 RD + \partial_3 AT + \partial_4 IND + \varepsilon$$

Results:

Source	DF	Squares	Square	F Value	Pr > F
Model	4	4.62476	1.15619	1.30	0.2723
Error	174	154.85583	0.88998		
Corrected Total	178	159.48059			

Root MSE	0.94339	R-Square	0.0290
Dependent Mean	1.30440	Adj R-Sq	0.0067
Coeff Var	72.32315		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.14981	0.27803	4.14	<.0001
AGE	1	-0.31230	0.33838	-0.92	0.3573
RD	1	0.05111	0.05962	0.86	0.3925
AT	1	0.00453	0.06657	0.07	0.9458
IND	1	-0.20281	0.19764	-1.03	0.3062

---

[a] MPI = Malmquist Productivity Index value for the period of 1990 -1996 .Values of MPI are obtained from Section 6.1, in which Pollution variable is involved in calculating MPI and its components.

[b] AGE = Accumulated Depreciation in 1990 / Assets in 1990

[c] RD = LOG (R&D in 1991 + ... + R&D in 1995)

[d] AT = LOG (Assets in 1990)

[e] if Industry = industrial and commercial machinery (SIC=35), then IND =1, otherwise IND=0

TABLE 31
MPI and Industry Effect: Electronic Equipment Industry

Model:

$$MPI^{a} = \partial_{0} + \partial_{1}AGE + \partial_{2}RD + \partial_{3}AT + \partial_{4}IND + \varepsilon$$

Results:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	18.43842	4.60960	5.69	0.0003
Error	174	141.04217	0.81059		
Corrected Total	178	159.48059			

Root MSE	0.90033	R-Square	0.1156
Dependent Mean	1.30440	Adj R-Sq	0.0953
Coeff Var	69.02208		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	0.59333	0.28102	2.11	0.0362
AGE	1	-0.30856	0.31907	-0.97	0.3348
RD	1	-0.02115	0.05919	-0.36	0.7213
AT	1	0.11167	0.06779	1.65	0.1013
IND	1	0.82474	0.19333	4.27	<.0001*

---

[a] MPI = Malmquist Productivity Index value for the period of 1990 -1996 .Values of MPI are obtained from Section 6.1, in which Pollution variable is involved in calculating MPI and its components.

[b] AGE = Accumulated Depreciation in 1990 / Assets in 1990

[c] RD = LOG (R&D in 1991 + ... + R&D in 1995)

[d] AT = LOG (Assets in 1990)

[e] if Industry = electronic equipment (SIC=36), then IND =1, otherwise IND=0

* significant at 90% probability level

TABLE 32
MPI and Industry Effect:
Transportation Equipment Industry

Model:

$$MPI^{a} = \partial_0 + \partial_1 AGE + \partial_2 RD + \partial_3 AT + \partial_4 IND + \varepsilon$$

Results:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	3.97074	0.99268	1.11	0.3531
Error	174	155.50985	0.89373		
Corrected Total	178	159.48059			

Root MSE	0.94538	R-Square	0.0249
Dependent Mean	1.30440	Adj R-Sq	0.0025
Coeff Var	72.47571		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.07735	0.26983	3.99	<.0001
AGE[b]	1	-0.22283	0.34030	-0.65	0.5135
RD[c]	1	0.04960	0.05972	0.83	0.4074
AT[d]	1	0.00493	0.06698	0.07	0.9414
IND[e]	1	0.12254	0.21772	0.56	0.5743

---

[a] MPI = Malmquist Productivity Index value for the period of 1990 -1996 .Values of MPI are obtained from Section 6.1, in which Pollution variable is involved in calculating MPI and its components.

[b] AGE = Accumulated Depreciation in 1990 / Assets in 1990

[c] RD = LOG (R&D in 1991 + ... + R&D in 1995)

[d] AT = LOG (Assets in 1990)

[e] if Industry = transportation equipment (SIC=37), then IND =1, otherwise IND=0

6.4 Analysis of Frontier Shift by using Grosskopf and Valdmanis (1987)

Before-participation and after-participation firms may have different production functions and use different technology, which may result in different production frontiers. To test this possibility, this study adopts the procedures of Grosskopf and Valdmains (1987). First, an overall efficiency index (EI) is calculated for each firm relative to the frontier for the entire sample. Then, a within-group efficiency index (EI*) is estimated for subsamples divided into before-participation and after-participation firms. Last, a between-group efficiency index (EI**) is estimated to determine whether the frontier of before-participation and after-participation firms differs. This study uses the Mann-Whitney test to determine if the difference in the between-group efficiency index (EI**) between two groups is statically significant.

The Mann-Whitney test, also known as the Wilcoxon Rank Sum test, is a nonparametric test that can be used to determine if there is any difference in the distribution of a variable across different groups. This test first draws a sample of size N_1 from one population, and draws a sample of N_2 from second population. There are N observations in all, where $N=N_1+N_2$. Then this test ranks all N observations. The sum W of the ranks for the sample is the Wilcoxon rank sum statistics. If two pollutions have the same distribution, then W has mean $\mu_w = \frac{n_1(N+1)}{2}$ and standard deviation $\sigma_w \sqrt{\frac{n_1 n_2 (N+1)}{12}}$.

The Mann-Whitney test rejects the hypothesis that the two populations have identical distribution when the rank sum W is far from its mean.

H_0: Two distributions are the same.

H_a: One population has values that are systematically larger.

For industry 2829 (chemical and petroleum firms) in EPA's 33/50 Program, this study estimates the overall efficiency indices for the entire sample, which includes 122 firm-observations in 1993 and 1996. According to Table 33, Panel A, the average overall efficiency score is 0.76. Next, the within-group efficiency indices for each subsample are estimated. The before-participation subsample has an average efficiency score of 0.72, while the after-participation subsample has an average efficiency of 0.79. Last, this study estimates the between-group efficiency indices for each subsample. The before-participation subsample has an average efficiency score of 0.89, while the after-participation subsample has an average efficiency score of 0.98. Table 33, Panel B, reports the Mann-Whitney Z score, which is -5.4010 with a p-value less than 0.0001. This implies that the frontiers of before-participation and after-participation firms are significantly different. Furthermore, information on Table 4 indicates that chemical and petroleum firms have reduced a significant amount of chemical releases from 1990 to 1996. The above evidence suggests that reducing a significant amount of pollution may lead to innovations, which usually cause a significant shift in the production frontier. This is consistent with the Porter Hypothesis.

TABLE 33
Analysis of Frontier Shift of EPA’s 33/50 Participants: Chemical and Petroleum Industry

Industry: EPA 2829 – Chemical and Petroleum Firms
Observation: 61
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Before	After	Before	After	Before	After
Range	(n= 122)	(n=61)	(n=61)	(n=61)	(n=61)	(n=61)	(n=61)
0.90 - 1.0000	48	20	28	9	27	33	59
0.80 - 0.8999	2	1	1	1	1	16	1
0.70 - 0.7999	15	7	8	4	8	5	1
0.60 - 0.6999	18	10	8	15	7	7	0
0.50 - 0.5999	32	18	14	22	15	0	0
< 0.50	7	5	2	10	3	0	0
Mean	0.76	0.64	0.78	0.72	0.79	0.89	0.98

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Before) vs. EI**(After)

Mann-Whitney Z Score	-5.401
One-sided Pr < Z	<0.0001*

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* significant at 10% level

Table 34 reports the overall, within-group and between-group efficiency indices for Industry 33 (Metal Firms) in EPA's 33/50 Program. According to Panel A, the average overall efficiency score is 0.49. Next, the within-group efficiency indices for each subsample are estimated. The before-participation subsample has an average efficiency score of 0.60, while the after-participation subsample has an average efficiency of 0.75. Last, this study estimates the between-group efficiency indices for each subsample. The before-participation subsample has an average efficiency score of 0.69, while the after-participation subsample has an average efficiency score of 0.79. Panel B, reports the Mann-Whitney Z score, which is -0.5850 with a p-value of 0.2793. This implies that the frontiers of before-participation and after-participation firms are not significantly different. It appears that metal firms did not experience a significant shift in their production frontier.

Information on Table 5 indicates that metal firms have not reduced a significant amount of chemical releases from 1990 to 1996. This evidence may explain the insignificant shift in the production frontier of metal firms. If the Porter Hypothesis is valid, then only reducing enough pollution may result in a significant shift in frontier. Since metal firms did not reduce enough pollution, it is not surprising that those firms did not experience a significant shift in their production frontier. Empirical results from Table 5 and 27 enhance the validity of the Porter Hypotheses, which encourages firms to reduce enough pollution.

TABLE 34
Analysis of Frontier Shift of EPA's 33/50 Participants: Metal Industry

Industry: EPA 33 – Metal Firms
Observation: 37
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Before	After	Before	After	Before	After
Range	(n=74)	(n=37)	(n=37)	(n=37)	(n=37)	(n=37)	(n=37)
0.90 - 1.0000	19	6	13	13	13	10	17
0.80 - 0.8999	0	0	0	0	3	2	0
0.70 - 0.7999	0	0	0	0	1	3	3
0.60 - 0.6999	2	0	2	4	9	7	2
0.50 - 0.5999	3	1	2	3	8	5	0
< 0.50	50	30	20	17	3	10	15
Mean	0.49	0.41	0.59	0.60	0.75	0.69	0.79

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Before) vs. EI**(After)

Mann-Whitney Z Score	-0.5850
One-sided Pr < Z	0.2793

Table 35 reports the overall, within-group and between-group efficiency indices for Industry 35 (Industrial and Commercial Firms) in EPA's 33/50 Program. According to Panel A, the average overall efficiency score is 0.58. Next, the within-group efficiency indices for each subsample are estimated. The before-participation subsample has an average efficiency score of 0.65while the after-participation subsample has an average efficiency of 0.80. Last, this study estimates the between-group efficiency indices for each subsample. The before-participation subsample has an average efficiency score of 0.73, while the after-participation subsample has an average efficiency score of 0.79. Panel B, reports the Mann-Whitney Z score, which is -1.7611 with a p-value of 0.0391. This implies that the frontiers of before-participation and after-participation firms are significantly different. Furthermore, information on Table 6 indicates that industrial and commercial firms have reduced a significant amount of chemical releases from 1990 to 1996. The above evidence suggests that reducing a significant amount of pollution may lead to innovations, which usually cause a significant shift in the production frontier. This is consistent with the Porter Hypothesis.

TABLE 35
Analysis of Frontier Shift of EPA's 33/50 Participants: Industrial and Commercial Machinery Industry

Industry: EPA 35 – Industrial and Commercial Machinery Firms
Observation: 28
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Before	After	Before	After	Before	After
Range	(n=56)	(n=28)	(n=28)	(n=28)	(n=28)	(n=28)	(n=28)
0.90 - 1.0000	18	5	13	10	16	11	18
0.80 - 0.8999	1	0	1	2	1	2	1
0.70 - 0.7999	2	0	2	3	2	1	2
0.60 - 0.6999	3	2	1	1	2	5	7
0.50 - 0.5999	9	5	4	1	4	4	1
< 0.50	23	16	7	10	3	5	0
Mean	0.58	0.47	0.64	0.65	0.80	0.73	0.79

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Before) vs. EI**(After)

Mann-Whitney Z Score	-1.7611
One-sided Pr < Z	0.0391*

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* significant at 10% level

Table 36 reports the overall, within-group and between-group efficiency indices for Industry 36 (Electronic Equipment Firms) in EPA's 33/50 Program. According to Panel A, the average overall efficiency score is 0.74. Next, the within-group efficiency indices for each subsample are estimated. The before-participation subsample has an average efficiency score of 0.76, while the after-participation subsample has an average efficiency of 0.85. Last, this study estimates the between-group efficiency indices for each subsample. The before-participation subsample has an average efficiency score of 0.86, while the after-participation subsample has an average efficiency score of 0.94. Panel B, reports the Mann-Whitney Z score, which is -2.3408 with a p-value of 0.0096. This implies that the frontiers of before-participation and after-participation firms are significantly different. Furthermore, information on Table 7 indicates that electronic equipment firms have reduced a significant amount of chemical releases from 1990 to 1996. The above evidence suggests that reducing a significant amount of pollution may lead to innovations, which usually cause a significant shift in the production frontier. This is consistent with the Porter Hypothesis.

TABLE 36
Analysis of Frontier Shift of EPA's 33/50 Participants: Electronic Equipment Industry

Industry: EPA 36 – Electronic Equipment Firms
Observation: 30
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Before	After	Before	After	Before	After
Range	(n=60)	(n=30)	(n=30)	(n=30)	(n=30)	(n=30)	(n=30)
0.90 - 1.0000	25	7	18	14	18	17	20
0.80 - 0.8999	1	0	1	0	2	4	10
0.70 - 0.7999	3	1	2	2	2	3	0
0.60 - 0.6999	5	3	2	2	4	3	0
0.50 - 0.5999	15	12	3	10	3	2	0
< 0.50	11	7	4	2	1	1	0
Mean	0.74	0.66	0.80	0.76	0.85	0.86	0.94

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Before) vs. EI**(After)

Mann-Whitney Z Score	-2.3408
One-sided Pr < Z	0.0096*

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* significant at 10% level

Table 37 reports the overall, within-group and between-group efficiency indices for Industry 37 (Transportation Equipment Firms) in EPA's 33/50 Program. According to Panel A, the average overall efficiency score is 0.72. Next, the within-group efficiency indices for each subsample are estimated. The before-participation subsample has an average efficiency score of 0.70, while the after-participation subsample has an average efficiency of 0.83. Last, this study estimates the between-group efficiency indices for each subsample. The before-participation subsample has an average efficiency score of 0.85, while the after-participation subsample has an average efficiency score of 0.99. Panel B, reports the Mann-Whitney Z score, which is -4.5766 with a p-value less than 0.0001. This implies that the frontiers of before-participation and after-participation firms are significantly different. Furthermore, information on Table 8 indicates that transportation equipment firms have reduced a significant amount of chemical releases from 1990 to 1996. The above evidence suggests that reducing a significant amount of pollution may lead to innovations, which usually cause a significant shift in the production frontier. This is consistent with the Porter Hypothesis.

TABLE 37
Analysis of Frontier Shift of EPA's 33/50 Participants: Transportation Equipment Industry

Industry: EPA 37 – Transportation Equipment Firms
Observation: 23
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Before	After	Before	After	Before	After
Range	(n=46)	(n=23)	(n=23)	(n=23)	(n=23)	(n=23)	(n=23)
0.90 - 1.0000	17	4	13	8	13	13	23
0.80 - 0.8999	2	1	1	1	2	1	0
0.70 - 0.7999	1	0	1	2	0	5	0
0.60 - 0.6999	9	5	4	5	4	2	0
0.50 - 0.5999	10	7	3	4	3	2	0
< 0.50	7	6	1	3	1	0	0
Mean	0.72	0.60	0.82	0.70	0.83	0.85	0.99

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Before) vs. EI**(After)

Mann-Whitney Z Score	-4.5766
One-sided Pr < Z	<0.0001*

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* significant at 10% level

Table 38 reports the overall, within-group and between-group efficiency indices for Industry 28/29 (Chemical and Petroleum Firms) in Canadian ARET Program. According to Panel A, the average overall efficiency score is 0.72. Next, the within-group efficiency indices for each subsample are estimated. The before-participation subsample has an average efficiency score of 0.75, while the after-participation subsample has an average efficiency of 0.89. Last, this study estimates the between-group efficiency indices for each subsample. The before-participation subsample has an average efficiency score of 0.85, while the after-participation subsample has an average efficiency score of 0.90. Panel B, reports the Mann-Whitney Z score, which is -1.6636 with a p-value of 0.0481. This implies that the frontiers of before-participation and after-participation firms are significantly different. Furthermore, information on Table 9 indicates that chemical and petroleum firms in Canadian ARET Program have reduced a significant amount of chemical releases from 1993 to 2000. The above evidence suggests that reducing a significant amount of pollution may lead to innovations, which usually cause a significant shift in the production frontier. This is consistent with the Porter Hypothesis.

TABLE 38
Analysis of Frontier Shift of Canadian ARET Participants: Chemical and Petroleum Industry

Industry: ARET 2829 – Chemical and Petroleum Firms
Observation: 24
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Before	After	Before	After	Before	After
Range	(n=48)	(n=24)	(n=24)	(n=24)	(n=24)	(n=24)	(n=24)
0.90 - 1.0000	18	5	13	10	18	11	17
0.80 - 0.8999	0	0	0	0	0	6	2
0.70 - 0.7999	1	1	0	0	0	2	0
0.60 - 0.6999	12	7	5	6	2	4	4
0.50 - 0.5999	8	4	4	6	4	0	0
< 0.50	9	7	2	2	0	1	1
Mean	0.72	0.63	0.80	0.75	0.89	0.85	0.90

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Before) vs. EI**(After)

Mann-Whitney Z Score	-1.6636
One-sided Pr < Z	0.0481*

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* significant at 10% level

Table 39
A Summary of the Relation between Pollution Reduction and Between-group Efficiency Index (EI**)

Program	SIC	Industry	Obs.	Pollution Reduction	EI**(Before) vs. EI**(After)
U.S.	28/29	Chemical and Petroleum	61	Significant	Significant
U.S.	33	Metal	37	Insignificant	Insignificant
U.S.	35	Industrial and Commercial	28	Significant	Significant
U.S.	36	Electronic Equipment	30	Significant	Significant
U.S.	37	Transportation Equipment	23	Significant	Significant
Canada	28/29	Chemical and Petroleum	24	Significant	Significant

Table 39 summarize the relation between pollution reduction and the between-group index (EI**). The information on pollution reduction is obtained from Table 4 – 9 in Section 5.3, while the between-group efficiency indices are estimated by using the procedures in Grosskopf and Valdmanis (1987). Results indicate that all industries that reduced a significant amount of pollution experienced a significant shift in the production frontier. This suggests that reducing (enough) pollution may lead to innovations that usually cause a (significant) shift in frontier. This is consistent with the Porter Hypothesis. Firms in industry 33 did not reduce enough pollution. As a result, those firms did not experience a significant shift in their production frontier. This evidence enhances the validity of the Porter Hypothesis. That is, not reducing enough pollution may not lead to innovations.

By using the same methodology, this study further examines the possibility of different production frontiers between participating firms and matched firms. In order to test this possibility, this study removes the “Pollution” variable out of the efficiency model, since the pollution information on targeted chemicals for matched firms is not available. The pooled sample consists of participating firms and matched firms.

For industry 28/29 (Chemical and Petroleum Firms) in EPA’s 33/50 Program, this study estimates the overall efficiency indices for the entire sample, which includes 62 participating firms and 62 matched firms in 1990. According to the results in Table 40, Panel A, the average overall efficiency score is 0.71. Next, the within-group efficiency indices for each subsample are estimated. The participating-firm subsample has an average efficiency score of 0.91, while the matched-firm subsample has an average efficiency of 0.52. Last, this study estimates the between-group efficiency indices for each subsample. The participating-firm subsample has an average efficiency score of 0.98, while the matched-firm subsample has an average efficiency score of 0.86. Table 40, Panel B, reports the Mann-Whitney Z score, which is 7.5081 with a p-value less than 0.0001. This implies that the frontiers of participating firms and matched firms are significantly different. The above evidence suggests that participating firms in EPA’s 33/50 Program are more technically efficient than non-participating firms from the same industry.

TABLE 40
Analysis of Frontier Shift of EPA's 33/50 Participants and Matched Firms: Chemical and Petroleum Industry

Industry: EPA 2829 – Chemical and Petroleum Firms
Observation: 61
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Sample	Matched	Sample	Matched	Sample	Match
Range	(n= 122)	(n=61)	(n=61)	(n=61)	(n=61)	(n=61)	(n=61)
0.90 - 1.0000	32	32	0	39	1	58	33
0.80 - 0.8999	26	26	0	20	3	3	16
0.70 - 0.7999	1	1	0	0	4	0	4
0.60 - 0.6999	5	2	3	2	14	0	5
0.50 - 0.5999	48	0	48	0	39	0	1
< 0.50	10	0	10	0	0	0	2
Mean	0.71	0.90	0.45	0.91	0.52	0.98	0.86

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Participating Firms) vs. EI**(Matched Firms)

Mann-Whitney Z Score	7.5081
One-sided Pr < Z	<0.0001*

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* significant at 10% level

Table 41 reports the overall, within-group and between-group efficiency indices for Industry 33 (Metal Firms) in EPA's 33/50 Program. The pooled sample consists of 37 participating firms and 37 matched firms in 1990. According to the results in Panel A, the average overall efficiency score is 0.35. Next, the within-group efficiency indices for each subsample are estimated. The participating-firm subsample has an average efficiency score of 0.78, while the matched-firm subsample has an average efficiency of 0.44. Last, this study estimates the between-group efficiency indices for each subsample. The participating-firm subsample has an average efficiency score of 0.62, while the matched-firm subsample has an average efficiency score of 0.61. Table 41, Panel B, reports the Mann-Whitney Z score, which is 0.5514 with a p-value of 0.2907. This implies that the frontiers of participating firms and non-participating firms are not significantly different. In other words, participating firms in the metal industry share a similar production frontier with non-participating firms.

TABLE 41
Analysis of Frontier Shift of EPA's 33/50 Participants and Matched Firms: Metal Industry

Industry: EPA 33 – Metal Firms
Observation: 37
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Sample	Matched	Sample	Matched	Sample	Matched
Range	(n=74)	(n=37)	(n=37)	(n=37)	(n=37)	(n=37)	(n=37)
0.90 - 1.0000	7	5	2	17	8	11	11
0.80 - 0.8999	0	0	0	5	1	3	2
0.70 - 0.7999	3	3	0	5	1	2	0
0.60 - 0.6999	2	2	0	3	1	1	2
0.50 - 0.5999	7	6	1	1	4	5	4
< 0.50	55	21	34	6	22	15	18
Mean	0.35	0.46	0.23	0.78	0.44	0.62	0.61

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Participating Firms) vs. EI**(Matched Firms)

Mann-Whitney Z Score	0.5514
One-sided Pr < Z	0.2907

Table 42 reports the overall, within-group and between-group efficiency indices for Industry 35 (industrial and commercial firms) in EPA's 33/50 Program. The pooled sample consists of 28 participating firms and 28 matched firms in 1990.According to the results reported in Panel A, the average overall efficiency score is 0.40. Next, the within-group efficiency indices for each subsample are estimated. The participating-firm subsample has an average efficiency score of 0.57, while the matched-firm subsample has an average efficiency of 0.61. Last, this study estimates the between-group efficiency indices for each subsample. The participating-firm subsample has an average efficiency score of 0.60, while the matched-firm subsample has an average efficiency score of 0.82. Table 42, Panel B, reports the Mann-Whitney Z score, which is -2.2614 with a p-value of 0.0119. This implies that the frontiers of participating and non-participating firms are significantly different. The above evidence suggests that non-participating firms are more technically efficient than participating firms in the industrial and commercial machinery industry.

TABLE 42
Analysis of Frontier Shift of EPA's 33/50 Participants and Matched Firms: Industrial and Commercial Machinery Industry

Industry: EPA 35 – Industrial and Commercial Machinery Firms
Observation: 28
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Sample	Matched	Sample	Matched	Sample	Matched
Range	(n=56)	(n=28)	(n=28)	(n=28)	(n=28)	(n=28)	(n=28)
0.90 - 1.0000	4	1	3	8	6	9	8
0.80 - 0.8999	0	0	0	2	0	2	7
0.70 - 0.7999	4	3	1	3	4	3	8
0.60 - 0.6999	4	0	4	1	2	2	4
0.50 - 0.5999	4	1	3	0	5	1	1
< 0.50	40	23	17	14	11	11	0
Mean	0.40	0.34	0.50	0.57	0.61	0.60	0.82

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Participating Firms) vs. EI**(Matched Firms)

Mann-Whitney Z Score	-2.2614
One-sided Pr < Z	0.0119*

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* significant at 10% level

Table 43 reports the overall, within-group and between-group efficiency indices for Industry 36 (electronic equipment firms) in EPA's 33/50 Program. The pooled sample consists of 30 participating firms and 30 matched firms in 1990. According to the results presented in Panel A, the average overall efficiency score is 0.35. Next, the within-group efficiency indices for each subsample are estimated. The participating-firm subsample has an average efficiency score of 0.77, while the matched-firm subsample has an average efficiency of 0.49. Last, this study estimates the between-group efficiency indices for each subsample. The participating-firm subsample has an average efficiency score of 0.63, while the matched-firm subsample has an average efficiency score of 0.54. Table 43, Panel B, reports the Mann-Whitney Z score, which is 0.8353 with a p-value of 0.2018. This implies that the frontiers of participating and non-participating firms are not significantly different. In other words, participating firms in the industrial and commercial machinery industry share a similar production frontier with non-participating firms.

TABLE 43
Analysis of Frontier Shift of EPA's 33/50 Participants and Matched Firms: Electronic Equipment Industry

Industry: EPA 36 – Electronic Equipment Firms
Observation: 30
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Sample	Matched	Sample	Matched	Sample	Matched
Range	(n=60)	(n=30)	(n=30)	(n=30)	(n=30)	(n=30)	(n=30)
0.90 - 1.0000	5	5	0	13	5	12	9
0.80 - 0.8999	3	3	0	2	2	5	1
0.70 - 0.7999	0	0	0	3	0	0	1
0.60 - 0.6999	2	2	0	4	2	0	2
0.50 - 0.5999	5	4	1	5	0	1	2
< 0.50	45	16	29	3	21	12	15
Mean	0.35	0.47	0.23	0.77	0.49	0.63	0.54

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Participating Firms) vs. EI**(Matched Firms)

Mann-Whitney Z Score	0.8353
One-sided Pr < Z	0.2018

Table 44 reports the overall, within-group and between-group efficiency indices for Industry 37 (transportation equipment firms) in EPA's 33/50 Program. The pooled sample consists of 23 participating firms and 23 matched firms in 1990. According to the results presented in Panel A, the average overall efficiency score is 0.47. Next, the within-group efficiency indices for each subsample are estimated. The participating-firm subsample has an average efficiency score of 0.77, while the matched-firm subsample has an average efficiency of 0.70. Last, this study estimates the between-group efficiency indices for each subsample. The participating-firm subsample has an average efficiency score of 0.76, while the matched-firm subsample has an average efficiency score of 0.56. Table 44, Panel B, reports the Mann-Whitney Z score, which is 2.4496 with a p-value of 0.0071. This implies that the frontiers of participating and non-participating firms are significantly different. The above evidence suggests that participating firms are more technically efficient than non-participating firms in the transportation equipment industry.

TABLE 44

Analysis of Frontier Shift of EPA's 33/50 Participants and Matched Firms: Transportation Equipment Industry

Industry: EPA 37 – Transportation Equipment Firms
Observation: 23
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Sample	Matched	Sample	Matched	Sample	Matched
Range	(n=46)	(n=23)	(n=23)	(n=23)	(n=23)	(n=23)	(n=23)
0.90 - 1.0000	2	1	1	10	9	6	3
0.80 - 0.8999	1	1	0	1	0	3	2
0.70 - 0.7999	4	3	1	4	3	5	3
0.60 - 0.6999	6	4	2	3	2	4	2
0.50 - 0.5999	8	5	3	1	3	5	4
< 0.50	25	9	16	4	6	0	9
Mean	0.47	0.56	0.37	0.77	0.70	0.76	0.56

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Participating Firms) vs. EI**(Matched Firms)

Mann-Whitney Z Score	2.4496
One-sided Pr < Z	0.0071*

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* significant at 10% level

Table 45 reports the overall, within-group and between-group efficiency indices for Industry 28/29 (Chemical and Petroleum Firms) in Canadian ARET Program. The pooled sample consists of 24 participating firms and 24 matched firms in 1993. According to the results reported in Panel A, the average overall efficiency score is 0.59. Next, the within-group efficiency indices for each subsample are estimated. The participating-firm subsample has an average efficiency score of 0.78, while the matched-firm subsample has an average efficiency of 0.77. Last, this study estimates the between-group efficiency indices for each subsample. The participating-firm subsample has an average efficiency score of 0.93, while the matched-firm subsample has an average efficiency score of 0.57. Table 45, Panel B, reports the Mann-Whitney Z score, which is 4.7432 with a p-value less than 0.0001. This implies that the frontiers of participating and non-participating firms are significantly different. The above evidence suggests that participating firms in the Canadian ARET Program are more technically efficient than non-participating firms from the same industry.

TABLE 45
Analysis of Frontier Shift of Canadian ARET Participants and Matched Firms: Chemical and Petroleum Industry

Industry: ARET 2829 – Chemical and Petroleum Firms
Observation: 24
Source of Efficiency Indices: DEA model

Panel A: Frequency and Summary Statistics of Efficiency Indices

	Overall Efficiency Indices (EI)			Within-group (EI*)		Between-group (EI**)	
	All	Sample	Matched	Sample	Matched	Sample	Matched
Range	(n=48)	(n=24)	(n=24)	(n=24)	(n=24)	(n=24)	(n=24)
0.90 - 1.0000	9	6	3	10	10	18	5
0.80 - 0.8999	1	1	0	2	2	2	1
0.70 - 0.7999	10	7	3	4	3	3	1
0.60 - 0.6999	5	4	1	3	4	0	2
0.50 - 0.5999	2	2	0	2	2	1	6
< 0.50	21	4	17	3	3	0	9
Mean	0.59	0.73	0.44	0.78	0.77	0.93	0.57

Panel B: Mann-Whitney z Score Test (Wilcoxon Rank Sum Test)

EI**(Participating Firms) vs. EI**(Matched Firms)

Mann-Whitney Z Score	4.7432
One-sided Pr < Z	<0.0001*

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* significant at 10% level

Table 46
A Summary of the Examination of the possibility of different frontiers: Participating Firms vs. Matched Firms

Program	SIC	Industry	Obs.	Difference in Frontier
				Participating vs. Matched Firms
U.S.	28/29	Chemical and Petroleum	61	Significant
U.S.	33	Metal	37	Insignificant
U.S.	35	Industrial and Commercial Machinery	28	Significant
U.S.	36	Electronic Equipment	30	Insignificant
U.S.	37	Transportation Equipment	23	Significant
Canada	28/29	Chemical and Petroleum	24	Significant

Table 46 summarize the results reported in the above 6 tables (Table 40 – 45). Empirical evidence indicates that participating firms from the following industries: U.S. chemical and petroleum, U.S. transportation equipment, and Canadian chemical and petroleum, are more technically efficient than their matched non-participating peers. Participating firms from the metal and electronic equipment industries appear to share the same production frontier with their matched non-participating peers. Last, results suggest that participating firms in the industrial and commercial machinery are less efficient than their matched non-participating peers.

CHAPTER 7

SUMMARY AND CONCLUSIONS

The purpose of this study is to empirically test the validity of the Porter Hypothesis by investigating the impact of complying with properly designed environmental programs (EPA’s 33/50 Program and Canadian ARET Program) on a firm’s technical efficiency. The results from this study should be of significant interest to managers, regulators and investors. If the Porter Hypothesis is valid, then it will provide a strong incentive for management to invest in an environmental cost management system. An ECMS can assist managers in obtaining correct costing of products, which is a pre-condition for making sound business decisions. In addition, such systems can help managers justify these cleaner production projects, and aid companies in the design of more environmentally preferable products, processes and services for the future. To regulators, evidence supporting the Porter Hypothesis would encourage regulators to introduce more properly designed regulations that create maximum opportunity for innovation. Properly designed environmental regulations can not only improve our living conditions but also motivate firms to find ways to reduce their environmental costs. To individual investors, evidence supporting the Porter Hypothesis would encourage them to invest in ‘greener’ firms, since ‘greener’ firms may have more competitive advantages over their competitors.

Empirical results indicate that the majority of participating firms have experienced significant increases in their efficiencies since participation, relative to matched firms. Furthermore, results suggest that reducing pollution has led to innovations among participating firms. The above evidence supports the Porter Hypothesis. In addition, both parametric and non-parametric models produced relatively similar results. It appears that both models are good tools to measure a firm's efficiency. This study also uses the procedures described in Grosskopf and Valdmanis (1987). A between-group efficiency index (EI**) is estimated to determine whether the frontier of before-participation and after-participation firms differs. Mann-Whitney Z Score test is used to measure the significance of the between-group efficiency index. Empirical results from this methodology also support the Porter Hypothesis. The fact that this study applies multiple methodologies to the same data set makes this study unique. Unlike other efficiency studies, this study uses a combination of different methodologies - Stochastic Frontier Analysis (SFA), Data Envelopment Analysis (DEA), Malmquist Productivity Index (MPI), and the methodology discussed in Grosskopf and Valdmanis (1987). Empirical results from each methodology seem to be relatively consistent. These similar results not only enhance the validity of the Porter Hypothesis but also strengthen the robustness of this study.

The above empirical results suggest that reducing pollution may bring future economic benefits to participating firms, and voluntarily environmental programs can lead to "win-win" situations. The above empirical evidence also supports the decisions that have made by the U.S. Environmental Protection Agency and Canada Environment to introduce more innovation-friendly environmental programs. Under such programs, firms are given maximum opportunities to discover how to solve their own problems. Such programs can trigger innovations that encourage compliance and, at the same time, reduce costs. From the policy maker's point of view, the paradigm shift from command-and-control regulations to voluntary programs has proved to be correct. Thus, more and more voluntary and innovation-friendly environmental programs can be expected in the near future.

By using regression analysis, this study examines the relation between changes in a firm's efficiency and three control variables. Regression results reveal that research and development activities play an important role in a firm's frontier shift. That is, conducing active research and development can cause innovations, which can benefit the firm. Regression results also suggest that it may be easier and faster for smaller firms to adopt and implement newly improved technology relative to larger firms.

There are several limitations of this study. First, firms often reduce pollution incrementally, and the stage and scope of such reduction can be difficult to determine. Also firms in this study may have participated in other environmental programs besides the EPA's 33/50 Program and Canadian ARET Program. Second, this study, like other prior studies, may be subject to selection bias. If the firm characteristics that led to program participation also led to superior (future) economic performance for reasons unrelated to reducing pollution, then any performance effects associated with program participation may actually caused by such characteristics. Third, the quality of pollution data in this study still remains unknown. Environmental Protection Agency (EPA) has not yet established any standards to measure and control the quality of the pollution data provided by firms.

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APPENDIXES

Appendix A

EPA's 33/50 Program

In 1991, the Environmental Protection Agency (EPA) introduced its first federal voluntary pollution prevention program, known as the 33/50 Program, which had the objective of reducing the emissions of 17 major chemicals by 33% by 1992 and by 50% by 1995. The EPA invited companies to participate, and those participated in the 33/50 Program were not restricted to the national goal of 33% and 50%, but were free to set their own reduction goals. There were about 1,300 companies that participated in the 33/50 Program. EPA claims that the 33/50 program broke the traditional mold of command-and-control regulatory paradigm that has dominated our nation's approach to environmental protection, and achieved impressive results. The national goal was achieved in 1991, one year ahead of schedule. EPA recognized the 33/50 Program as a model for a new way of doing business with companies.

There are 17 major chemicals targeted in 33/50 program. These chemicals are (1) Benzene, (2) Carbon Tetrachloride, (3) Chloroform, (4) Dichloromethane, (5) Methyl ethyl Ketone, (6) Methyl isobutyl Ketone, (7) Tetrachloroethylene, (8) Toluene, (9) 1.1.1 – Trichloroethane, (10) Trichloroethylene, (11) Xylenes, (12) Cadmium and Cadmium Compounds, (13) Chromium jand Chromium Compounds, (14) Cyanide Compounds, (15) Lead and lead Compounds, (16) Mercury and mercury Compounds, and (17) Nickel and nickel Compounds.

Appendix B

Canadian Accelerated Reduction/Elimination of Toxics (ARET) Program

In 1994, Environment Canada launched its first voluntary pollution prevention program, known as the National Accelerated Reduction/Elimination of Toxics (ARET), which had the objective of reducing the emissions of 30 persistent and bio-accumulative chemicals by 90% by 2000 and reducing an additional 87 chemicals by 50% by 2000. Canadian ARET program expands on the EPA's 33/50 program. Like the 33/50 Program, the ARET Program is based on voluntary participation. Participating firms were free to set their own reduction goals. According to the Ministers of Environmental, Health and Industry of Canada, the ARET Program succeeded in attracting participation from 8 major industry sectors and 171 companies by the year 2000, and represented a significant step forward by Canadians to prevent and control pollution.

30 persistent and bio-accumulative chemicals

Benz(a)anthracene
Benzo(a)pyrene
Benzo(e)pyrene
Benzo(b)fluoranthene
Benzo(j)fluoranthene
Benzo(k)fluoranthene
Benzo(g,h,i)perylene
Chrysene
Dibenz(a,h)anthracene
Dibenzo(a,i)pyrene
Dibenz(a,j)acridine
7H-Dibenzo(c,g)carbazole
Fluoranthene
Indeno(1,2,3-c,d)pyrene
Perylene
Phenanthrene
Pyrene
1.6-Dinitropyrene
1.8-Dinitropyrene
Polychlorinated biphenyls
Hexachlorobenzene
Alpha-hexachorocyclohexane
Gamma-hexachorocyclohexane
4,4'-Methylenebis
Octachlorostyrene
Pentachlorophenol
2,3,7,8-Tetrachlorodibenzofuran
2,3,7,8-Tetrachlorodibenzofuran-p-dioxin
Methyl mercury
Tributyltin

Additional 87 Chemicals

1,4-Dichlorobenzene
Cadmium compounds
Anthracene
7,12-Dimethylbenz(a)anthracene
Dimethylnaphthalene
o-Anisidine
Cyanides
4,6-Dinitro-o-cresol
1,4-Dioxane
Ethylene oxide
Acetaldehyde
Acetamide
Acrolein
Acrylonitrile
Acrylamide

3,3-Dichlorobenzidine
Hexachlorocyclopentadiene
2,4,6-Trichlorophenol
Bis(2-ethylhexy)phthalate
Tetraethyl lead
Benzo(a)fluorence
Benzo(b)fluorence
Dibenz(a,h)acridine
a-Chlorotoluene
Bis(2-chloroethy)ether
Bromodichloromethane
1,2-Dichloroethane
Methylene chloride
1,1,2,2-Tetrachloroethylene
2,3,4,6-Tetrachloroethylene
Arsenic
Asbestos
Beryllium
Chromium
Cobalt
Copper
Lead
Mercury
Nickel
Silver
Uranium
Zinc
2-Naphthylamine
2-Nitropropane
Thiourea
Bis(chloromethyl)ether
Epichlorohydrin
1-Bromo-2-chloroethane
1-Chloro-4-nitrobenzene
1,2-Dibromo-3-chloropropane
1,2-Dichlorobut-3-ene
2,4-Dichlorophenol
1,3-Dichloropropene
1,1,2-Trichloroethylene
4-Aminoazobenzene
4-Aminobiphenyl
Aniline
Benzene
Benzidine
Dimethylphenol
2,6-Dimethylphenol
2,4-Dinitrotoluene
2,6-Dinitrotoluene
1,2-Diphenylhydrazine
2-Methylpyridine
Phenol
Toluene diisocyanates
N-Nitrosodimethylamine
N-Nitrosodiphenylamine
1,3-Butadiene
Chlorine dioxide
n-Dodecane
Ethanol
Ethylene dibrommide
Ethylene thiourea
Formaldehyde
Hydrazine
Hydrogen sulphide
Methyl isobutyl ketone
4-Nitrosomorpholine
Quinoline
Tetramethylthiuram disulphide
Vinyl bromide

APPENDIX C

Environmental Costs

According to EPA, environmental costs include the following four different kinds:

(1) Direct costs

Direct costs are those costs directly linked with a product, project, or process. Examples are depreciations on equipments, materials, labor, waste management, etc.

(2) Hidden costs

Hidden costs are those refer to regulatory compliance or other costs that are hidden or lumped into a general account. Examples include compliance reporting, monitoring, legal support, etc.

(3) Contingent liability costs

Contingent liability costs are those associated with liabilities that may result from waste and materials management.

(4) Less tangible costs

Less tangible costs are very difficult for firms to estimate. When a company releases more pollution, it may suffer loss that derives from damaged corporate image. The loss is an example of less tangible costs.

APPENDIX D

Burnett (2003) vs. Murty and Kumar (2003)

	Burnett (2003)	Murty and Kumar (2003)
Theory Tested	The Porter Hypothesis	The Porter Hypothesis
Environmental Regulation	1990 CAAA	Unknown
Industry	Electric Utility	Water-polluting Industry
Country	U.S.	India
Efficiency	Technical Efficiency	Technical Efficiency
Efficiency Model	DEA[13]	SFA[14]
Output Variable	Kilowatt-hours	Sales Revenue ($) Biological Oxygen Demand Chemical Oxygen Demand Suspended Solids
Input Variable	Total Capital Cost ($) Fuel Cost ($) Operating Cost ($)	Material Cost ($) Labor Cost ($) Capital Cost ($)
Variable Measurement	Physical and Monetary	Physical and Monetary
Result	Support the Porter Hypothesis	Support the Porter Hypothesis

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[13] Data Envelopment Analysis – a classical nonparametric model to measure efficiency.
[14] Stochastic Frontier Analysis – a classical parametric model to measure efficiency.

APPENDIX E

Burnett (2003) vs. This Study

	Burnett (2003)	*This Study*
Theory Tested	The Porter Hypothesis	The Porter Hypothesis
Environmental Regulation	Mandatory 1990 CAAA	Voluntary EPA's 33/50 Program, and Canadian ARET Program
Industry	Electric Utility	Multiple Industries
Country	U.S.	U.S. and Canada
Efficiency	Technical Efficiency	Technical Efficiency
Efficiency Model	DEA	SFA and DEA
Output Variable	Kilowatt-hours	Sales Revenue Pollution Reduction
Input Variable	Total Capital Cost Fuel Cost Operating Cost	COGS Selling, general and administrative Expense Capital Expenditure
Variable Measurement	Physical and Monetary	Physical and Monetary
Result	Support the Porter Hypothesis	Support the Porter Hypothesis

APPENDIX F

Approaches to Measure the Impact of Environmental Regulations on a Firm's Technical Efficiency

According to Murty and Kumar (2003), there are three major approaches used in the literature to measure the effect of environmental regulation on the technical efficiency of a firm:

(i) adjusting the output of the plant to account for undesirable outputs, such as emissions, (Pittman 1981, 1983, Coggins and Swinton 1994, Fare Grosskopf, Lovell and Yaisawarng 1993). The primary purpose of these studies is to demonstrate the importance of including undesirable outputs when making comparisons of technical efficiency among economic entities.

(ii) accounting for the effect of pollution abatement cost on total factor productivity (Gollop and Roberts 1980, Gray and Shadbegian 1995). These papers often attempt to investigate the relationship between a plant's technical efficiency and its pollution abatement expenditures.

(iii)measuring efficiency from the changes in inputs and outputs (Fare et al. 1986, 1989, Boyd and McClelland 1999, Burnett 2003, Burnett and Hansen 2004, Marklund 2003, Murty and Kumar 2003). In recent years, many studies in this category have increasingly focused on the frontier efficiency, which measures deviations in performance from that of 'best practice' firms on the technical efficiency frontier.

All of these above studies can be further classified into two types. The first type uses conventional approaches, such as production functions, while the second type uses distance functions to measure production efficiency[15]. Fare et al. (1993) suggest that the distance function has several advantages over conventional approaches. First, the distance function completely describes technology. Second, it models joint production of multiple outputs, including desirable and undesirable outputs. Third, it assumes weak disposability of undesirable outputs, since polluting firms cannot dispose bad outputs freely.

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[15] In a multiple-input/output framework, an output distance function is defined as the reciprocal of the maximum proportional expansion of the output vector, given inputs. An input distance function is defined as the reciprocal of the maximum proportional contraction of the input vectors, given outputs.

APPENDIX G
List of Sample Firms

Panel A: EPA 33/50 Program

Firm	SIC
FMC CORPORATION	2829
IMPERIAL CHEMICAL INC.	2829
CALGON CARBON CORPORATION	2829
ENGELHARD CORPORATION	2829
AIR PRODUCTS AND CHEMICALS	2829
CROMPTON CORPORATION	2829
E. I. DU PONT DE NEMOURS & CO	2829
ALBEMARLE CORPORATION	2829
DOW CHEMICAL COMPANY	2829
DOW CORNING CORPORATION	2829
ROGERS CORP.	2829
ROHM AND HAAS COMPANY	2829
HOECHST CELANESE CORPORATION	2829
ABBOTT LABORATORIES	2829
BRISTOL-MYERS SQUIBB COMPANY	2829
JOHNSON & JOHNSON	2829
LILLY CORPORATE CENTER	2829
MERCK & COMPANY INCORPORATED	2829
PAR PHARMACEUTICAL INC	2829
PERRIGO COMPANY	2829
PFIZER INC	2829
RHONE-POULENC INC	2829
ROCHE HOLDINGS INC	2829
SCHERING-PLOUGH CORPORATION	2829
SMITHKLINE BEECHAM	2829
THE DEXTER CORPORATION	2829
WARNER-LAMBERT COMPANY	2829
PROCTER & GAMBLE COMPANY	2829
STEPAN COMPANY	2829
KATY INDUSTRIES INC	2829
MOORE CO.	2829
FERRO CORPORATION	2829
LILLY INDUSTRIES INC	2829
SHERWIN-WILLIAMS COMPANY	2829
VALSPAR CORPORATION	2829
LUBRIZOL CORP.	2829
LYONDELL CHEMICAL CO	2829
UNIROYAL CHEMICAL CORPORATION	2829

AKZO NOBEL INC	2829
BASF CORPORATION	2829
CABOT CORPORATION	2829
HERCULES INCORPORATED	2829
MORTON INTERNATIONAL INC	2829
NALCO CHEMICAL COMPANY	2829
PETROLITE CORPORATION	2829
AMERADA HESS CORPORATION	2829
AMOCO CORPORATION	2829
ASHLAND OIL INC	2829
ATLANTIC RICHFIELD COMPANY	2829
BURMAH CASTROL INC	2829
CHEVRON CORPORATION	2829
ELF AQUITAINE INC	2829
EXXON CORPORATION	2829
FINA INC	2829
MOBIL CORPORATION	2829
SHELL OIL COMPANY	2829
TEXACO INC	2829
UNOCAL CORPORATION	2829
USX CORPORATION	2829
WITCO CORPORATION	2829
QUAKER CHEMICAL CORPORATION	2829
ACME Metal CORP.	33
AK STEEL CORPORATION	33
ARMCO INC	33
BAYOU STEEL CORP.	33
BETHLEHEM STEEL CORPORATION	33
CARPENTER TECHNOLOGY CORP.	33
COMMERCIAL METALS COMPANY	33
GENEVA STEEL	33
J & L SPECIALTY STEEL INC	33
LTV CORPORATION	33
NATIONAL STEEL CORPORATION	33
ROANOKE ELECTRIC STEEL CORP.	33
TALLEY INDUSTRIES INC	33
TEXAS INDUSTRIES INC	33
WEIRTON STEEL CORP.	33
ASARCO INCORPORATED	33
INCO INC	33
HANDY & HARMAN	33
WOLVERINE TUBE INC	33
BELDEN WIRE AND CABLE COMPANY	33
BICC USA INC	33
DYNAMIC MATERIALS CO.	33
HARSCO CORPORATION	33

LINDBERG CORPORATION	33
REVCO/LINDBERG	33
BALL CORPORATION	33
GILLETTE COMPANY	33
STANLEY WORKS	33
CHART INDUSTRIES INC	33
CHEMI-TROL CHEMICAL CO	33
PENN ENG. & MFG. CORP.	33
TRIMAS CORPORATION	33
EKCO GROUP INC	33
ZERO CORPORATION	33
AERO METAL FINISHING INC.	33
PARKER HANNIFIN CORPORATION	33
DIEBOLD INC.	33
DEERE & COMPANY	35
GEHL CO.	35
JLG IND. INC.	35
BUCYRUS CO.	35
CASCADE CORP.	35
RAYMOND CORPORATION	35
ILLINOIS TOOL WORKS INC	35
LINCOLN ELECTRIC CO.	35
BLACK & DECKER CORPORATION	35
INGERSOLL-RAND COMPANY	35
THOMAS INDUSTRIES INC	35
TWIN DISC INC.	35
SKF INC	35
TIMKEN CO.	35
DONALDSON COMPANY INC	35
FARR COMPANY	35
NORDSON CORPORATION	35
IBM	35
SUN COMPANY INC	35
STORAGE TECHNOLOGY CORPORATION	35
MEMOREX CORPORATION	35
CANON INC.	35
KEY TRONIC CORP.	35
BELL & HOWELL COMPANY	35
AMERICAN STANDARD COMPANIES	35
KYSOR INDUSTRIAL CORPORATION	35
PEERLESS MFG INC.	35
TECUMSEH PRODUCTS COMPANY	35
EMERSON ELECTRIC CO	36
SPX CORPORATION	36
BALDOR ELECTRIC CO.	36
WHIRLPOOL CORPORATION	36

HUBBELL INCORPORATED	36
HARMAN INTERNATIONAL INDS INC	36
INTERNATIONAL JENSEN INC	36
SONY USA INC	36
ZENITH ELECTRONICS CORPORATION	36
COMDIAL CORPORATION	36
TELLABS INC.	36
ERICSSON G E MOBILE COMM. HLD	36
MOTOROLA	36
CTS CORPORATION	36
AMP-AKZO COMPANY	36
CIRCUIT SYSTEMS INC.	36
HADCO CORPORATION	36
NATIONAL MFG. CO.	36
SHELDAHL INC	36
AMERICAN ELECTRONIC COMPONENTS	36
BURR-BROWN CORP.	36
INTEL CORPORATION	36
NATIONAL SEMICONDUCTOR CORP.	36
OPTEK TECH. INC.	36
PHOTRONICS INC	36
TEXAS INSTRUMENTS INC.	36
OAK INDUSTRIES INC	36
FIFTH DIMENSION INC.	36
GTI CORPORATION	36
DURACELL INTERNATIONAL INC	36
AMERICAN HONDA MOTOR CO INC	37
CHRYSLER CORPORATION	37
GENERAL MOTORS CORPORATION	37
NAVISTAR INTL CORP	37
DANA CORPORATION	37
EAGLE-PICHER INDUSTRIES INC	37
EATON CORPORATION	37
MODINE MFG. CO.	37
WABASH NATL. CORP.	37
UNITED TECHNOLOGIES CORP	37
MCDONNELL DOUGLAS CORP	37
GENERAL ELECTRIC COMPANY	37
B F GOODRICH COMPANY	37
BOEING COMMERCIAL AIRPLANE	37
ROHR INC.	37
SUNDSTRAND CORPORATION	37
GENERAL DYNAMICS CORPORATION	37
LITTON INDUSTRIES INC	37
AVONDALE IND. INC.	37
GENCORP INC	37

HI-SHEAR INDUSTRIES INC	37
LOCKHEED MARTIN CORPORATION	37
POLARIS INDUSTRIES PARTNERS LP	37

Panel B: Canadian ARET Program:

Firm	SIC
Nexen Chemicals Canada	2829
BASF Canada Limited	2829
Bayer Canada Inc.	2829
Rhodia Canada Inc.	2829
Kronos Canada Inc.	2829
Shell Canada Limited	2829
Crompton Canada Company	2829
Dupont Canada Inc.	2829
Dow Chemical Canada Inc.	2829
Rohm and Haas Canada Inc.	2829
Wyeth-Ayerst Canada Inc.	2829
Stepan Canada Inc.	2829
PPG Canada Inc.	2829
Huntsman Corporation Canada	2829
Lubrizol Canada Inc.	2829
Methanex Corporation	2829
Comstock Canada	2829
Union Carbide Canada Inc.	2829
Cytec Canada Inc.	2829
Hercules Canada Inc.	2829
Nalco/Exxon Energy Chemicals Inc.	2829
Imperial Oil Limited	2829
Petro-Canada	2829
Suncor Energy Inc.	2829

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Title of Study: VOLUNTARY ENVIRONMENTAL PROGRAMS AND TECHNICAL EFFICIENCY: ANOTHER EXAMINATION OF THE PORTER HYPOTHESIS

Page in study: 143 Candidate for the Degree of Doctor of Philosophy

Major Field: Accounting

Scope and Method of Study: The Porter Hypothesis argues that properly designed environmental regulation not only increases environmental quality, but also makes firms more technically efficient. The purpose of this study is to empirically test the validity of the Porter Hypothesis by investigating the impact of complying with properly designed environmental programs (the U.S. EPA's 33/50 Program and the Canadian ARET Program) on participants' technical efficiencies. Motivated by the idea of methodology crosschecking, this study applies both parametric and nonparametric methods to measure the efficiencies.

Findings and Conclusions: Empirical results indicate that the majority of participating firms have experienced significant increases in their efficiencies since participation, relative to matched firms. Furthermore, results suggest that reducing pollution has led to innovations among participating firms. The above evidence supports the Porter Hypothesis. In addition, both parametric and non-parametric models produced relatively similar results. It appears that both models are good tools to measure a firm's efficiency. This study also uses the procedures described in Grosskopf and Valdmanis (1987). A between-group efficiency index is estimated to determine whether the frontier of before-participation and after-participation firms differs. Empirical results from this particular methodology also support the Porter Hypothesis.

Dr. Don R. Hansen

ADVISER'S APPROVAL: ________________________________