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FOUR ESSAYS ON TECHNOLOGY, PRODUCTIVITY AND ENVIRONMENT

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Abstract

The main subject of this thesis is the relationship between economic growth and environmental effects when the interaction between firms' behaviour and regulations are taken into account. In the first three papers I discuss different aspects of the relationship between regulations and environmental effects. In the last paper I perform a factor demand analysis within a multiproduct framework.

In **Chapter 2**, I focus on the frequently discussed question about the relation between liberalisation of trade and its effects on the environment. I study the North American Free Trade Agreement (NAFTA) between Mexico, United States and Canada, signed 1994, and its effects on the emission of carbon dioxide from the manufacturing industry in Mexico. I apply a dynamic factor demand model, for the Mexican manufacturing industry, to examine the changes in economic development, factor demands and the development of carbon dioxide emission following trade liberalisation. My results indicate a technological shift in the manufacturing industry after 1994, when Mexico joined NAFTA. This led to a more factor intensive use of energy, and less emission of carbon dioxide, than with a regime without NAFTA.

In **Chapter 3**, the focus is on the concern that environmental regulations hamper competitiveness and economic growth. The empirical relationship between environmental regulations and productivity growth is studied. The overall effect of the regulatory stringency faced by plants on plants' productivity growth is statistically insignificant when productivity growth is measured without environmental detrimental factors. However, when these factors are included, the effect is positive and statistically significant. This indicates that not accounting for emission reductions when measuring productivity growth can result in too pessimistic conclusions regarding the effect of regulatory stringency on productivity growth.

In **Chapter 4**, the focus is on one particular environmental regulation. The *Integrated Pollution and Prevention Control* (IPPC) directive from the European Union implies that regulatory emission caps should be set in accordance with each industry's *Best Available Techniques* (BAT). *Data Envelopment Analysis* (DEA) is used to construct a frontier of all efficient plants. This provides us with an interpretation of BAT. We assume that all plants emit in accordance with the best practice technology, represented by the frontier, by reducing all inputs proportionally. The interpretation reveals a strong potential for emission reductions. Further, abatement cost estimates indicate that considerable emission reductions can be achieved with low or no social costs, but that the implementation of BAT for all plants involves substantial costs.

In **Chapter 5**, the aim is to test a multiproduct specification up against a single homogeneous output approach. Although most of the production activities involve multiple outputs, econometric models of production or cost functions normally involve only one single homogeneous output. The aim of this paper is to test the hypothesis that a multiproduct specification for Norwegian primary aluminium production is superior to a model with a single homogeneous product. To do this, I use a Multiproduct Symmetric Generalized McFadden (MSGM) cost function.

Keywords: BAT, DEA, Dynamic factor demand, Efficiency, Emission, Environmental regulation, Multiproduct symmetric generalized McFadden cost function, Malmquist index, Mexico, NAFTA, Norwegian manufacturing, Productivity, Trade liberalisation,

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Contents

Chapter 1

Introduction

The main subject of this thesis is the relationship between economic growth and environmental effects when the interaction between firms' behaviour and regulations are taken into account. In the first Chapters 2, 3 and 4, I discuss different aspects of the relationship between regulations and environmental effects. In Chapter 5 I perform a factor demand analysis within a multiproduct framework.

In Chapter 2, I focus on the frequently discussed question about the relation between liberalisation of trade and its effects on the environment. I study the North American Free Trade Agreement (NAFTA) between Mexico, United States and Canada, signed 1994, and its effects on the emission of carbon dioxide from the manufacturing industry in Mexico. The NAFTA agreement has been of vital importance for the development of the Mexican Economy. Mexico's manufacturing production and exports to the U.S. have risen significantly (see e.g. Kose et al 2004). However, increased economic activity and free trade are believed to have conflicting impacts on the environment.

The NAFTA together with the Uruguay Round of GATT negotiations was the main causes of the starting of an intense debate on the role trade liberalisation plays on environmental outcomes in particular developing countries (for an extensive survey see e.g. Jayadappeda and Chhatre 2000, Verbruggen 1999 or Copeland and Taylor 2004). Two lines of arguments dominate the debate: The *environmentalist* and the *pro-trade* line. The typical *environmentalist* argument is that rich countries export ecological costs to less developed countries, and that trade liberalisation leads to *ecological dumping*[1] *(*Rauscher 1994). According to the *pollution-haven hypothesis*, highly polluting

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[1] Rauscher (1994) defines ecological dumping as a policy which "price environmental harmful activities at less than marginal cost of environmental degredations, i e. a policy which does not internalise the environmental externalities"

industries tend to locate away from countries with high costs of emission control to countries where the local government is more concerned with economic growth and less is spent on pollution control (Faber 1992, Daly 1993). A variation on this problem is that local industries in poor countries compete with industries from developed countries with more sophisticated technology, and therefore limit investments in pollution control to keep their costs low. Governments in may use environmental policy to protect local firms in lack of trade policy instruments. The literature has been focused on three motives for protection: (1) when a country is large enough to affect world prices the *terms of trade motive* arises, (2) when firms are big enough to have market power, a *strategic motive* arises - government can intervene to try to give their firms strategic advantages over foreign firms, (3) a *political economy motive* for protection arise even in a small economy when government responds to interest groups pressure (Copeland and Taylor 2004). Countries turn to specialise in sectors in which they enjoy comparative advantages. If comparative advantages derive from differences in environmental regulation, then the composition effect of trade liberalisation may damage the environment (see e.g. Stagl 1999).

The conventional economic pro-trade position advocates that developing nations should incorporate themselves into the world trading system as a necessary step for economic growth (see e.g. Srinivasan 1982). Trade liberalisation stimulates economic growth and investment by increasing the efficiency of both production and consumption. Higher growth and higher per capita income will produce the resources necessary to invest in pollution control and enhance the ability of consumers to select less environmentally damaging products. Free trade also permits the import of pollution control technologies that have been developed elsewhere (Bhagwati 1993). Antweiler et al. (2001) divide trade impacts on pollution into scale, technique and composition effects. Their conclusion when combining these effects is that free trade appears to be good for the environment.

As described above, free trade has several impacts on environment. Two of them are economic growth and technical change. Economic growth increases factor demand and emissions, but also fosters technological change. The first order effect of technological change is decreasing in factor demand and reduction of emissions. However, the second order effect is higher economic growth, increased demand, increased production, factor demand and environmental stress. The question raised in this chapter is which effect on the environment is the strongest. I apply a dynamic factor demand model introduced by Walfridson (1987), for the Mexican manufacturing industry to examine the changes in economic development, factor demands and the development of carbon dioxide emission following trade liberalisation. My results indicate a technological shift in the manufacturing industry after 1994, when Mexico joined NAFTA. This led to a more factor intensive use of energy. I run two alternative scenarios. In the reference scenario, low production growth and low energy prices characterise the non-NAFTA situation. An alternative NAFTA scenario induces higher growth but also higher energy prices. In the NAFTA scenario, the emissions of carbon dioxide are lower than the reference scenario, opposed to the worst concerns of the environmentalists.

The subject in Chapter 3 and 4 in my thesis is the environmental effect of regulation and productivity change. The construction of regulations is vital to the efficiency of the policy instrument correcting environmental externalities and to the economic effects. Inefficient regulations may actually harm economic growth and be worse for the environment than alternative instruments. For the purpose of examining the efficiency of environmental instruments, policies can be characterized as either *command-and-control* or *market-based* approaches (Jaffe et al. 2002). Market-based instruments - such as pollution charges, subsidies, tradable permits or some types of information programs - can encourage firms to undertake pollution control efforts that are in their own interests and collectively meet policy goals (Starvin 2001). On the other side, commando-and-control regulations tend to force firms to take on similar shares of the pollution-control burden, regardless of costs. Uniform standards for firms are the most prevalent of performance- and technology-based standards. The appropriate technology in one firm may not be cost-efficient in another (Jaffe et al. 2002). Hence, holding all firms to the same target can be expensive and, in some circumstances, counterproductive, because the costs of controlling emissions may vary greatly among firms.

However, command and control policy also has its advocates. Porter and van der Linde (1995) argue that properly crafted environmental regulations can serve positive influences at least at six fields; they (1) give signals about resource inefficiencies and potential technical improvements, (2) focus on information gathering and can achieve benefits by raising companies awareness, (3) reduce uncertainties for environmental investments, (4) create pressure that motivates innovation and progress, (5) level the transitional playing field, and (6) are needed in the case of incomplete offsets. Porter and van der Linde (1995) argue that stringent regulation can produce greater innovation and innovation offsets than lax regulation.

It is a concern to policymakers that environmental regulations may hamper competitiveness and economic growth. Several economists have estimated the effect of environmental regulations on traditional measures of growth in total factor productivity, and their results suggest that the concern is not unwarranted (Christiansen and Haveman 1981, Jaffe et al. 1995). Recently, however, it has been suggested that the empirically detected inverse relationship between environmental regulations and productivity growth is an almost inevitable consequence of the current methods used to measure productivity – methods that fail to account for improvements in environmental performance (Repetto et al. 1997).

In recent times, methods that account for environmental performance when measuring productivity have been developed, and most empirical studies have revealed that failure to account for emissions results in understatement of productivity growth (Weber and Domazlincky 2001, Färe et al. 2001, Hailu and Veeman 2000). These studies are often motivated by the conjecture that inclusion of environmental factors in measures of productivity will influence the results of analysis of the relationship between environmental regulations and productivity growth.

In Chapter 3, the focus is on the concern that environmental regulations hamper competitiveness and economic growth. The empirical relationship between environmental regulations and productivity growth is studied. To credit a firm for emission reductions, we include emissions when calculating an *environmental*

Malmquist productivity index (EMI); and for the sake of comparison, we perform the analysis on the *traditional Malmquist* index (MI) where emissions are not accounted for. Regression analyses of productivity growth on regulatory stringency using plant level data are performed. The overall effect of the regulatory stringency faced by plants on plants' productivity growth is statistically insignificant when MI is applied to measure productivity growth. However, when EMI is applied, the effect is positive and statistically significant. This indicates that not accounting for emission reductions when measuring productivity growth can result in too pessimistic conclusions regarding the effect of regulatory stringency on productivity growth.

In Chapter 4, the focus is on one particular environmental regulation. The *Integrated Pollution and Prevention Control* (IPPC) directive from the European Union implies that regulatory emission caps should be set in accordance with each industry’s *Best Available Techniques* (BAT). The directive, which represents a harmonizing of environmental regulations towards a BAT principle, is currently implemented in all of the member states and the states associated with the European Economic Area. The effect of this implementation with respect to expected emission reductions and increases in costs are studied, using data from Norway. *Data Envelopment Analysis* (DEA) is used to construct a frontier of all efficient plants. This provides us with two alternative interpretations of BAT. First assumption is, that all plants emit in accordance with the best practice technology, represented by the frontier, by reducing all inputs proportionally. Second the assumption is, that all plants emit in accordance with the best practice technology by reducing emissions only. Both interpretations reveal a strong potential for emission reductions. Further, abatement cost estimates indicate that considerable emission reductions can be achieved with low or no social costs, but that the implementation of BAT for all plants involves substantial costs.

I end my thesis with a separate paper in Chapter 5, where the aims is to test a multiproduct specification up against a single homogeneous output approach. Although most production activities involve multiple outputs, econometric models of production or cost functions normally involve only one single homogeneous output. To test the multi-output hypothesis, I use a Multiproduct Symmetric Generalized McFadden

(MSGM) cost function, introduced by Kumbhakar (1994). This functional form is globally concave and flexible in the sense that it provides a second order differentiable approximation of any arbitrary cost function which is twice continuously differentiable and linear homogeneous in input prices. In an empirical application on a panel data from ten Norwegian primary aluminium plants, I find support for our hypothesis that a multi-output approach better fits the actual data proven. I present estimates on price elasticities, returns to scale and scope, and product specific demand elasticities. My results indicate economies of scope, i.e. it is more profitable to produce more than one output, and show sensitivity of factor demand when the product mix changes.

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Chapter 2

Trade liberalisation and carbon dioxide emissions: The importance of NAFTA for the Mexican manufacturing industry

Abstract

The North American Free Trade Agreement (NAFTA) between Mexico, United States and Canada that was signed in 1994 has been of vital importance for the development of the Mexican economy. Mexico's manufacturing production and exports to the U.S. have risen significantly. However, increased economic activity and free trade are believed to have conflicting impacts on the environment. Economic growth and technological change may both increase or decrease the stress on the environment. The question raised in this paper is which effect on the environment is stronger - the negative or the positive one. We apply a dynamic factor demand model for the Mexican manufacturing industry to examine the changes in the economic development and factor demands as well as the development of carbon dioxide emission following trade liberalisation. Our results indicate a technological shift in the industry after 1994 when Mexico joined NAFTA. This led to a more factor intensive use of energy. We run two alternative scenarios. In the reference scenario, low production growth and low energy prices characterise the non-NAFTA situation. An alternative NAFTA scenario induces higher growth but also higher energy prices. In the NAFTA scenario, the emission of carbon dioxide is less than the reference scenario, which should help reduce the worst concerns of the environmentalists.

***Keywords*:** Trade liberalisation, Environment, Growth, Dynamic factor demand, Energy, Carbon dioxide emission, Manufacturing industry, NAFTA, Mexico.

2.1 Introduction and Overview of the Study

2.1.1 Introduction

Mexico is an interesting example of an intermediate economy that has experienced a fairly rapid rate of growth and succeeded, at least partially, with its industrialisation. Early in its 19th century history it was considered rich and promising. After the unsuccessful wars against the US and during the first part of the 20th century Mexico went through an unusually painful revolution and was economically very weak. During the second half of the past century the country succeeded, partly with the help of vast oil revenues and partly through other policies, in rising well into the ranks of the middle-income countries and is now a member of the OECD (since 1994). One of the pillars of the Mexican ideology – like that of several other Latin-American countries – was import substitution and the so-called "dependency" school of thought had many supporters[1]. According to this theory, countries in the "Periphery" went through a process of "underdevelopment" as a mirror image and result of the development in the advanced capitalist economies. While this school of thought is definitely discredited as a theory today, there still remain some of the facts that the theory sought to explain. For instance, it was observed that Mexico's industrialisation accelerated considerably when imports became unavailable during the World War II.

Based on this observation and the theories of dependency a program for import protection, government subsidies and a favourable tax system was formulated in order to develop a strong and independent industry after the end of the war. This was fairly successful for a number of decades, but in the early 1970s Mexico experienced a balance of payment crisis, which was temporarily alleviated by international bank loans and particularly by the development of the large petroleum reserves, which were so conveniently discovered after the first oil price chock in 1973. Declines in agriculture and crude oil prices caused a default on external debt obligations. This forced the Mexican government to make structural reforms and open the Mexican economy for

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[1] See for instance Blomström and Hettne (1981)

international trade. At the end of 1985, the government announced accession to the GATT as well as a new liberalisation program. This opening process continued and the Mexican signatory of the North American Free Trade Agreement (NAFTA) in 1994 can be seen as a logical continuation of this process.

The North American Free Trade Agreement (NAFTA) was signed by Canada, the United States and Mexico in 1994. The intention of the agreement is to increase the exchange of goods and services among these three North American Countries. The agreement calls for the elimination or gradual phase-out of tariffs on goods and services exchanged among these countries. The phase-out of tariffs period was 15 years starting in January 1, 1994. The first phase included manufacturing and agricultural goods. The tariffs on these products were supposed to be phased out after ten years.

After the NAFTA entrance the Mexican economy experienced a positive development in several fields. The growth rate of the economy increased. Exports had a remarkable development, mostly explained by increased export to the U.S. Inflation decreased and relative factor prices equalised compared to the U.S.. Mexico has also experienced a growth of finance flow into Mexico[2]. Appendix A1 presents more details on the economic development and trade in Mexico.

NAFTA brought to public attention the impact of increased trade on the environmental stress in countries with different levels of economic development. The United States is one of the largest nations in the world with a substantial regulatory infrastructure dedicated to environmental protection. Mexico is a middle-income nation that experienced severe economic crises during the 1980s. Mexico's environmental conditions were deteriorating in terms of industrial pollution and population-related environmental degradation. The extent to which environmental problems might affect many facets of trade, or vice versa, has been the subject of considerable debate over these years, (for an extensive survey see e.g. Jayadappeda and Chhatre, 2000 ,Verbruggen, 1999 or Copeland and Taylor, 2004).

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[2] Similar result are also found by Kose et al. (2004)

Two lines of argument dominate the debate about the relationship between free trade, environmental quality, and environmental regulation in developing countries. Many of these arguments were also included in the debate before the NAFTA agreement. For a review of the debate see e.g. Johnson and Beaulieu (1996). The typical environmentalist argument is the concern for ecological dumping[3]. Rich countries export ecological costs to less developed countries. According to this pollution-haven hypothesis, highly polluting industries tend to locate away from countries with high costs of emission control to countries where the local government is more concerned with economic growth and spends little or no resources on pollution control (Faber, 1992, Daly, 1993). A variation on this theme is that local industries in poor countries will be forced to compete with industries from developed countries with more sophisticated technology, and therefore be forced to limit investments in pollution control to keep their costs down. Those who are sceptical to trade liberalisation assume that if trade and investment liberalisation causes an increase in economic activities, and if the structure of activities remains unchanged, the total amount of pollution must increase. Another argument is focused on the composition effects that result from changes in trade policy. When trade is liberalised, countries specialise to a great extent in sectors in which they enjoy comparative advantages. If comparative advantages derive from differences in environmental regulation, then the composition effect of trade liberalisation may damage the environment (see e.g. Stagl 1999).

The conventional economic pro-trade position advocates that developing nations should incorporate themselves into the world trading system as a necessary step for economic growth (see e.g. Srinivasan, 1982). Trade liberalisation will stimulate economic growth and investment by increasing the efficiency of both production and consumption. Higher growth and higher per capita income will produce the resources necessary to invest in pollution control and enhance the ability of consumers to select less

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[3] Rauscher (1994) define ecological dumping as a policy which "price environmental harmful activities at less than marginal cost of environmental degradations, i e. a policy which does not internalise the environmental externalities".

environmentally damaging products. Free trade also permits the import of pollution control technologies that have been developed elsewhere (Bhagwati, 1993).

In an empirical study Antweiler et al. (2001) find that openness in trade raises both output and income by 1 %, pollution concentration, regarding sulphur dioxide, will fall by 1 %. They use panel data for 108 cities in 43 countries spanning the years 1971-1996. In their analysis, they pay special attention to scale, technique and composition effects when they examine the sulphur dioxide concentrations in air.

A more sophisticated argument that shows why free trade may harm both the environment and the economic development in the poorer country is presented in Chichilinsky (1994). She argues that the lack of well-functioning property rights in the poorer country may be sufficient to turn free trade into a mechanism for impoverishment instead of the traditional beneficial gain we expect.

One obvious result of the debate on environmental consequences was the accompanying side agreement, the North American Agreement on Environmental Cooperation (NAAEC)[4]. The key objectives are to promote sustainable development, encourage pollution prevention policies and practices, and enhance compliance with environmental laws and regulations. Logsdon and Husted (1997, 2000) argue that this debate has made the Mexican government give priority to the environmental policy. During and after the NAFTA negotiation period, the environmental policy and practice were strengthened.

Grossman and Krueger (1995) find that trade liberalisation may lead to increased Mexican specialisation in sectors with a high intensity of low-skilled workers. These sectors may be assumed to cause less than average amounts of environmental damage. By using a computable general equilibrium model under different scenarios, Gale (1994) shows a slower increase of carbon dioxide emission with free trade than with a status quo scenario. Gale (1995) attains similar results using a static input-output analysis. This is the result of a shift in the structure of production and consumption away from the most carbon dioxide intensive sectors. Antweiler et al. (2001) find some

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[4] For details of the agreement, see www.naaec.gc.ca

evidence of pollution-haven pressures but also find evidence suggesting that the higher capital intensity of many pollution intensive sectors are best suited to capital abundant industrialised countries. As trade becomes increasingly liberalised, such sectors may therefore find themselves subjected to opposing forces of comparative advantage, with the net effect indeterminate.

In this paper, we focus on carbon dioxide emissions from the Mexican manufacturing industry. If the environmentalists' economic trade hypothesis were to hold, we would expect emissions to be higher under a free trade regime compared to a regime without the NAFTA agreement. Under the opposite hypothesis we expect the carbon dioxide emissions to decrease with trade liberalisation.

It should be noted that a focus on carbon dioxide emissions as an environmental indicator is not the best in this context. Their effects only apply at the global level, where Mexican emissions are quite small. The relationship between trade and environment would be better applied to such pollutants that affect local environments and human health. However, aggregated statistics are so difficult to get for other pollutants that we have chosen to focus on carbon dioxide.

The aim of our study is to test the environmentalists' hypothesis using time series data for the Mexican manufacturing industry, before and after Mexico joined the NAFTA agreement. We expect that trade liberalisation leads to increased exports and production growth and thereby an increase in emissions of carbon dioxide. On the other hand, energy prices will rise as subsidies are removed and competition increases. This will tend to reduce the consumption of energy. A third effect is the technological improvement following new investments. One hypothesis is that investments improve the overall technology. The other is that investments actually are an escape of inefficient technology from competing countries, and therefore do not contribute to technological improvement. In this paper we also test the hypothesis of trade liberalisation and technical change

We use a dynamic cost function approach for aggregate manufacturing, developed by Walfridson (1987, 1992). Our model incorporates both the long and short-run behaviour of the industry. The factor demands depend on output production, factor prices and technological development. From these demands for energy we can calculate the industrial emission of carbon dioxide.

In section 2.2, we present the Walfridson interrelated factor demand (WIDE) model. Earlier studies, such as Walfridson (1987, 1992) and Mlambo (1993), have found that the WIDE model is superior to other dynamic factor demand models, such as the cost of adjustment (COA) model (Berndt, Fuss and Wavermann 1977, 1980), mainly because WIDE separates short- and long-run substitution possibilities.

Section 2.3 presents the empirical data used in this study, comprising Mexican manufacturing data for the period 1960-1999 at an aggregate level. The factors considered are electricity, aggregate fuel, labour and capital. We also present the econometric specifications in this section. In section 2.4 we present the econometric results.

In section 2.5 we illustrate the relative importance of production growth and the increased competition due to the trade liberalisation, by making forecasts and comparing the outcomes in two alternative scenarios for the period 1990-2012. In the first, the reference scenario, we forecast the future factor demands as well as the emission of carbon dioxide for the manufacturing industries in Mexico, under a regime without the NAFTA agreement. In the second scenario, with the NAFTA regime, we simulate the outcome of higher growth and higher energy prices. These results do show that NAFTA is quite an impetus to growth. On the other hand, an upward adjustment of energy prices in Mexico will be quite a powerful force in reducing energy demand. Finally we summarise and discuss the results in section 2.6.

2.2 Estimating Energy Demand in a Dynamic Factor Demand Model

2.2.1 Introduction

In this section we present a dynamic factor demand model, the WIDE model, introduced by Walfridson (1987, 1989). First we provide a theoretical discussion of alternative approaches to dynamic factor demand modelling. Berndt, Morrison and Watkins (1981) identify three generations of dynamic factor demand models. The first generation consists of traditional partial adjustment, single equation models, using a Koyck partial adjustment or the Balestra-Nerlove captive and flexible demand formulation (Balestra and Nerlove, 1966). The role of economic theory is limited and interactions with other inputs are neglected. The second generation incorporates interrelated factor demands and the long run adjustment to equilibrium, but the adjustment path is not modelled as an optimisation problem (Nadiri and Rosen 1969, 1973). The third generation models developed by Berndt, Fuss and Wavermann (1977, 1980) are characterised by explicit dynamic optimisation. A significant property of the second and third generation of models is that a measure of capacity utilisation can be defined and constructed.

2.2.2 The Methodology of General Factor Demand Model Construction

The model applied in this study might, according to the classification above, be called a second-generation model because it focuses on the adjustment of demand towards long-run equilibrium. However, this model has some special attractive features that actually belong to the third generation models, as will be discussed below. The core of this type of models consists of a system of equilibrium demand equations, derived from a production or a cost function. The adjustment process of a factor towards the equilibrium is then expressed as a difference equation.

The most frequently used model of the second-generation dynamic models is the interrelated disequilibrium NRIDE model, introduced by Nadiri and Rosen (1969, 1973). The model is set up in two stages. First, a long run solution to the cost minimising problem of the firms is derived. The input vector v_t^* represents the optimal choice at every time t. Second, the process of adjustment towards the actual demand v_t is formulated. Formally, this is done through a generalisation of the Koyck single equation adjustment process:

$$v_t - v_{t-1} = \mathrm{B}(v_t^* - v_{t-1}), \tag{2.1}$$

where B is a $n \times n$ partial adjustment matrix. Depending on the actual specification of the demand functions, certain restrictions can be set on the elements of B.

According to Berndt, Fuss and Wavermann (1977), four criteria have to be fulfilled by a factor demand model. First, the modelling of lagged adjustment in an optimisation process requires that the speed of adjustment should be endogenous and not constant. Second, the specification of the model should account for the possibility of general disequilibrium, i.e. the extent of disequilibrium for one factor should be reflected on all the other factors. The third criterion is the Le Chatelier principle, which demands that the short-run price elasticity should not be larger in absolute value than the long-run price elasticity. Finally, the fourth criterion states that the output feasibility constraints should be met throughout the disequilibrium process, i.e. that the predicted factor demands are sufficient to produce the exogenous observed output. Berndt et al. tested different specifications of the NRIDE model and concluded that the model did not satisfy all the above criteria. The first criterion was violated since the optimisation of the adjustment process is implicit in the demand equations and therefore not endogenous. The three other criteria may or may not be fulfilled depending on the specification of the cost function and the adjustment process.

As an alternative to the NRIDE model, Berndt et al. (1977, 1980) developed a dynamic cost of adjustment (COA) model, based on Lucas' (1967) and Treadway's (1971) integration of the dynamic cost of adjustment into the neo-classical theory of the firm. These models are classified as the third generation of dynamic factor demand functions (Berndt, Morrison and Watkin, 1983). What characterises the third generation of models is that they are based on explicit optimisation of factors, which are fixed in the short run but variable in the long run. This type of models satisfies all the above stated criteria. For an overview, see Nadiri and Prucha (1999).

However, empirical applications of the COA model have not been able to produce convincing estimates of the dynamic properties of demand. For example they often find only small differences between the short- and long-run price elasticities. This means that the dynamic structure of these models fails to provide a full explanation for the adjustment of factor demands to factor price shocks. Therefore, there has been renewed interest in revisiting earlier models in order to find ways to remodel the observed differences between short- and long-run elasticities[5]. Walfridson (1992) argues that in the COA model, the quasi-fixed factor, even though it is assumed to be fixed in the short run, can be substituted for any variable factor. Therefore the model gives biased elasticity estimates. Watkins (1990) also criticises the COA model and revisits the first generation model to show that it could be interpreted as a special case of the third generation. A study by Mlambo (1993) shows that the WIDE model has better performance than the COA model.

Walfridson's solution to the problem, the WIDE model (Walfridson 1987, 1989, 1992), is based on Johansen's (1968) concept of capacity[6], employing an ex ante cost function to model long-run substitution possibilities in the establishment of capacity, and modelling capacity utilisation effects as factor specific short-run output elasticities.

2.2.3 The WIDE Model

In the WIDE approach, the vintage or putty-clay concept of Johansen (1972) is used. Capital is regarded as a capacity input, i.e. the stock of capital embodies the optimal output at the level of a plant. In the short run the stock of capital is fixed and its properties are given by more or less fixed coefficients. In the long run, however, capital is also a substitute for or a complement to other factors, implying that the optimal capital/output ratio is a function of relative factor prices. Long run substitution possibilities are given by an ex ante production function in which substitution possibilities are considerable. Within the short-run time frame, however, most of the capital is fixed and only new investments enjoy this ex ante flexibility. Once undertaken

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[5] See for example Northworth and Harper (1981), Kokkelnberg (1981), Walfridson (1987, 1989), Hogan (1989) and Watkins (1990).

[6] Johansen (1968: p. 52) provides a widely accepted and useful definition "*...the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted*." The Johansen definition is a short-run concept of capacity in that there are fixed and variable inputs.

the investment also becomes a part of the fixed capital and the total stock of capital is analysed as in a vintage model.

In order to take these issues into account, Walfridson (1987) integrates some elements from the COA and the NRIDE models. The Walfridson interrelated disequilibrium model (WIDE) is based on the idea by Fuss (1977) of a "putty semi-putty" production framework which allows for ex post substitution. Input optimisation is thus considered as a two level process, first as a long run investment, concerning output growth and input substitution, and then as a short-run problem, concerning the utilisation of the existing capacity. As in the COA-model, capital is assumed to be quasi-fixed but WIDE differs from COA in that WIDE assumes short-run non-substitutability between quasi-fixed and variable factors. Its similarity to NRIDE is that the long-run input substitution is represented by a long-run cost function and that adjustment costs exist for all inputs. The differences between WIDE and COA are the relationship between the short-run factor demand and capacity utilisation, and the gradual response to changing relative factor prices. The strength in WIDE is the specification of capacity as well as the relation between the demand for variable input factors, capacity and capacity utilisation. It gives WIDE other dynamic qualities than COA, where the demand for variable input factors is expressed as a function of the capital stock instead of capacity.

The basic structure, common to both models in this section, is that we use the external cost-of adjustment model, assuming a restricted cost function representation of technology with four input factors: capital (K), labour (L), electricity (E) and other fuel (F). Assume the following production function:

$$Y = f\,(v_i,\ Q,\ T) \quad i \in \{\mathrm{K, L, E, F}\}. \tag{2.2}$$

Y denotes actual output net of non-energy inputs, Q is the capacity output, and v_i the vector of inputs. Note that capital is regarded as a variable input in the long-run cost function. We assume that the effects of real capital investment on the demand for variable factors depend on whether it constitutes a capacity or substitution investment. The argument T represents technical change, measured by year.

Consistent with the theory of duality, a technology can be represented by either a production or a cost function:

$$C=g(w_i, Q, T), \quad i \in \{\mathrm{K, L, E, F}\}, \tag{2.3}$$

where w_i is the price vector of factor inputs. Assuming the cost function is differentiable in factor prices, we can apply Shephard's lemma and derive the factor demands as follows:

$$\partial C/\partial w_i = v_i(Y, w_i, T), \quad i \in \{\mathrm{K, L, E, F}\}. \tag{2.4}$$

If we divide the factor demands with their capacity output Q:

$$\mathrm{v_i/Q = a_i(Y, w_i, T)}, \quad \mathrm{i} \in \{\mathrm{K, L, E, F}\}, \tag{2.5}$$

we get a_i which refers to the input coefficient for factor i.

In the long-run equilibrium the shadow value of capital must equal the expected user-cost of capital. This is used to determine the long-run optimal capital input. The adjustment of the capital stock to its optimal level is assumed to be associated with adjustment costs, such that the marginal cost of adjustment is increasing.

Turning to the dynamics of the firm, Walfridson identifies two effects that cause input demand to diverge from its long-run equilibrium path, namely the variation in relative prices and the variation in capacity utilisation.

The long-run cost function is specified as a constant return to scale Generalized Leontief cost function with specific input technical change:

$$C = Q\left(\sum_i \sum_j \beta_{\mathrm{ij}}(w_i w_j)^{1/2} + \sum_i w_i T_{it}\right), \qquad \mathrm{i, j} \in \{\mathrm{K, L, E, F}\}, \tag{2.6}$$

which by Shephard's lemma gives the long-run equilibrium value for the factor demand:

$$v_i^* = \frac{\partial C}{\partial w_i} = Q\left(\sum_{\mathrm{j}} \beta_{\mathrm{ij}}(w_j / w_i)^{1/2} + T_{it}\right), \qquad \mathrm{i, j} \in \{\mathrm{K, L, E, F}\} \tag{2.7}$$

or

$$a_i^* = \frac{v_i^*}{Q} = \left(\sum_{\mathrm{j}} \beta_{\mathrm{ij}} (w_j / w_i)^{1/2} + T_{it} \right), \quad \mathrm{i, j} \in \{\mathrm{K, L, E, F}\} \qquad (2.8)$$

where a^*_i denotes the input coefficient in the frontier technology, i.e. the new technology investments.

The technical change term T_{it} is not simply associated with time, but with the changes in the long-run input coefficients. Following Walfridson (1992), it is specified as the sum of the constant annual percentage factor specific component T_{it}, where $i \neq k$, and the capital embodied component, proportional to new capital formation, T_{kt}. In the case where β_{iT}, $i \neq k$, is equal to zero only Hicks-neutral technical development occurs. We will test this hypothesis.

$$T_{it}=T_{it-1}+a^*_{i,t-1}(\beta_{iT}+\beta_{KT}) \quad i \in \{ L, E, F\} \qquad (2.9)$$

$$T_{kt}=T_{kt-1}+a^*_{k,t-1}\beta_{KT} \qquad (2.10)$$

The unit cost function:

$$UC^*= \Sigma_i w_i a^*_i \quad i \in \{K, L, E, F\} \qquad (2.11)$$

and the cost share for factor *i*:

$$S^*_i=w_i a^*_i/UC^* \quad i, j \in \{K, L, E, F\} \qquad (2.12)$$

represent the optimal choice of technology at time t in the long-run equilibrium.

Assuming long-run constant returns to scale, the capital requirement for a plant with production capacity Q can be obtained as:

$$K=Qa^*_k. \qquad (2.13)$$

The capacity available at a certain point in time is a result of a cumulative process of investments and obsolescence through which various vintages of capital are aggregated to the capital stock. All these investments are carried out under different circumstances with respect to output technology and expected output and input prices.

We identify two main effects that cause diversion between the actual input demand and the long-run equilibrium: First, the variations in relative prices and second, the variation in capacity utilisation.

From the theory of production, we know that firms adjust their demand for quasi-fixed factors as the relative prices change. The adjustment is not immediate, however, because of the dependence on the existing capital stock. We assume that capacity expansion takes the form of an adjustment process with adaptive expectation. For that reason, we assume that the short-run optimal demand for the quasi-fixed inputs follows a partial adjustment process with a uniform adjustment rate, μ_t, for all inputs:

$$\tilde{a}_{i(t)}=\mu_t a^*_{i(t-1)}+(1-\mu_t)\tilde{a}_{i(t-1)} \quad i, j \in \{K, L, E, F\} \tag{2.14}$$

The variable μ_t is defined as the substitution adjustment parameter, depending on the rate of adjustment λ_0, the capacity growth dQ, and the depreciation rate δ_t:

$$\mu_t=dQ_t+\lambda_0+\delta_t. \tag{2.15}$$

Initial values for the input coefficients at t_0 are obtained by a truncated expansion of (2.14):

$$\tilde{a}_{i(t_o)} = \sum_{s=0}^{n} \omega_s \sqrt{a^*_{it_0-1-s}} \quad i, j \in \{K, L, E, F\} \tag{2.16}$$

where

$$\omega_s = \frac{\mu(1-\mu)^s}{1-(1-\mu)^{s+1}}. \tag{2.17}$$

The second cause of disequilibria relates to the variation in capacity utilisation and the adjustment to new capacity. Capacity utilisation, *CU*, is defined as the ratio between current output and capacity:

$$CU_t = Y_t / Q_t. \qquad (2.18)$$

We can now derive the observed demand for input factors by taking the capacity utilisation into account. The assumption of a predetermined capacity level through (2.18) makes it possible to identify the effects of the capacity utilisation on short-run factor demand. The effects of the short-run substitution and short-run output elasticities are now derived by assuming specific elasticities for each input with respect to capacity utilisation so that the actual observed input coefficient are given by:

$$a_i = \tilde{a}_i \, CU^{(1-\beta_{iCU})} \quad i \in \{L, E, F\}. \qquad (2.19)$$

The input coefficient for the quasi-fixed capital is assumed to depend on the profit margin, here defined as the ratio of the output price and unit cost in period t, and the change in this ratio:

$$a_K = a_K * (p_t / UC_t)^{\beta_{k1}} \Delta(p_{t-1}/UC_{t-1})^{\beta_{k2}}. \qquad (2.20)$$

This completes the model specification of the Generalized Leontief model.

In the constant returns to scale specification that we have used, the long-run output elasticities are equal to unity, but the short-run output elasticities are given by the logarithmic differentiation of the demand for the input variable:

$$\varepsilon_{iQ}^{SR} = \frac{\partial \ln v_i}{\partial \ln Q} \quad i \in \{K, L, E, F\}. \qquad (2.21)$$

Rearranging equation (2.5) and substituting in equation (2.19), we get:

$$v_i = Q * (Y/Q)^{(1-\beta_{iCU})} * \tilde{a}_i = Q^{\beta_{iCU}} * Y^{(1-\beta_{iCU})} * \tilde{a}_i \quad i \in \{K, L, E, F\}. \qquad (2.22)$$

Taking the logarithm of (2.22) we get:

$$\ln(v_i) = \beta_{iCU} \ln(Q) + (1-\beta_{iCU}) \ln(Y) + \ln(\tilde{a}_i), \; i \in \{K, L, E, F\} \qquad (2.23)$$

and the short-run output elasticities then become:

$$\varepsilon_{iQ}^{SR} = \frac{\partial \ln v_i}{\partial \ln Q} = \beta_{iCU} \quad i \in \{K, L, E, F\}. \qquad 2.24)$$

The long-run price elasticities of the Generalized Leontief model are obtained by calculating $(dv_i/dw_j)(w_j/v_i)$ using equation (2.7):

$$\varepsilon_{ij}^{LR} = \frac{\frac{\beta_{ij}}{a_i^*}\sqrt{\frac{w_j}{w_i}}}{2} \quad i \neq j \in \{K, L, E, F\} \qquad (2.25)$$

Multiplying long-run elasticities with the substitution adjustment parameter μ_t derives the short-run price elasticities. This means that if μ_t is 1 then the short and long run elasticities are the same, but if μ_t tends towards zero the elasticities also tend towards zero.

$$\varepsilon_{ij}^{SR} = \varepsilon_{ij}^{SR}\mu_t \quad i \neq j \in \{K, L, E, F\} \qquad (2.26)$$

The long-run Allen elasticity of substitution (AES) is defined as the price elasticity divided by the estimated long run factor share, defined in (2.12):

$$\delta_{ij}^{LR} = \frac{\varepsilon_{ij}^{LR}}{s_i^*} \quad i, j \in \{K, L, E, F\} \qquad (2.27)$$

The short-run AES is defined as the short-run price elasticities divided by the actual factor share.

$$\delta_{ij}^{SR} = \frac{\varepsilon_{ij}^{SR}}{s_i} \quad i, j \in \{K, L, E, F\} \qquad (2.28)$$

2.2.4 Modelling NAFTA

We have chosen to model the entry in NAFTA by two different approaches. The hypothesis behind the first approach is that entrance leads to an increasing demand for Mexican manufacturing products and thereby a shift in efficiency. Capacity is expanded at the given technology. The effect of this increase in demand is an exogenous shift to a new level of the long run demand for the input factors, defined in (2.8). Our assumption is that the demand will be stable at this new level. The dummy variable N, denoting the time when the NAFTA agreement is in function, takes the value one from year 1994 and after. The parameter ϕ, common for all equations, is assumed to pick up the effect of the assumed trend shift in the demand level:

$$a^*_i=v^*_i/Q=\Sigma_j\beta_{ij}(w_j/w_i)^{½}+\beta_{it}T_i+\phi N,\ i, j \in \{K, L, E, F\} \tag{2.29}$$

The alternative hypothesis is that the technical change term, defined in (2.9) and (2.10), changes endogenously. The change in demand followed by the NAFTA entrance leads to increased investment in capacity based on imported technology. Output may not be produced by the same methods subsequent to foreign investments. The parameter η, common for all equations is assumed to pick up the effect of the assumed trend shift in the technical change term. This should describe a shift in the embodied technical parameter:

$$T_i=T_{it-1}+a^*_{i,t-1}(\beta_{iT}+\beta_{KT})+\eta N_{94},\ i \in \{L, E, F\} \tag{2.30}$$

$$T_k=T_{kt-1}+a^*_{k,t-1}(\beta_{KT})+\eta N_{94}\,. \tag{2.31}$$

The signs of these trend parameters reveal whether the new investments are made according to the environmentalists' pollution leakage hypothesis, where polluting firms invest in less developed countries, or whether investments are channelled into modern more efficient and clean technologies.

2.3 Data description and econometric specification

2.3.1 Definition of variables and data sources

In our study we have used data for the manufacturing industry for the period 1966 to 1999. In our model we assume one homogeneous output, three variable inputs (electricity, fossil fuel and labour), and one quasi-fixed input (capital). Output is measured as output net of non-energy inputs, which is the same as value-added and energy input. The latter is calculated as the quantities of electricity and aggregated fuel consumed, measured in MWh, multiplied by their corresponding base-year prices. Real value-added is compiled from the Sistemas de Cuentas de Nationales, INEGI.

The capital stock is measured as the net capital stock of buildings, constructions and machinery, at fixed prices. We have chosen to accumulate investments by using the perpetual inventory method for the calculation of the capital stock.

In the discrete time series data, the perpetual investment method is based upon the following relation:

$$K_t = I_t + (1-\delta)\,K_{t-1}, \qquad (2.32)$$

where K_t is the capital stock at the end of period t, I_t is the quantity of investment in the period t and δ is the rate of depreciation of capital. The time series for the investment in fixed prices, the benchmark for capital and the rate of depreciation were obtained from Banco de Mexico. The depreciation rate is set to six per cent per year. Investment data was obtained from Banco de Mexico. Capital costs are defined as gross operating surplus, i.e. output net of intermediate inputs and labour costs.

The labour input, measured as working hours, is obtained from the Sistemas de Cuentas de Nationales, INEGI. Electricity and aggregated fuel inputs are measured in MWh consumed. The data for the total manufacturing industry is obtained from the Energy Balances, INEGI. Prices of the different fuels are obtained from Petróleos Mexicanos (PEMEX). The price of electricity is obtained from Comision Federal de Electricidad (CFE). Summary statistics and correlations for the variables are presented in table 1 and table 2 respectively. A more comprehensive review of the development of the Mexican manufacturing is presented in Appendix A1.

Table 1 Summary statistics of production and factor use in the Mexican manufacturing industry, 1970-1999

Variable	Mean	Std dev	Min	Max
Production (1990 year’s prices)	693629	277812	271385	1303227
Electricity (GWh)	35120	13820	17400	66163
Other Fuel (GWh)	233625	56681	123527	335213
Labour (1000')	3062	337	2281	3471
Capital (1990 year’s prices)	587166	158047	266471	878442
Price of output $P_{1990}=1$	0.717	1.177	0.001	4.147
Price of electricity $P_{1990}=1$	0.626	1.003	0.002	3.549
Price of fuel $P_{1990}=1$	0.637	1.050	0.001	3.43
Wages $P_{1990}=1$	0.741	1.221	0.001	4.439
Price of capital $P_{1990}=1$	0.883	1.651	0.001	6.852

Table 2 Correlation table

	Y	E	F	L	K	P_Y	P_E	P_F	P_L	P_K
Y	1	0.984	0.931	0.956	0.791	0.866	0.875	0.856	0.870	0.824
E	0.984	1	0.896	0.909	0.724	0.911	0.914	0.906	0.908	0.866
F	0.931	0.896	1	0.956	0.872	0.652	0.658	0.647	0.650	0.592
L	0.957	0.909	0.956	1	0.898	0.717	0.722	0.709	0.718	0.679
K	0.791	0.724	0.872	0.898	1	0.498	0.485	0.490	0.494	0.512
P_Y	0.866	0.911	0.652	0.717	0.498	1	0.993	0.990	0.995	0.980
P_E	0.875	0.914	0.658	0.722	0.485	0.993	1	0.982	0.997	0.972
P_F	0.856	0.906	0.647	0.709	0.490	0.990	0.982	1	0.976	0.962
P_L	0.870	0.908	0.650	0.718	0.494	0.995	0.997	0.976	1	0.980
P_K	0.824	0.866	0.592	0.679	0.512	0.980	0.973	0.962	0.980	1

2.3.2 Econometric Specifications

The model specified in equations (2.8) – (2.10) is estimated using all the Mexican manufacturing industry data for both the periods 1966-1993 and 1966-1999. For the second period, we have modified the model so as to account for the effects of the NAFTA treaty. This was done in two separate ways, as described in equations (2.29 - 2.31), respectively.

In the model, estimation constraints are imposed on time lag in equation (2.16) of the WIDE models. The likelihood function is found to be insensitive to increasing the maximum lag length n of the equation (2.16) beyond 5. Constraining $n = 5$ yields almost the same first period impact as for an unconstrained Koyck process. The results presented are obtained for $n = 5$.

We use the SAS MODEL *Procedure* to define, analyse the structure, and estimate the unknown parameters of the non-linear demand system defined above. We have four endogenous variables: labour, electricity, fossil fuel, and capital, and nine exogenous variables: production, output price, factor demand prices, discount rate, and a time variable to describe the technical development. The system comprises 15 structural parameters to be estimated. The shared parameters are estimated with respect to the covariance matrices of the residuals across the equations. The final estimation model is a system consisting of a series of four endogenous variables defined as functions of exogenous variables and lagged endogenous variables that are simultaneously determined.

In the estimated models, data has been adjusted for serial correlation, according to the Cochran-Orcutt iterative estimation procedure[7]. The adjusted data is assumed to generate residuals that are contemporaneously correlated across the equations but uncorrelated over the observations. The distribution is assumed to be multivariate normal. The estimation method used is full information maximum likelihood.

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[7] See Kmenta (1986), pp 314-317.

In order to test the model specification, we have estimated two alternative versions of the models. First, we assume factor-specific technical change and as an alternative we assume Hicks-neutral technical change. As described in section two, the trend parameter characterising the technical development was divided into a capital embodied neutral technical change β_{tK} and a disembodied factor specific factor β_{ti} for all the variable input factors *i.* Formally, we are testing for Hicks neutrality if $\beta_{ti}=0$ for all *i.* We test the neutrality hypotheses with a likelihood ratio (LR) test, where L_0 is the log likelihood value for the unrestricted model and L_r is the restricted Hicks-neutral model:

$$\text{LR: } -2\,(\ln L_0 - L_r) \qquad (2.33)$$

The LR test statistic is distributed asymptotically as a chi-square variable, with degrees of freedom equal to the difference between the number of free parameters estimated in the restricted and the unrestricted model.

2.4 Empirical Results

2.4.1 Parameter estimates

The model specified in chapter 2.3 three is first applied to the entire manufacturing industry in Mexico and industry data for the period 1966-1993 is used. This model is later referred to as the "reference model". Then two new regressions are defined for the period 1966-1999, based on the assumption of a structural change in connection with the entrance in NAFTA. In the first regression, we add a new variable to the long run demand function described in (2.29). We call this model "NAFTA with demand shift". In the second regression, named "NAFTA technical spill-over", the variable is added to the technical change term, as described in (2.30) and (2.31). We have done this in order to study if and where the effects of the NAFTA agreement may arise. The regression most applicable to the existing data is chosen for the alternative scenario in our forecasts.

The regression statistics with adjusted R^2-values, the Log likelihood values, the Durbin-Watson statistics and the estimated coefficient of autocorrelation, ρ, for the manufacturing industry are reported in tables 3 and 4. The reference model is reported in table 3. There we also report test statistics for the test of Hicks-neutral technical change. The null-hypothesis of neutral technical change is rejected. The likelihood ratio value is 24.68. The critical χ^2 -value at 5 % and 3 degrees of freedom is 9.35. In table 4 two variations of the NAFTA model are reported. The model where the "NAFTA" variable is applied on the technical change factor, gives a better fit to the data.

Table 3 **Regression statistics for the reference model (1965-1993). Total manufacturing**

	H1: Factor specific technical change			H2: Hicks-neutral technical change		
	R^2(adj)	DW	ρ	R^2(adj)	DW	ρ
Electricity	98.59	1.76	-0.122 (0.207)	98.58	2.06	-0.260 (0.191)
Fuel	87.67	2.17	-0.285 (0.191)	87.67	2.16	-0.205 (0.192)
Labour	98.01	1.54	0.064 (0.257)	97.8	1.44	0.093 (0.237)
Capital	96.77	1.82	1.03 (0.008)	89.88	1.31	1.009 (0.005)
Log Likelihood	231.74			219.40		
Likelihood ratio test	24.68*					

Critical value at 5%=9.35.
Standard error in parenthesis

Table 4 **Regression statistics for the NAFTA models (1965-1999). Total manufacturing**

	NAFTA (1965-1999)			NAFTA (1965-1999)		
	Technical spill over			Demand shift		
	R^2(adj)	DW	ρ	R^2(adj)	DW	ρ
Electricity	99.03	1.93	-0.186 (0.184)	98.86	1.598	-0.189 (0.180)
Fuel	94.1	2.20	-0.242 (0.177)	91.25	1.804	-0.084 (0.226)
Labour	98.65	1.92	0.597 (0.336)	98.67	1.901	0.531 (0.292
Capital	93.58	1.30	1.025 (0.014)	93.59	1.317	1.030 (0.011)
Log Likelihood	271.54			264.09		

Standard error in parenthesis

The parameter estimates presented in table 5 show that the results do not change much when the time spans changes. None of the parameters differ significantly within a 95% confidence interval. Three parameters that are significantly different from zero in the reference model but not in the NAFTA models are the β_{K2}, β_{LL} and $\beta_{Ft.}$ The first parameter, β_{K2}, is interpreted as the second order adjustment parameter to the optimal capital stock. The second parameter, β_{LL}, is the intercept of the long run labour demand equation and has no easy economic interpretation. The third parameter, β_{Ft}, is the technical change parameter for fuel, which is significantly negative. This parameter is also negative in the NAFTA models but not significant.

The results for the parameters associated with the price variation (the coefficients β_{ij} where $i \neq j$) are mixed. All the parameters except those connected to fuel are significant. The most interesting result is that the parameter β_{LE}, that indicates substitution possibilities between labour and electricity, is significantly negative. This indicates that labour and electricity are complementary inputs.

The factor specific technical change is the sum of the Hicks-neutral technical change parameter of capital, β_{kt}, which is the same for all input variables and a factor specific technical change parameter, β_{it}. The technical change parameters indicate that non-neutral technical change is an important determinant of long-run factor demand. The annual technical change is the sum of the parameter of capital embodied technical change, β_{Kt}, and the factor specific parameters, β_{it}. In both models the capital parameter is significantly positive, which indicates that production becomes more capital-intensive over time. The factor specific technical change parameters are all negative, but the parameter for electricity is small and insignificant. The factor specific technical change parameter value exceeds the capital parameter only for labour, β_{lt}, which indicates a labour saving bias. The labour input coefficient falls by about one per cent annually.

The coefficient ϕ in the "Demand shift model", where the NAFTA variable is applied at the long run demand function, is not significantly different from zero. However, in the "Technical spill over" model, where the NAFTA variable is applied to the technical change factor, the coefficient η is significantly negative at the 5% level of significance. On the basis of the sign and the significance of this parameter, we find that our data do not support the pollution-haven hypothesis that technology will become more polluting. Instead the data support the other hypothesis that the effect of technical progress will dominate. The combination of a better fit to the existing data and the significance of the two coefficients, ϕ and η, indicates that the NAFTA "Technical spill over" model is the best model for estimation. For simplicity, we term it the NAFTA model.

Table 5 Parameter estimates. Total manufacturing.

Parameters	Reference model. 1966-1993	NAFTA Demand shift model. 1966-1999	NAFTA Technical spill over model. 1966-1999
β_{KK}	**2.456** (1.825)	**1.342** (1.785)	**1.851** (3.323)
β_{KL}	**0.329** (0.106)*	**0.812** (0.271)*	**0.934** (0.435)*
β_{KE}	**0.141** (0.062)*	**0.266** (0.084)*	**0.286** (0.133)
β_{KF}	**0.015** (0.015)	**-0.013** (0.028)	**-0.023** (0.020)
β_{LL}	**0.370** (0.075)*	**-0.008** (0.135)	**-0.051** (0.136)
β_{LE}	**-0.083** (0.031)	**-0.120** (0.038)*	**-0.133** (0.062)*
β_{LF}	**0.009** (0.006)	**0.027** (0.011)*	**0.028** (0.012)*
β_{EE}	**-0.010** (0.036)	**-0.100** (0.040)*	**-0.108** (0.056)*
β_{EF}	**0.012** (0.011)	**0.030** (0.018)	**0.039** (0.022)
β_{FF}	**0.013** (0.013)	**-0.007** (0.016)	**-0.002** (0.014)
β_{Kt}	**0.064** (0.015)*	**0.050** (0.015)*	**0.043** (0.012)*
β_{Lt}	**-0.074** (0.013)*	**-0.056** (0.016)*	**-0.051** (0.013)*
β_{Et}	**-0.011** (0.013)	**-0.019** (0.014)	**-0.012** (0.009)
β_{Ft}	**-0.074** (0.011)*	**-0.025** (0.020)	**-0.016** (0.009)
β_{K1}	**-0.774** (0.099)*	**-0.316** (0.097)*	**-0.276** (0.090)*
β_{K2}	**-0.165** (0.079)*	**-0.171** (0.098)	**-0.138** (0.092)
β_{LCU}	**0.774** (0.043)*	**0.680** (0.093)*	**0.676** (0.100)*
β_{ECU}	**0.568** (0.068)*	**0.646** (0.057)*	**0.625** (0.053)*
β_{FCU}	**0.613** (0.070)*	**0.692** (0.103)*	**0.643** (0.042)*
β_0	**0.154** (0.060)*	**0.052** (0.021)*	**0.048** (0.019)*
Φ		**-0.022** (0.017)	
η			**-0.010** (0.004)*

Standard error in parenthesis. *=Significant at 95 % level.

2.4.4 Elasticity of price and substitution

The long- and short-run price elasticities for the NAFTA model are presented for three chosen years in table 6. Price elasticities are calculated as defined in (2.25-2.26).All the own price elasticities have the expected sign. All are below one in magnitude, except for electricity at the beginning of the period. All are diminishing until 1990, but for the last year all elasticities, except capital, have risen. All cross-price elasticities, except the first long-run cross-price elasticity between electricity and capital, are below one in magnitude. Two cross-price elasticities are negative. These are the elasticities between electricity and labour, and fuel and capital, which indicate that these factors are complementary. All other cross-price elasticities are positive. The short run elasticities are defined as the long run elasticities multiplied by the substitution adjustment parameter μ_t, defined in (2.15). Our results indicate that there are small substitution possibilities in the short run, due to a low value of μ_t. The cross-price elasticities for capital are all close to zero, except for electricity, indicating that there are small substitution possibilities.

The Allen elasticity of substitution (AES) defined in (2.27-28) is a traditional measurement of the substitution possibilities between two inputs, when all other inputs and output are held constant. Table 7 presents the substitution elasticities for selected years. Contrary to the price elasticities, some substitution elasticities are high. This is partly due to low factor shares for electricity.

Table 6 Price elasticities for the NAFTA model for selected years. Total manufacturing

WIDE	Year	Electricity		Fuel		Labour		Capital	
		LR	SR	LR	SR	LR	SR	LR	SR
Electricity	1970	-1.401	-0.151	0.289	0.031	-1.311	-0.141	2.423	0.261
	1980	-1.016	-0.111	0.183	0.020	-1.036	-0.113	1.868	0.204
	1990	-0.619	-0.031	0.124	0.006	-0.429	-0.021	0.923	0.046
	1999	-0.712	-0.111	0.154	0.024	-0.542	-0.084	1.100	0.171
Fuel	1970	0.354	0.038	-0.443	-0.048	0.285	0.031	-0.196	-0.021
	1980	0.276	0.030	-0.360	-0.039	0.257	0.028	-0.171	-0.015
	1990	0.923	0.046	-0.239	-0.012	0.154	0.008	-0.126	-0.006
	1999	1.099	0.065	-0.506	-0.079	0.350	0.055	-0.265	-0.041
Labour	1970	-0.099	-0.011	0.018	0.002	-0.568	-0.061	0.649	0.070
	1980	-0.093	-0.008	0.015	0.002	-0.610	-0.054	0.688	0.075
	1990	-0.103	-0.003	0.022	0.001	-0.641	-0.020	0.722	0.036
	1999	-0.119	-0.018	0.028	0.004	-0.797	-0.124	0.887	0.138
Capital	1970	0.037	0.004	-0.002	-0.0003	0.131	0.014	-0.166	-0.018
	1980	0.022	0.002	-0.001	-0.0001	0.092	0.010	-0.117	-0.012
	1990	0.016	0.001	-0.001	-0.0001	0.052	0.003	-0.066	-0.002
	1999	0.010	0.002	-0.001	-0.0001	0.038	0.006	-0.047	-0.007

Table 7 The Allen elasticity of substitution for the NAFTA model for selected years. Total manufacturing

WIDE	Year	Fuel		Labour		Capital	
		Long run	Short run	Long run	Short run	Long run	Short run
Electricity	1973	28.604	3.084	-7.973	-0.860	2.980	0.321
	1983	26.538	2.892	-8.969	-0.977	2.154	0.235
	1993	13.317	0.656	-6.653	-0.323	2.353	0.050
	1999	47.653	7.416	-13.438	-2.091	1.160	0.181
Fuel	1973			1.733	0.187	-0.241	-0.026
	1983			2.210	0.241	-0.197	-0.022
	1993			2.353	0.116	-0.135	-0.039
	1999			8.963	0.181	-0.279	-0.043
Labour	1973					0.799	0.086
	1983					0.793	0.086
	1993					0.793	0.039
	1999					0.936	0.146

2.4.5 Technical change

Our test in Table 3 shows that the technical development is not Hicks-neutral. Setting all factor specific technical change to zero is rejected. The technical change for capital is estimated to be positive, i.e. more capital intensive technique is used in the production. All the factor specific technical change parameters are negative but they are not all significantly different from zero. The technical change is significant and negative for labour demand in all the three models. The estimated technique parameter for fuel is significant for the reference model but not for the NAFTA models. The parameter for electricity is not significant in any model. The NAFTA parameter, η, is negative and significant. The aim of this parameter is to examine if there has been a shift in the embodied technical change parameter. Its interpretation is that capacity with new technology is installed in the manufacturing industry. The sign shows that the new technology is factor saving and supports our alternative hypothesis of free trade bringing in environmentally acceptable technology.

2.5 Forecasting with the different models

In this section, we will see how the different models act under two alternative scenarios for the manufacturing industries up to year 2012.

In the "reference scenario", we use the coefficients estimated in the first model for the period 1965-1993, and make a forecast for the period after the NAFTA entry, from 1994 to 2012. This implies a steady economic growth trend of two per cent annually, which is roughly the growth rate before the NAFTA agreement. We also assume that the energy prices grow by one per cent annually relative to all the other prices. This is in line with the assumption of a global rise in energy prices due to the Kyoto process.

In the "NAFTA scenario", we use the second model for the period 1965 to 1999, including the NAFTA variable for the period after 1994. Several empirical studies (see e.g. Brown et. al., 1993, and Klein and Salvatore, 1995), assume an economic growth of around two per cent annually for the Mexican economy after the NAFTA entry. We also assume that energy factor prices will gradually reach the U.S. and Canada level. At the same time, we assume that the energy prices in U.S. and Canada will grow relative to the labour costs. Even though U.S. has withdrawn from the Kyoto-protocol and Canada has not yet officially ratified the protocol, the Bush-administration has proposed an alternative climate plan, whereby the U.S. will reduce the emission intensity of GDP.

According to the plan, the greenhouse gas emission intensity will be reduced by 17.5 per cent (1.9 per cent annually) during the period 2002-2012 (The White House, 2002). In this case, we assume that the electricity and fuel prices will grow by two per cent annually.

We also include a third scenario, with the same conditions as in the "NAFTA scenario", but where we exclude the NAFTA variable from the model. Then we can decompose the effect of the technological shift into the price and growth effects in the forecast. We call this "NAFTA scenario II".

Our results indicate that the demand for both electricity and fuel will be higher in the reference scenario, even though we assume a higher economic growth of production in the NAFTA scenario. In the reference scenario we predict linear growth in electricity, whereas in the NAFTA scenario the growth rate diminishes. This is due to a combination of the price effect and a more efficient use of electricity, characterised by a shift in the technical change element T_E. This effect is not so obvious for the fuel because of a lower price elasticity on fuel. For the demand for labour the situation is the opposite. The reference scenario could not predict the shift in demand during the late 90s. Both the reference and the NAFTA scenarios predict similar small diminishing trends for the labour demand, but at a higher level for the NAFTA scenario. The mechanisms behind the process get clearer when we study the forecast without the NAFTA variable. We can see that the isolated price and growth effects lead to an increase in the demand for electricity and fuel, compared to the reference scenario. The effect is most obvious for electricity. This development can be partly explained by the differences in the factor prices. Another explanation is the structural change of the manufacturing sector, from energy intensive industries toward more labour intensive industries.

In table 8, we have summarised the components of industrial fuel consumption and of electricity generation in 1998. The carbon dioxide emission coefficients for each fuel are also given. The emissions are calculated as direct effects from the energy consumed. The shares of the various fuels are assumed to be constant during the scenario period.

Table 8 The composition of electricity generation, industrial fuel consumption and carbon dioxide emission coefficients in 1998.

Fuel	Generation of electricity (in per cent)	Industrial fossil fuel consumption (in per cent)	Carbon dioxide emission coefficients (kg CO_2/MWh)
Hydro power	14.2	-	0
Geothermal power	2.9	-	0
Nuclear	4.5	-	0
Oil	62.0	38.5	277
Natural gas	6.9	50.3	202
Coal	9.5	0.1	331
Coke	0	11.1	371

Source: Balanca de energia, Secretaria de Energia, Mexico, 1999.

We have calculated the emission of carbon dioxide for the three scenarios. According to our calculations, the actual emissions were 92.8 million tonnes in 1999. In the ex post forecast of the reference scenario, we estimate the emission to be 5.4 million tonnes, or 5.5 per cent higher than the forecast of the NAFTA scenario for the same year.

In the future, our calculations forecast increased emissions of carbon dioxide of about 27 % for the reference scenario and 24 % for the NAFTA scenario, between year 2000 and 2012. This gives ten per cent less emissions under the NAFTA scenario in 2012. With our decomposition we can clearly see that the shift in technology explains more than the differences first observed between the two main scenarios. The scenario with only the growth and price assumptions leads to more emissions than the reference scenario. This result supports the hypothesis that free trade tends to improve environmental quality.

Figure 1 Alternative scenario, Electricity

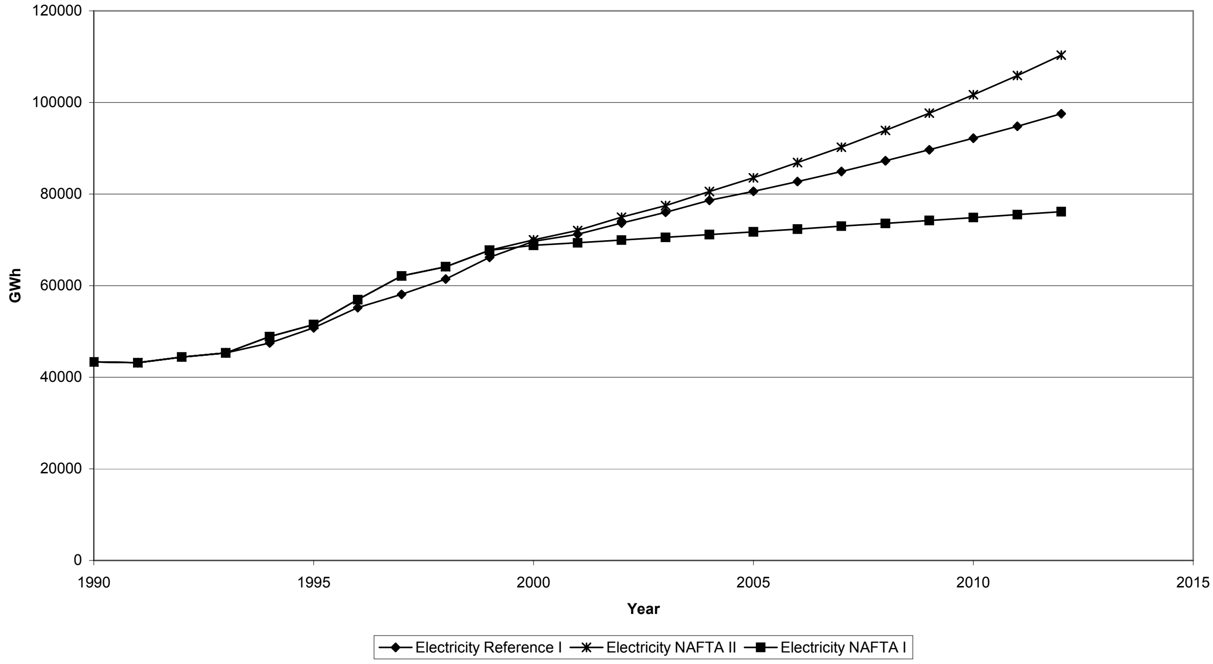


Figure 2 Alternative scenario, Fuel

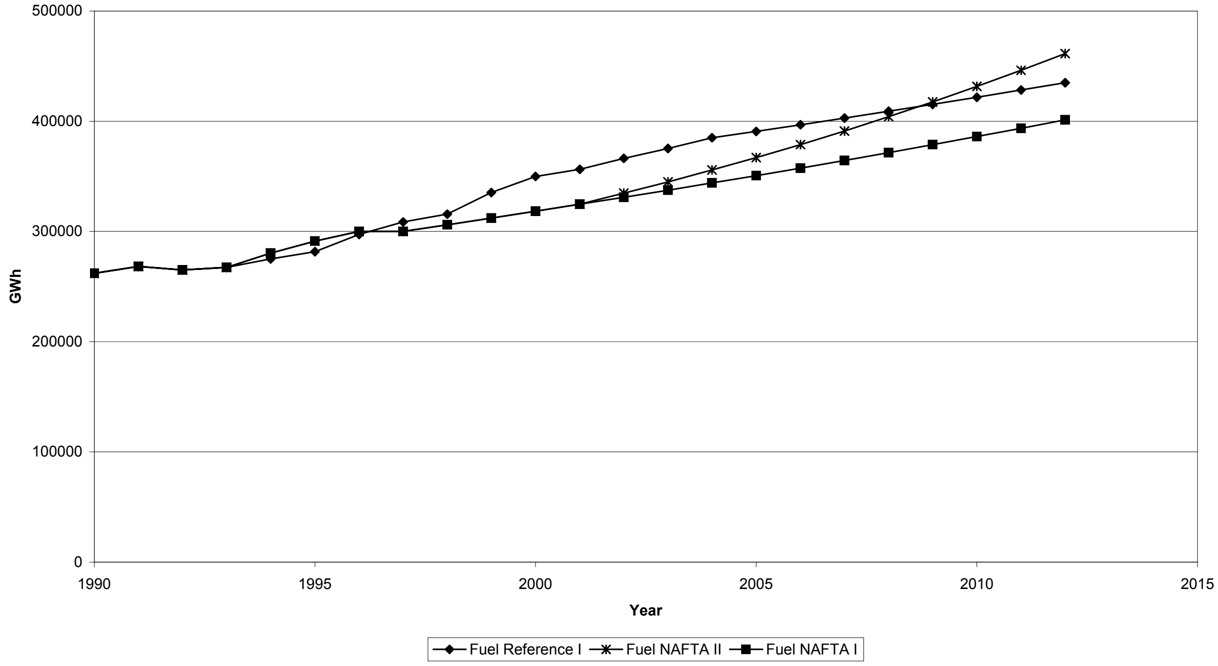


Figure 3 Alternative scenario, Labour

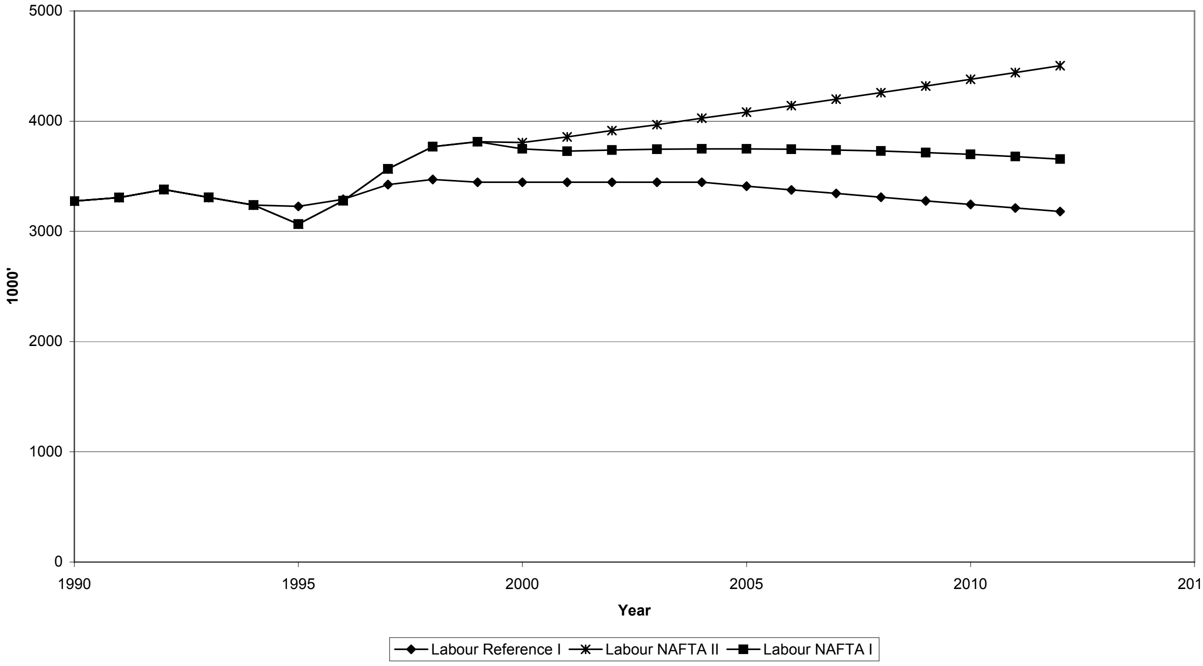
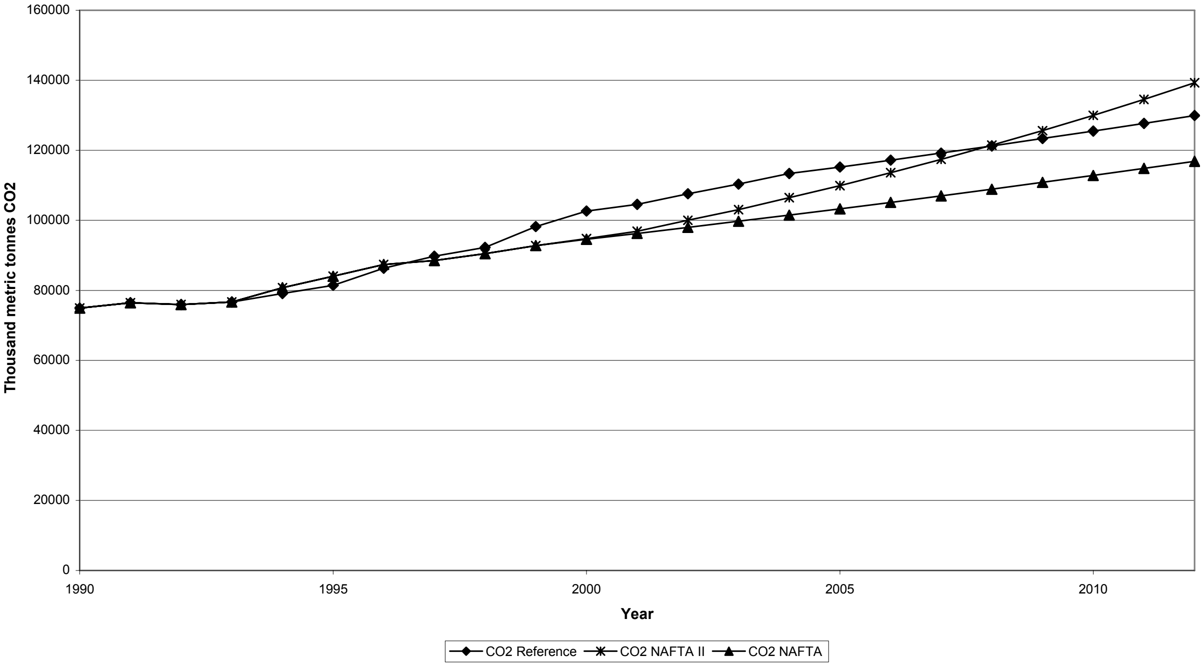


Figure 4 Carbon dioxide emissions



2.6 Summary and Conclusions

In this paper we have studied the relationship between trade, economic growth, technological change and environmental strain in connection to the NAFTA agreement between Mexico, United States and Canada. Special focus is set on the emission of carbon dioxide from the Mexican manufacturing industry. There is an ongoing debate about the effect of trade liberalisation on the environment between environmentalist groups and conventional trade liberalisation advocates. The trade between developed and developing countries is particularly in focus. Environmentalists argue that trade liberalisation may lead to movements of heavy-polluting industries from rich to less developed countries, as a result of new specialisation patterns. In low-income countries, local governments are allegedly more concerned with economic growth and spend little or no resources on pollution control. If this pollution leakage hypothesis is true, we should expect emissions to increase as a result of Mexico's entry in NAFTA.

By applying a dynamic factor demand model to the Mexican manufacturing industry, we have isolated a trend shift in the technical change term in the cost function after the NAFTA entry in 1994. As a result, we find a significant improvement in factor efficiency. In two different scenarios, we have combined different price and growth effects characterising the situation with and without the NAFTA regime. We conclude that the liberalisation of trade did not increase carbon dioxide emissions from manufacturing. On the contrary, we estimate a lower increase of carbon dioxide emission in the NAFTA scenario compared to the reference scenario. Thus we do not find any support for the pollution leakage hypothesis in this case. However, we should bear in mind that this study solely focuses on the carbon dioxide emissions from the manufacturing industry. It does not reveal the effects of other emissions from this industry or the effects of emissions from other sectors in the economy. Many of the processes that underlie the notions of pollution leakage would perhaps apply better to local pollutants than to carbon dioxide, which is a global pollutant. General conclusions concerning total national emissions of other pollutants require further studies with much more detailed data which are very hard to get for the whole economy. Mine results however, are in line with other empirical researches, e.g. Antweilen et al. (2001)

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Appendix A1

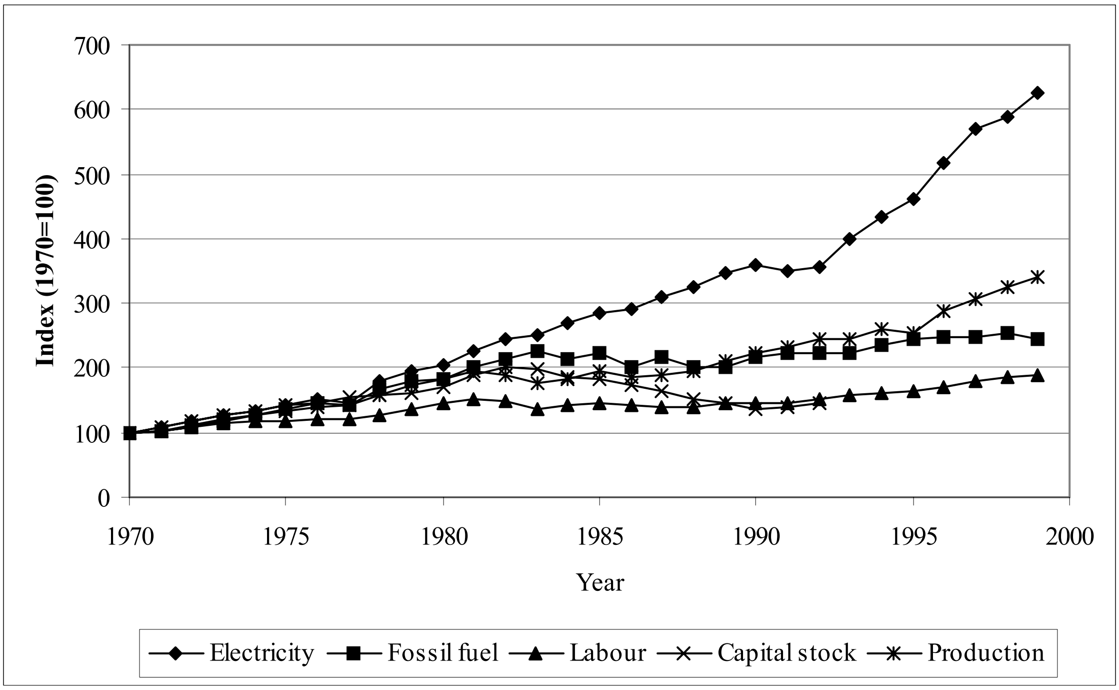
The Mexican manufacturing industry before and after NAFTA

Mexico is one of the most industrialised countries in the Third World and a major oil producer. The domestic energy demand has been quite heavily subsidised. Fuel and electricity prices are only a fraction of the corresponding prices in the U.S. or other Latin American countries, with the exception of other oil producing countries like Venezuela. Energy has been considered a "crucial" factor for the economic development and has motivated the subsidizing of the energy price. Another important reason is that many energy industries exhibit considerable economies of scale in production and distribution and are thus "natural monopolies". This has led Mexico, like many countries in the Third World, to nationalise its energy industry. One of the main goals for having control over the energy industry has been to provide the other fields of the economy with cheap energy and thereby stimulate the economic growth.

The Mexican economy has gone through a number of very different phases during this period. These include the rapid growth during the 1960s, and the high inflation, the huge external debt as well as the stagnation in the economy during the 80s. Since the 90s the government has gradually reduced the tariffs and removed the trade restrictions. On the 1st January 1994, the North American Free Trade Agreement (NAFTA) between Mexico, U.S. and Canada came into effect, with the goal of increasing the trade among these states. This has implied a considerable stimulus to the Mexican economy.

The Mexican manufacturing industry grew rapidly in the period 1960-1980. Mexico, as an oil-exporting country, counted much on its oil resources and used a great share of the income for investments in the manufacturing industry after the oil boom in 1979-1981. This led to growing investments in the domestic industry, but also to over consumption, and Mexico developed most of the symptoms of the "Dutch disease". The economy was overheated and the inflation rose over 100 %. As a consequence the capital investments fell dramatically in the beginning of the 1980s. It became even so low, that the investments did not manage to compensate for depreciation, and the capital stock diminished. Electricity was the only input factor that did not contract in this period and had an annual growth rate of about 8 % until 1990. This development can be seen in figure A1. A drop in production, in connection with the financial crisis in 1995, can also been seen.

Figure A1. The growth of production, labour force, capital investments and energy use in the Mexican manufacturing industry. (Index 1965=100)

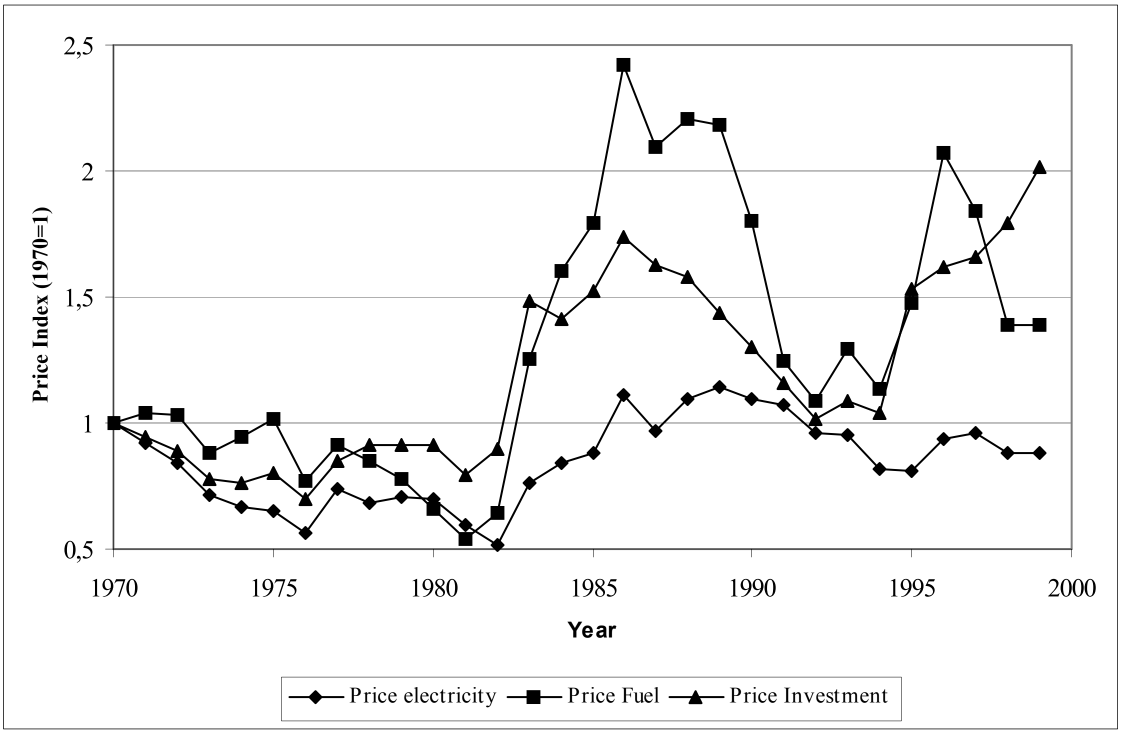


Sources: INEGI: Cuenta National and Banco de Mexico.

The Mexican industry has been provided with cheap energy. During the period 1966-1981, labour costs increased by 900 % in nominal terms, whereas fuel and electricity prices only increased by 300 %. In 1980 the Mexican domestic energy prices ranged from 10 % to 70 % of comparable US prices (see Sterner, 1985, p 13). Even the price of capital fell relative to labour costs during this period.

In figure A2 we can see the development of the factor prices relative to labour costs. In the years 1982-1986, there was a period with very high inflation. The fuel prices increased at an annual rate of 62 %, the price of electricity and investment goods increased by about 50 %, but wages only increased by about 35 %. As a result, there was a tremendous shift in the relative prices. During the period 1986-1995, fuel and investment goods became cheaper relative to labour. After 1995 the prices of fuel and investment goods have risen, but electricity prices have been relatively stable. Looking at the whole period, the relative prices of fuel and capital ended up at higher levels than in 1970, while electricity became cheaper relative to labour.

Figure A2 Price of electricity, fuel and investment goods relative to labour wages index in manufacturing. (Index 1970=1)

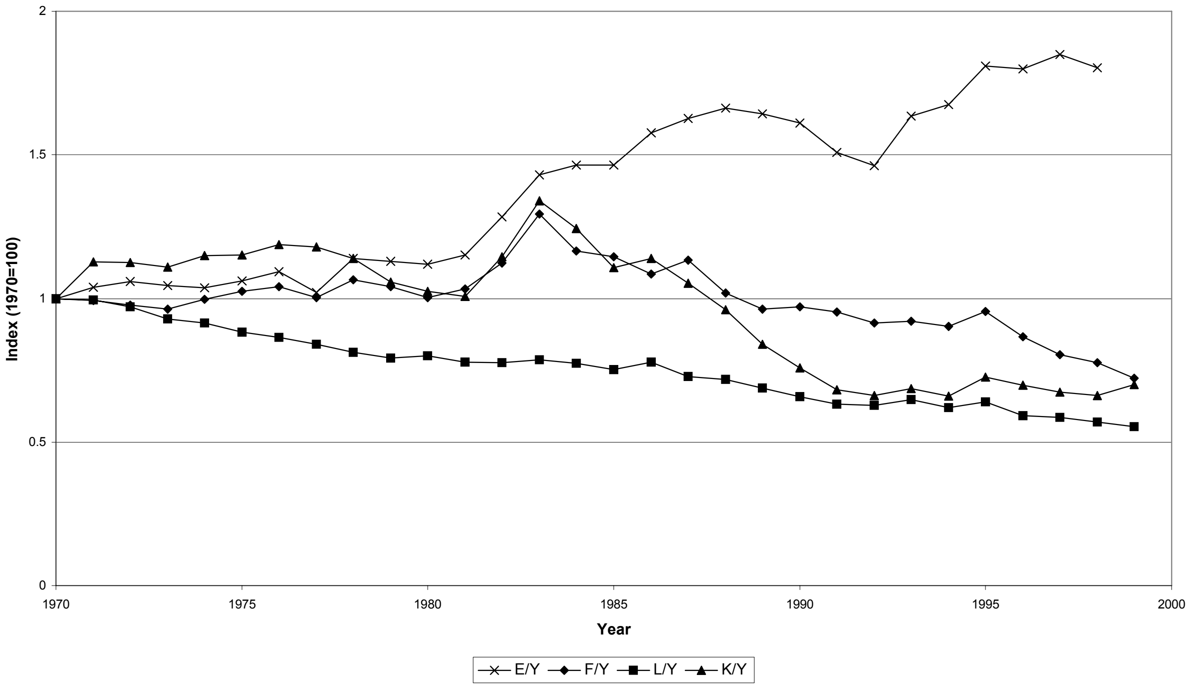


Sources: INEGI: Cuenta National and Banco de Mexico.

If we now look at the factor use in the Mexican manufacturing, we can ask how these shifts in the relative prices affect the use of inputs. In figure A3 we see the development of the input/output ratio for the different factors. Obviously the industry as a whole has used more electricity. Electricity is the only input factor for which the relative factor prices have in the long run become significantly cheaper. The industry has used the other input factors more efficiently, especially labour. We cannot see any dramatic changes due to the shifts in the relative prices in the short run. However, further investigation would be needed to explain the actual effects of the relative prices on demand, both in the short and the long run.

In table A1 we have divided the statistics into three separate time periods. The first time span is between 1965 and 1981. This period is characterised by fast growth and moderate inflation, but the growth rate of wages was twice as high as for energy prices. Sterner (1989) has shown that the development of relative prices between labour and fuel were very different compared to the U.S. In the U.S. fuel prices increased 3.5 times more than wages, but in Mexico the fuel price increase was only 40 per cent of the increase in wages. Particularly during periods with high international oil prices, Mexico maintained its domestic fuel prices at a low level. In 1970 the fuel price was around 70 per cent of the corresponding U.S. price. By 1981 it had fallen to 15 per cent of the U.S. price. The next period between 1982 and 1993 was characterised by an unstable economy with low production growth and hyperinflation. The inflation rate was about 50 per cent annually. In this period the energy prices grew faster than the wages. The situation was the opposite in the U.S., where wages increased around 30 per cent more than energy prices. During the last period after 1994 the economic development has once again stabilised. The growth rate in the manufacturing industry was about 3.9 per cent annually, and factor prices have had quite a similar development, although somewhat higher for energy. In the U.S. however, the wages have continued to grow relative to the energy prices.

Figure A3 Electricity/output ratio (E/Y), fuel/output ratio (F/Y), labour/output (L/Y), and capital/output (K/Y) in manufacturing. (Index 1970=1)



Sources: INEGI: Cuenta National and Banco de Mexico.

Table A1 Rates of change for output and prices in the manufacturing industry

	Annual growth	Inflation	Electricity prices	Fuel prices	Wages
1965-1981	5.9	16.1	9.4	7.8	15.4
1982-1993	1.8	51.8	45.0	45.7	39.4
1994-1999	3.9	19.4	19.1	21.7	17.7

Sources: INEGI: Cuenta National and Banco de Mexico.

We now turn to the question of how the structure of the manufacturing industry has changed during the last decade. Table A2 shows the structure of the manufacturing industry in 1990 and 1999. The main change is that one single sector, namely Metal products, has grown dramatically during the period, from 26.9 to 40.2 per cent. We can aggregate the industry into two sectors, one energy intensive sector, including Paper and publishing, Chemical products, Non-metal minerals and Primary metals, and one non-energy intensive sector, including the rest of the sectors. We can then see that the energy intensive industries have fallen from 33 to 25 per cent over the period.

Table A2 The structure of the Manufacturing industry in 1990 and 1999 in per cent of production

Sector	1990	1999
Food beverage and tobacco	25.7	22.2
Textile	8.7	7.7
Wood and wood products	3.2	2.2
Paper and publishing	5.1	3.7
Chemical products	16.6	12.5
Non-metal minerals	4.6	4.0
Primary metals	6.7	4.5
Metal products, machinery and equipments	26.9	40.2
Other manufacturing industries	2.4	2.9

Sources: INEGI: Cuenta de Bienes y Servicios.

In table A3 we report the relative prices of electricity and fuel with respect to wages in Mexico and the U.S. There are obvious differences in the factor price development between the two countries. Mexico, as an oil-producing country, has maintained low domestic prices on energy during periods with high international oil prices. This policy could not go on during periods when the oil prices decreased. This has lead to a counter-cyclic development of domestic fuel prices. With low oil prices, the Mexican government could not continue to subsidise domestic consumption because of budget restrictions. The price of fuel relative to wages in Mexico decreased to 0.34 in the period 1965 to 1981, but increased to 0.89 after 1981. However, subsidises on electricity still remain, albeit to a smaller extent.

Table A3 Relative prices of electricity, fuel and labour in the U.S. and Mexico

Year	U.S. prices					Mexico prices				
	Labour	Electricity	Fuel	Relative prices E/L	Relative prices F/L	Labour	Electricity	Fuel	Relative prices E/L	Relative prices F/L
1965	1	1	1	1	1	1	1	1	1	1
1981	3.06	4.30	11.11	1.40	3.63	10.05	4.47	3.46	0.44	0.34
1993	450	485	498	1.08	1.11	1253	895	1039	0.71	0.83
1999	533	443	544	0.83	1.02	3388	2219	3024	0.66	0.89

Sources: For the U.S., wages Bureau of labour statistics, U.S. Department of labour, Energy price data from Energy Information Administration, Official Energy statistics from the U.S. Government. For Mexico, the same sources as used in the rest of the paper.

Table A4 shows how Mexican exports to different countries and regions have changed after NAFTA. The direction of exports is quite different before and after NAFTA. The export shares to all other regions than the U.S. have declined. But the export shares to the U.S. have increased from 68.8 per cent of the total exports in 1990 to 88.4 per cent in 1999. The trade with Canada, however, has not increased in this period, measured in export shares.

Table A4 The flow direction of the Mexican exports in 1990 and 1999

Region	1990	1999
U.S. %	68.8	88.4
Canada %	1.7	1.7
Latin America %	4.7	2.2
Western Europe %	14.0	4.2
Asia %	7.8	1.6
Other regions %	2.9	2.0

Source: INEGI, SHCP and BANXICO, Estadisticas del Comercio Exterior de México.

In table A5 we have divided Mexico's exports into major tradable goods. It is not a fall in the export of petroleum products that has caused the observed fall in their export share. The export of petroleum products has in fact been at a constant level during the whole period. The growth in exports can be explained by the increase in the export of the manufactured products. This also explains the change in the trade flow. Manufactured products solely explain the growth of the exports to U.S.

Table A5 The composition of the Mexican exports in 1990 and 1999

Tradable goods	1990	1999
Total exports in million dollars	42687	158443
Agricultural products %	8.1	2.9
Manufactured products %	52.0	89.5
Petroleum products %	37.6	7.3
Other extractable products %	2.3	0.3

Source: INEGI, SHCP and BANXICO, Estadisticas del Comercio Exterior de México.

Chapter 3

Do environmental regulations hamper productivity growth?

How accounting for improvements of plants' environmental performance can change the conclusion

Kjetil Telle and Jan Larsson

Abstract

Many economists maintain that environmental regulations hamper productivity growth; a view supported by several empirical studies on industry or state level data. However, there is little research of the relationship between the stringency of environmental regulation and productivity growth at the plant level; and the results of the few existing studies are ambiguous. Moreover, the measures of productivity growth applied in previous studies do not credit plants for emission reductions, and this may result in understatement of productivity growth. We perform regression analyses of productivity growth on regulatory stringency using plant level data. To credit a plant for emission reductions, we include emissions as inputs when calculating an environmental Malmquist productivity index (EMI); and do not include emissions when calculation the traditional Malmquist productivity index (MI). The regression analyses show that the overall effect of the regulatory stringency faced by plants on plants' productivity growth is statistically insignificant when MI is applied to measure productivity growth. However, when we apply EMI, the effect is positive and statistically significant. This indicates that not accounting for emission reductions when measuring productivity growth can result in too pessimistic conclusions regarding the effect of regulatory stringency on productivity growth.

Keywords: Environmental regulation; Productivity growth; Malmquist index

JEL classification: Q28, D24, Q25, L60

3.1 Introduction

It is a concern to policymakers that environmental regulations hamper competitiveness and economic growth. Several economists have estimated the effect of environmental regulations on traditional measures of growth in total factor productivity, and their results suggest that the concern is not unwarranted (Christiansen and Haveman 1981, Jaffe et al. 1995). Recently, however, it has been suggested that the empirically detected inverse relationship between environmental regulations and productivity growth is an almost inevitable consequence of the current methods used to measure productivity – methods that fail to account for improvements in environmental performance (Repetto et al. 1997).

In recent times, methods that account for environmental performance when measuring productivity have been developed, and most empirical studies have revealed that failure to account for emissions results in understatement of productivity growth (Weber and Domazlincky 2001, Färe et al. 2001, Hailu and Veeman 2000). These studies are often motivated by the conjecture that inclusion of environmental factors in measures of productivity will influence the results of analysis of the relationship between environmental regulations and productivity growth. To our knowledge, the present paper is the first to investigate this conjecture empirically; we study the empirical relationship between environmental regulations and productivity growth. To credit a firm for emission reductions, we include emissions when calculating an environmental Malmquist productivity index (EMI); and for the sake of comparison, we perform the analysis on the traditional Malmquist index (MI) where emissions are not accounted for.

There are many studies of the relationship between environmental regulations and productivity growth (not accounting for environmental performance) that employ industry or state level data, and they generally find that such regulations hamper productivity growth (Christiansen and Haveman 1981, Jaffe et al. 1995). However, as regulations are usually set at the plant level, employing industry or state level data can be an important shortcoming. When it comes to studies of environmental regulations and traditional measures of productivity growth employing plant level data, the literature is scarce and the results ambiguous (Jaffe et al. 1995, Jenkins 1998).[1]

Gollop and Roberts (1983) investigate the effect of firm specific environmental regulations on traditional measures of productivity growth in the U.S. electric power industry. The authors conclude that environmental regulations have resulted in markedly lower productivity growth. Similarly, Gray and Shadbegian (1993, 2002) include analyses of the relationship between productivity growth and environmental regulations for plants in three US industries. When environmental regulations are measured by compliance costs, they tend to find a negative relationship between the degree of environmental regulation and productivity growth. However, when other commonly used measures of regulatory stringency are employed, like compliance status or the number of inspections by the regulatory agency, the estimated coefficients are generally not significant.[2]

These previous firm level studies employ traditional measures of productivity growth. We are not aware of any study that investigates the relationship between environmental regulations and a measure of productivity growth that accounts for emission reductions. The contribution of the present paper is to provide empirical regression analyses showing how the estimated relationship between stringency of environmental regulations and productivity growth can depend on whether *MI* or *EMI* is applied. Based on empirical studies elsewhere (e.g. Magat and Viscusi 1990, Laplante and Rilstone 1996), regulatory stringency or enforcement is assumed to rise with inspection frequency. Inspection frequency serves as our measure of regulatory stringency.

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[1] In the present paper, we consider one measure of economic performance; productivity growth. The literature on the relationship between regulations and other measures of economic performance is not scarce; see e.g. the frequently cited work by Jorgensen and Wilcoxen (1990) on economic growth for the overall US economy. Firm level studies of regulation and profitability or efficiency do also exist; see e.g. Brännlund et al. (1995) and Hetemäki (1996).

[2] Gray and Shadbegian (2003) is related to Gray and Shadbegian (1993, 2002) and the results indicate a negative relationship between compliance costs and productivity (see also e.g. Shadbegian and Gray 2003 or Boyd and McClelland 1999). However, in their study of US oil refineries, Berman and Bui (2001) find that environmental regulations have increased productivity.

The *MI/EMI* type of index has advantages over other measures of total factor productivity, like the Törnquist or Fischer index: The *MI/EMI* type of index can be computed solely on the basis of quantities, getting around the problem of recovering (shadow) prices on emissions. Although implying that the *EMI* specified in this study cannot be directly related to changes in welfare, it does provide a more complete picture of changes in productivity, as emissions, which are of concern to society, are included. We use nonparametric linear programming to estimate distance functions, which are used to define the *MI/EMI* for each plant in each year (see e.g. Färe et al. 1994). Based on plant specific data, we estimate a technology frontier using data envelopment analysis for each industry. The *MI/EMI* comprises changes in plants' distance to the frontier and movement of the frontier. Contrary to econometric approaches used to estimate productivity, like e.g. Klette (1999) or Gray and Shadbegian (2002), the approach taken in the present paper requires no assumptions of the functional form of the production function. In addition, when estimating productivity growth, we avoid imposing the same production function structure on all firms within an industry. Finally, we do not need to impose optimizing behavior.

Norway's most energy intensive manufacturing industries are included in the present study. The Pulp and paper, Primary aluminum, Inorganic chemicals and Ferro alloy industries consume about 50 percent of the energy of the overall Norwegian manufacturing industry. These industries are major contributors to national emissions. In 2000, these four industries caused more than 80 percent of Norwegian manufacturing industry's emissions of SO_2, more than 50 percent of emissions of acids, and about 50 percent of the emissions of CO_2 or greenhouse gases (Statistics Norway 2003a).

In Section 2, we present the econometric model and the data, and outline how the productivity indexes are estimated. Section 3 presents the regression results for the two measures of productivity growth on regulatory stringency. Section 4 concludes.

3.2 Models and data

3.2.1 Econometric framework

In this sub-section we introduce the econometric model, which is applied to test the sign of the relationship between environmental regulatory stringency and productivity growth. As mentioned in the introduction, empirical studies of the relationship between environmental regulation and productivity growth on firm level data are scarce, and the results ambiguous. The differing methods applied in previous studies may be one reason for the ambiguous results.

Gollop and Roberts (1983) estimate a cost function to test for the impacts of regulatory stringency of sulfur dioxide emissions. Gray and Shadbegian (1993, 2002) let the residuals evolving from a regression of a three input production function model serve as measures of the total factor productivity levels. Then they estimate the effect of various measures of regulatory stringency on productivity growth.

Our approach is similar to the one taken by e.g. Gray and Shadbegian (1993, 2002): We regress productivity growth on regulatory stringency. However, we also apply a measure of productivity growth that accounts for emission reductions (*EMI*). The regression model, where $Productivity\_growth_{i,t}$ for plant i in year t is either the logarithm of *EMI* or *MI*, is as follows:

$$\text{Productivity\_growth}_{i,t} = \text{a} + \sum_j b_j * Stringency_{i,t-j} +$$
$$\text{c*Controls}_{i,t} + \text{v}_i + \text{w}_t + \text{u}_{i,t}\,, \ \text{j}=0,1,..,\tau \quad (3.1)$$

where *Stringency* is a measure of the stringency of the environmental regulation of the plant in the year, *Controls* is a vector of control variables, v is plant specific effects and w is year dummies. u is an error term. These variables are explained more carefully in the following paragraphs.

The stringency or enforcement of environmental regulations may be operationalized in numerous ways. The following are examples from the abovementioned papers; compliance costs, the number of new regulations taking effect, discrepancy between non-constrained emissions and actual emissions, and the number of inspections. In the present paper, we use inspections, which are a reasonable indicator of regulatory stringency or enforcement for several reasons. First, previous studies elsewhere have shown that inspections increase enforcement by reducing emissions (e.g. Magat and Viscusi 1990, Laplante and Rilstone 1996). Second, the costs for the Norwegian Pollution Control Authority (NPCA), which monitors and enforces environmental regulations of Norwegian firms, of inspections have to be covered by the inspected plant; and in addition, if violations are revealed, both future inspection frequency and the plant's expectation of future sanctions tend to increase (Nyborg and Telle 2004).

Finally, the most important criteria determining the inspection frequency of a plant is the risk class of the plant. When a firm is granted an emission permit,[3] the NPCA simultaneously puts the firm in one of four risk classes; with the potentially most environmentally dangerous plants in risk class one, etc. Plants in lower risk classes are generally also more stringently regulated. Hence, as the inspection frequency is in general higher for more regulated plants, the *Stringency* variable includes not only stringency of enforcement, but also elements of the stringency of regulation.

The *Stringency* variable is the number of inspections of the plant during a calendar year. In studies where compliance costs or emissions are used as measures of regulatory stringency (e.g. Gray and Shadbegian 1993, 2002), it is commonly recognized that measurement errors may bias the estimates (Berman and Bui, 2001, Gray and Shadbegian 2002). As our data builds on the registration routines of the regulator (NPCA), and as the registration is crucial as documentation for future follow up or prosecution of violators, there is little reason to believe the data are not complete. Hence, it seems reasonable to say that measurement errors in the stringency variable are

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[3] Permits are routinely granted for a period of 10 years, and although it appears that moving a firm across risk classes based on compliance history can be an advantage to the regulator (Harrington 1988), NPCA does not seem to change the risk class of the firm based on compliance records (Nyborg and Telle 2004).

not a serious problem in the present study. As improvements in productivity growth requires changes in production procedures and/or investments, it appears reasonable that some time is required from a change in regulatory stringency can influence productivity growth. Therefore, we allow for one or more lags in the stringency variable. See Nyborg and Telle (2004) for an introduction to the Norwegian regulatory system, and for a more careful presentation of these data.

What control variables (*Controls*) we include in the analysis depends on the regression model employed; we focus on the random effects model and the fixed effects model. In the fixed effects model, v_i is plant specific fixed effects and w_t is year dummies. This model effectively controls for plant specific characteristics that do not vary over time. Examples of such variables are the industry that the plant belongs to, plant's location or risk class, or time invariant elements of plant vintage, technology, management, or employee motivation and education. As there may be e.g. differences in economies of scale across plants (and over time), we control for size by including capital stock.

As an alternative, we also report results from regressions on a random effects model. In the random effects model v_i is considered randomly distributed across plants, see Greene (2000). In the random effects model, we also include industry and year dummies (w_t).[4]

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[4] Endogeneity problems, which lead to biased estimates, might arise if e.g. plants with increasing emissions are inspected more frequently than other plants, and such increasing emissions translate into lower productivity growth. However, there is little reason to expect such endogeneity to be important in our regressions. First, changes in a plant's emissions are not an important determinant of the inspection frequency, which is mainly due to the risk class of the plant. The risk class is determined when the emission permit is granted and routinely evaluated only every tenth year (see Nyborg and Telle 2004). Indeed, to allow the plant some time from a change in regulatory stringency to impact on productivity growth (see above), we use inspections in previous periods as explanatory variables. This makes it difficult to maintain that inspection frequency is determined by changes in emissions and/or productivity growth, as information about changes in emissions and/or productivity growth in year *t* is not available for the regulator when the inspection frequency in *t-1* is determined.

3.2.2 Productivity growth

In this subsection, we outline the calculation of *EMI* and *MI*. There is an extensive literature on the Malmquist productivity index (see e.g. Färe et al. 1994), including a relatively new and growing strand where this kind of index is amended to include environmental factors (see e.g. Färe et al. 1989, Färe et al. 1996, Chung et al. 1997, Färe et al. 2001).

Consider a production technology where an output vector, $y \in R_+^M$, is produced using a vector of inputs, $x \in R_+^{N+D}$. The input vector consists of N normal and D environmentally detrimental inputs. Let S^t be the technology set at time t. Following Shephard (1953, 1970) and Färe and Primont (1995), we define the input distance function of plant i in year t as follows:

$$d_i^t(y_{i,t}, x_{i,t}) = \max_{\theta_{i,t}} \left\{ \theta_{i,t} : \left(y_{i,t}, \frac{x_{i,t}}{\theta_{i,t}} \right) \in S^t \right\} \tag{3.2}$$

The value of the input oriented distance function measures the maximum amount by which the input vector can be deflated, provided that the output vector is unchanged. In a given period, it is clear that $d_i^t \geq 1$, and that a plant is operating on the boundary of the technology set (S^t) if $d_i^t = 1$.

The data envelopment analysis involves the use of linear programming methods to construct a non-parametric piecewise frontier (the boundary of the technology set) as outlined in Coelli et al. (1998).[5] Actual observations of $x_{i,t}$ and $y_{i,t}$ for all plants i in t belonging to the same industry defines the technology set (S^t).

The distance function d_i^t can be calculated accounting or not accounting for emissions. If $x \in R_+^N$ the distance function does not capture the emissions required by the plant to produce y, while if $x \in R_+^{N+D}$ emissions are also accounted for.

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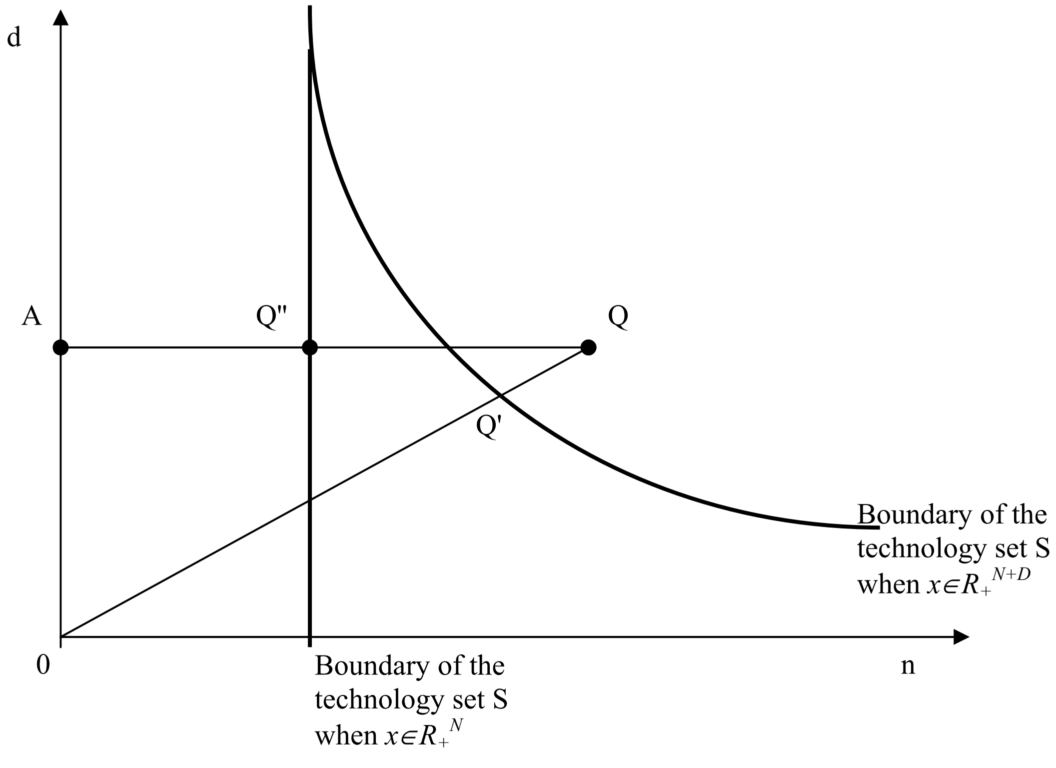
[5] The actual estimations of the indexes are performed using Onfront version 2.02, see Färe and Grosskopf (2000).

These two distance functions can be illustrated with the aid of a diagram. Consider Figure 1 where plant Q employs the input bundle *(n,d)* to produce the output level *y*. Let us think of *n* as a normal input (like labor, capital or intermediates) and *d* as an environmentally detrimental input (like emissions of some pollutant). The distance function seeks the largest proportional contraction of the input bundle that allows production of the original output level. For plant Q in this example, the input function accounting for emissions takes on the value 0Q/0Q'. Similarly, the input function not accounting for emissions takes on the value AQ/AQ''. We see that in both cases, the distance function is greater than or equal one.

Figure 1: The input distance function including and not including emissions in one period. *n* represents a traditional input while *d* represents emissions of a pollutant.



We compute *MI* (where the distance function is based on $x \in R_+^N$) and *EMI* (where the distance function is based on $x \in R_+^{N+D}$). These indexes capture the change in productivity computed excluding and including emissions as inputs, respectively. These plant and year specific indexes are computed for each of the four industries individually. Grifell-Tatje and Lovell (1994) show that in the presence of non-constant returns to scale, the Malmquist index does not accurately measure productivity change. To address this, and to avoid computation difficulties, we follow the recommendation of Coelli et al. (1998) and assume constant returns to scale. We assume that inputs are strongly disposable. Annual means of each industry are weighted by production.

Following Färe et al. (1994) we specify the input oriented Malmquist productivity index for each plant *i* in year *t* as:

$$m_{i,t}(y_{i,t+1}, x_{i,t+1}, y_{i,t}, x_{i,t}) = \left[\frac{d_i^t(x_{i,t+1}, y_{i,t+1})}{d_i^t(x_{i,t}, y_{i,t})} \frac{d_i^{t+1}(x_{i,t+1}, y_{i,t+1})}{d_i^{t+1}(x_{i,t}, y_{i,t})} \right]^{\frac{1}{2}} \tag{3.3}$$

This represents the geometric mean of the two Malmquist input-oriented productivity indexes, each with the period *t*- and *t-1*-technology as base technology. Our measure of *MI*/*EMI* is defined by (3.3). *MI* is defined by applying the distance functions (d_i^t, d_i^{t+1}) that are calculated using the input vector *excluding* emissions (i.e. $x \in R_+^N$); while *EMI* is defined by applying the distance functions (d_i^t, d_i^{t+1}) that are calculated using the input vector *including* emissions (i.e. $x \in R_+^{N+D}$).[6]

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[6] Despite some methodological complications, a two-stage procedure where the values of the distance function or efficiencies resulting from the DEA are applied as the explanatory variable in a succeeding regression analysis is often advocated (see e.g. Coelli et al. 1998, p. 170f). Hence, this procedure has often been applied in empirical studies. While some of the methodological problems occurring in regressions on values of the distance function/efficiencies may not arise in regressions on the Malmquist index, others may. As there seem to be no consensus on what approach may be superior (see e.g. Murillo-Zamorano 2004) and theory is not well developed in this field, we stick to the common approach in applied work of ignoring such possible complications.

3.2.3 Data

Our plant-level data set covers the following industries: Pulp and paper, Primary aluminum, Ferro alloys and Inorganic chemicals.[7] As mentioned in the introduction, these industries are energy intensive and an important source of emissions in Norway. In 2000, the plants in our sample cover about 90 percent of the production, material and man-hours of the four industries, and about 95 percent of the energy use. Hence, we cover the most polluting industries and the sample covers the biggest and most polluting plants of these industries.

The unique data set[8] includes annual plant specific emissions available from self-reports to NPCA for 1992-2002. Inspection data from NPCA are available from 1990; and census data on output, intermediate inputs, labor and capital comes from Statistics Norway (2003b). Our panel comprises 46 different plants, of which 37 are present in all years while we lack observations (mainly on emissions) in one or more years for the remaining 9 plants. This results in 484 plant-year observations. As *EMI/MI* indexes the change between two subsequent years, we lose at least one observation for each plant, and are left with 427 observations of 46 different plants in 10 years (1993-2002) for the regression analyses.

Output, intermediate inputs and capital are deflated to 2000 NOK. Labor is the number of man-hours. The capital stock is calculated based on fire insurance value in 1992 and 1993 and succeeding net annual investments, where net investments are calculated using gross investments and industry specific depreciation rates from Todsen (1997). We have information to calculate the capital stock for all plant-years for which we have emission

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[7] NACE 21.1, 27.421, 27.35, and 24.13, respectively.

[8] See Bruvoll et al. (2003) or Larsson and Telle (2003) for further documentation of the data set. Data on greenhouse gases are estimated using disaggregated data (from Statistics Norway 2003b) on consumption of various energy carriers within each plant, and the carrier specific emission coefficients used by Flugsrud et al. (2000). We lack data for some smaller plants. The analysis is restricted to these four industries because the data quality is generally lower for other, less regulated, industries.

data. The logarithm of capital is applied to control for plant size in the regressions. We have data on two pollutants. *Greenhouse gases* is an aggregate of carbon dioxide (CO_2), methane (CH_4) and nitrous oxygen (N_2O), measured in tons of CO_2-equivalents.[9] *Acidifying substances* is an aggregate of sulfur dioxide (SO_2), nitrogen oxides (NO_x) and ammonium (NH_3), measured by the acidifying component.[10]

To calculate *MI* we use output, intermediate inputs, labor and capital; while greenhouse gases and acids are also included when calculating *EMI*. Summary statistics on these variables are presented in Table A1 in the Appendix. Table 1 presents summary statistics for the variables used in the regression analyses. On average, both *EMI* and *MI* indicate productivity growth over the period, but some variations across industries are evident. The mean of the *Stringency* variable is about 0.7, revealing that on average the plants in the sample where inspected 0.7 times a year. The Ferro alloy and Inorganic chemicals industries each comprise about a quarter of the observations, while Primary aluminum and Pulp and paper comprise about one sixth and one third of the observations. In Table 2 we present the correlations between these variables.

Table 1 Summary statistics for variables included in the regressions.

	Total		Pulp and paper		Inorganic chemistry		Ferro alloy		Primary aluminium	
Obs.	427		144		108		105		70	
	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.
Log EMI	0.015	0.25	-0.013	0.262	0.038	0.302	-0.008	0.205	0.051	0.112
Log MI	0.019	0.13	0.009	0.140	0.029	0.128	0.0002	0.131	0.034	0.101
Stringency	0.71	0.62	0.771	0.726	0.630	0.522	0.819	0.662	0.714	0.486
Size	13.7	1.08	13.875	1.315	13.082	0.623	13.420	0.436	14.969	0.460

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[9] Greenhouse gases are computed using the weights of the Kyoto protocol, i.e.:$CO_2+CH_4*21+N_2O*310$.

[10] Acids are an aggregate of the total acidifying effect (H^+), i.e. $SO_2/32+NO_x/46+NH_4/17$.

Table 2: Correlations across variables (p-value in parenthesis).

	Log EMI	Log MI	Stringecy $_{t-1}$	Stringecy $_{t-2}$	Size
Log EMI	1				
Log MI	0.449 (<0.001)	1			
Stringecy$_{t-1}$	0.098 (0.043)	0.011 (0.83)	1		
Stringecy$_{t-2}$	0.044 (0.37)	0.015 (0.019)	0.136 (0.005)	1	
Size	0.062 (0.20)	0.049 (0.31)	0.216 (<0.001)	0.241 (<0.001)	1

Note: Number of observations: 427.

3.3 Estimation results

As mentioned in the introduction, it is not clear whether we should expect a positive or negative relationship between our measure of regulatory stringency and productivity growth, i.e. whether *b* in (3.1) is positive or negative. Nevertheless, since *EMI* also credits a firm for emission reductions, it seems reasonable to expect a more positive (or a less negative) relationship between environmental regulations and productivity growth when applying *EMI* than when applying *MI*.

The results of the regressions on (3.1) are presented in Table 3 for the logarithm of *EMI* as the dependent variable.[11] The effect of regulatory stringency on *log(EMI)* is positive. *Log(EMI)* increases with regulatory stringency one period ago, and the effect is statistically significant. From the results of the fixed and random effects model 2, where 2 lags of *stringency* are included, we also find a positive relationship between inspections and productivity growth. We note that this main result regarding the positive

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[11] The F-test statistics reported in the table reveal that the hypothesis of no fixed effects can be rejected. The reported Hausman test statistics reveal that a hypothesis that the plant specific effects are uncorrelated with the other regressors in the model cannot be rejected. This indicates that the assumption of the random effects model that the plant specific effects are uncorrelated with the other regressors is not violated. The regressions reported in the paper were performed using SAS (proc tscsreg).

effect of *Stringency* do hardly vary across the models reported in the table. Moreover, a hypothesis that the sum of the one and two lag effects of *Stringency* on *log(EMI)* is zero, can be rejected for both the fixed and random effects model (F-test statistics is 7.99 and 8.04, respectively). Hence, the results of the regressions on *log(EMI)* support a view that there is a positive relationship between regulatory stringency and productivity growth.

Table 3 The result of the regressions where the logarithm of *EMI* is the dependent variable (standard error in parenthesis).

	Fixed effects 1	Random effects 1	Fixed effects 2	Random effects 2
Stringency $_{t-1}$	0.055**	0.053**	0.064***	0.059***
	(0.023)	(0.021)	(0.024)	(0.022)
Stringency $_{t-2}$			0.041*	0.035
			(0.024)	(0.022)
Size	0.24*	0.028	0.23*	0.018
	(0.13)	(0.036)	(0.13)	(0.034)
Aluminum dummy		-0.050		0.060
		(0.11)		(0.10)
Ferro dummy		-0.029		0.022
		(0.088)		(0.082)
Chemical dummy		0.095		0.09
		(0.089)		(0.84)
F-test of no fixed effects (F-value)	1.38*		1.44***	
Hausman test (m-value)		2.81		3.19

Note: Number of observations (*i*, *t*): 427 (46,10).
*,**, and *** indicates significance at the 10, 5 and 1 percent level, respectively.

Table 4 presents the results of the regression on (1) when the logarithm of *MI* is the dependent variable. The effect of *Stringency* on *log(MI)* is not clear. The sign of the coefficient is negative for the first lag of *Stringency* in all specifications, a result in line with the conclusion of Gollop and Roberts (1983), but not significant. However, when one lag more is included, this lag is significantly positive. One may take this to indicate that there is also a positive effect of stringency on traditional productivity growth, but that this effect needs longer time to materialize. However, this is not so. One may not conclude that there is a positive overall effect of *Stringency* on traditional productivity growth, since the sum of the one and two lag effects of *Stringency* is not statistically different from zero (F-test statistic is 2.04 and 3.05 in the fixed and random effects model, respectively). Hence, the results of the regressions on *log(MI)* does not support a view that there is a positive relationship between regulatory stringency and productivity growth.

Table 4 The result of the regressions where the logarithm of *MI* is the dependent variable (standard errors in parenthesis).

	Fixed effects 1	Random effects 1	Fixed effects 2	Random effects 2
Stringency $_{t-1}$	-0.018	-0.0080	-0.0092	-0.0091
	(0.012)	(0.011)	(0.013)	(0.011)
Stringency $_{t-2}$			0.038***	0.035***
			(0.013)	(0.011)
Size	0.010	0.0039	-0.0044	-0.0025
	(0.073)	(0.0072)	(-0.72)	(0.0073)
Aluminum dummy		0.019		0.025
		(0.020)		(0.020)
Ferro dummy		-0.0074		-0.011
		(0.016)		(0.016)
Chemical dummy		0.020		0.022
		(0.017)		(0.017)
F-test of no fixed effects (f-value)	1.20		1.22	
Hausman test (m-value)		2.20		0.56

Note: Number of observations (*i*, *t*): 427 (46,10).
*,**, and *** indicates significance at the 10, 5 and 1 percent level, respectively.

3.4 Concluding remarks

The present paper provides the first empirical support of a claim that evaluations or recommendations of environmental policies that are based on a traditional measure of total factor productivity can be misleading: When using a measure of productivity growth that accounts for emissions, we find a positive and significant relationship between regulatory stringency and productivity growth (*EMI*). However, we do not find a significant relationship between regulatory stringency and a traditional measure of productivity growth (*MI*).

This paper has investigated one possible aspect of the costs of environmental regulations: reduced growth in total factor productivity. Contrary to what is traditionally claimed, our result indicates that environmental regulations have *not* reduced productivity growth when measured in a way that credits plants for emission reductions.

When a firm allocates resources to abatement activities, this is conventionally believed to reduce productivity measured by ordinary outputs. However, over time the firm may accomplish the same amount of abatement by allocating fewer resources from ordinary production to abatement activities. The main point of the present paper is that this improvement in abatement technology should constitute one element of the firm's overall technical progress. We find that accounting for this element is sufficient to observe a positive relationship between productivity growth and regulatory stringency.

Recently some authors have been arguing that environmental regulations can in fact improve the economic performance of firms, a stand often labeled the Porter Hypothesis (see e.g. Porter 1991 or Porter and van der Linde 1995). These authors propose several mechanisms to support a presence of such win-win-opportunities; like e.g. that regulations enhance motivation for innovations that improve competitiveness. Porter and van der Linde (1995), e.g., argue that even if environmental regulations were not profitable in the short run, they may improve competitiveness in the long-run. Since productivity growth is an important determinant of long-term competitiveness, many of the arguments supporting the Porter Hypothesis applies to our measures of productivity growth. However, there are a couple of reasons why our empirical results may not be interpreted as support for the Porter Hypothesis. First, we do not find a significant effect of regulatory stringency on *MI*. Second, and more importantly, while Porter and van der Linde (1995) focus on private costs when maintaining that regulations can improve competitiveness, we have considered a measure of productivity growth that incorporates emissions. This represents an extension of focus from inputs associated with pure private costs to environmentally detrimental inputs of concern to society. Along with others, we have argued that inclusion of environmental impacts of production is appropriate when policy evaluations of regulations are to be undertaken.

It seems likely that the effect of regulatory stringency on productivity growth would depend on the specific features of the actual regulatory regime, and probably also on the technological and institutional characteristics of the industries studied. Complementing the present study with analyses on data sets covering other industries and regulatory regimes is obviously necessary before categorical conclusions regarding the relationship between regulatory stringency and productivity growth can be drawn. Still, we believe that the results based on our limited data set reveal some interesting patterns worth studying further as the availability of plant level panel data improves.

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Appendix

Table A1: Summary statistics for variables used in the calculations of *MI*/*EMI*.

Industry	Total		Pulp and Paper		Inorganic chemistry		Ferro alloy		Primary aluminium	
Obs.	484		172		119		116		77	
	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev.
Output (mill NOK)	879	971	844	820	300	159	524	240	2390	1146
Labor (mill h)	542	437	567	402	278	170	330	163	1211	360
Intermediate inputs (mill NOK)	591	637	640	589	198	104	347	165	1456	802
Capital (mill NOK)	1601	1692	1965	1896	608	373	750	285	3606	1657
Greenhouse gases (1000 tonne)	9768	22752	27444	32128	2069	2495	3156	13611	420.45	226.49
Acids (tonne)	1334	6880	4.59	5.89	26.23	22.32	29.12	25.10	11.18	7.10

Chapter 4

Consequences of the IPPC's BAT requirements for abatement costs and emissions

Jan Larsson and Kjetil Telle

Abstract

The *Integrated Pollution and Prevention Control* (IPPC) directive from the European Union implies that regulatory emission caps should be set in accordance with each industry's *Best Available Techniques* (BAT). The directive, which represents a harmonizing of environmental regulations towards a BAT principle, is being implemented currently in all of the member states and the states associated with the European Economic Area. We examine the effect of this implementation with respect to expected emission reductions and increases in costs, using data from Norway. *Data Envelopment Analysis* (DEA) is used to construct a frontier of all efficient plants. This provides us with two alternative interpretations of BAT. First, we assume that all plants emit in accordance with the best practice technology, represented by the frontier, by reducing all inputs proportionally. Second, we assume that all plants emit in accordance with the best practice technology by reducing emissions only. Both interpretations reveal a strong potential for emission reductions. Further, abatement cost estimates indicate that considerable emission reductions can be achieved with low or no social costs, but that the implementation of BAT for all plants involves substantial costs.

Keywords: IPPC, BAT, Emissions, DEA, Technical efficiency.

JEL classification: D21, K23, K32, L61, L65, L73, Q48, R38.

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4.1 Introduction

Environmental policy instruments may be characterized as either command-and-control or market-based approaches (Jaffe et al. 2002). Although economists tend to favor market-based instruments, such as pollution charges, subsidies and tradable permits, policy makers often chose command-and-control regulations, such as performance and technical-based standards. These standards tend to force all firms to take on the same shares of the pollution control burden, regardless of costs. Holding all firms to the same target is not cost efficient since the costs of controlling emissions may vary greatly among firms (Jaffe et al. 2002). Despite economists' concern about cost inefficiency, the *Integrated Pollution Prevention and Control* directive (IPPC 1996), under implementation in the member states of the European Union and the states associated with the European Economic Area[1] (EEA), largely holds each firm within an industry to the same emission targets.

The IPPC directive obliges the states to let each industry's *Best Available Techniques* (BAT) determine the conditions in the assignment of emission permits—that is, reference values for emission limits will be based on BAT. Alternatively, instead of basing the emission limits on the best available techniques, the limits could be based on cost efficiency, such that further emission reductions would occur for the plant that had the lowest marginal emission costs.

As one of the states associated with EEA, Norway implemented the IPPC directive from 1999 (Ot. Prp. 59, 1998-99). Before the implementation of the IPPC-directive into Norwegian law, the anti-pollution law of 1981 emphasized overall economic efficiency. Indeed, in the most important documents for the interpretation of the law, a BAT principle was explicitly rejected in favor of a more cost efficient one (Bugge 1999, Ch. 8.2, Asdal 1998, Ot. Prp. 11 1979-80). Hence, the implementation of the IPPC-directive, required reformulations of the laws on provision of permits (Ministry of Environment 2002). Contrary to the pre-IPPC law, the new one explicitly relates the provision of permits to requirements concerning BAT.

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[1] Iceland, Lichtenstein and Norway.

The aim of our paper is to analyze the impact that implementation of the BAT requirements will have on emission reductions and abatement costs using data from Norway. We perform *Data Envelopment Analyses* (DEA) to construct frontiers for all technically efficient plants. The frontier consists of the firms within an industry using the *Best Practice Technique* (BPT). We estimate the changes in emissions that occur as a result of the implementation of the BAT requirements in two alternative ways. Both are based on the difference between each plant's actual emissions and the BPT emissions. First, we estimate *technical efficiency*, that is, the ratio between the amount of inputs required to produce the observed output with the frontier technology, and the observed amount of inputs. This is a reasonable interpretation of the BAT requirements, given that the price ratio of traditional inputs and detrimental emissions reflects the social costs. However, if the price of detrimental emissions is undervalued, the intention of the directive should imply higher emission reductions. This price is not directly set in the market, but can be viewed as a shadow price that reflects the abatement costs for the firms. Second, an estimate of *environmental efficiency* provides an alternative illustration, where environmental efficiency is defined as the distance to the frontier in the environmental dimension only—that is, the ratio of the amount of detrimental emissions when the observed output is produced with the frontier technology and the observed amount of detrimental emissions when traditional inputs are held constant.

Further, we illustrate the short-run costs for the plants and the society. We assume a so-called *putty-clay* technology, that is, fixed short-run input coefficients, for which stricter permit standards are achieved solely through reductions in production. The social costs are calculated as the loss in aggregated value added minus wages.

We base the analysis on plant-specific data from four of the most energy-intensive industries in Norway: the pulp and paper, primary aluminum, ferro alloy, and inorganic chemistry industries. These industries consume about 50% of the energy in Norwegian manufacturing industries. In 2000, they were the major contributors of air pollution emissions in Norway. They caused more than 50% of total acid emissions and about 50% of the emissions of carbon dioxide (CO_2) and other greenhouse gases. Thus, these industries are the subject of special attention from the Norwegian Pollution Control

Authority (NPCA) and, as a group, are subject to similar regulations and policies regarding enforcement and deterrence.

Most of the papers that have studied the environmental implications of the IPPC directive have used a life-cycle assessment perspective (see, for example, Fatta *et al.* 2003, Gelderman and Rentz 2001, Pellini and Morris 2001, Schultmann et al. 2001). Lübbe-Wolff (2001) provided an overview of regulatory approaches in European countries and related these to the IPPC approach. We are not aware of any other economics papers concerned with the IPPC from an empirical point of view. However, analyses of BAT concepts, including, for example, *Best Available Technology Not Entailing Excessive Cost* (BATNEEC), are well known to economists; see, for example, Førsund (1992) and Pearce and Brisson (1993). Despite a growing literature on environmental efficiency (see, for example, Bruvoll et al. 2003, Lansink and Silva 2003, Reinhard et al. 2000, Zaim 2004), our approach of using DEA to evaluate the effects of the BAT requirement of the IPPC directive seems novel.

In the next section, we define two interpretations of the BAT requirement, which are technical efficiency and environmental efficiency. In section 4, these definitions will be used to illustrate the emission reductions that can result from the implementation of the BAT requirement in Norway. From economic theory, we expect that shifting the focus of Norwegian environmental regulations from cost efficiency to BAT requirements would be costly. In section 2, we propose a method of estimating these costs. The actual estimates are presented in section 5. Section 6 concludes the paper.

4.2 Theoretical framework

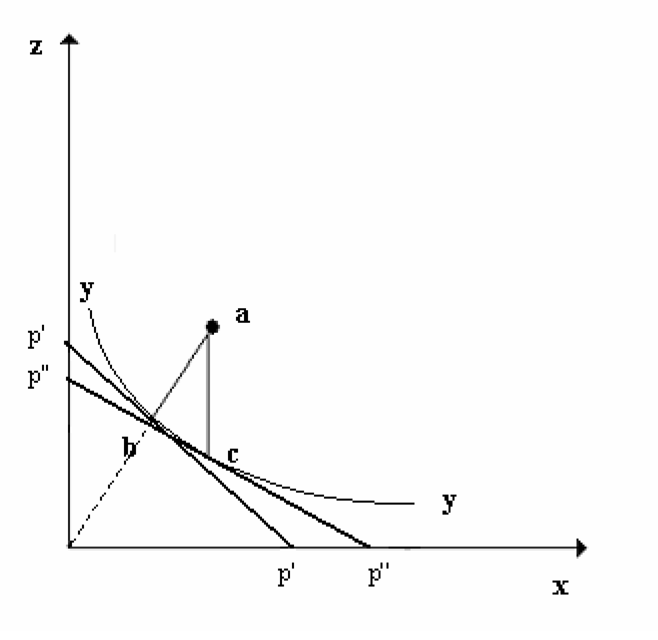
4.2.1 BPT as a representation of BAT

In principle, BAT may include techniques that are not in use within the member states of the EU. However, in practice, the BAT requirement does not normally include such techniques. The less demanding objective, BPT, mirrors the techniques already *actually employed* by existing plants in the industry. Therefore, the DEA method, which involves reference techniques using the *best practices* within each industry, seems to be a reasonable approximation of BAT.

We adopt two slightly different measures of BPT: the overall best practice techniques, and the best practice techniques in the environmental dimension only. The first approach represents a proportional reduction of all inputs, including emissions. The second calculates the distance to the best practitioners in the environmental dimension only. Arguments for each of these measures can be deduced from the reference to "*costs and advantages*" in Article 2 in the IPPC directive (IPPC 1996). Although this reference is linked to the economic principle that marginal costs should equal marginal benefits, the principle itself is not vital in the determination of BAT (Faure and Lefevere 1999, Lübbe-Wolff 2001, Winter 1999).

As environmental quality has no market price, the plant-specific shadow price of pollution may fall short of the marginal cost to society. Then, environmentally detrimental emissions would need to be reduced excessively compared with the reduction in normal inputs to achieve the economically efficient techniques. However, if the plant-specific shadow price equals the marginal cost to society, the proportion of traditional inputs to detrimental emissions reflects the price ratio, and the economically efficient techniques could be achieved by a proportional reduction of all inputs, including the environmentally detrimental ones. We argue that this method is a reasonable approximation of the economically efficient techniques.

Figure 1. Technical and environmental efficiency



This is illustrated in Figure 1 under the assumption of constant returns to scale (CRS), where **x** denotes normal inputs and **z** denotes environmentally detrimental inputs. The isoquant **y-y** is the technically efficient frontier that produces **y**. The plant **a** is technically inefficient. Assume that plant **a** faces the correct shadow prices of emissions. Then, point **b**, where the isocost line **p'-p'** intersects with the frontier, is technically, as well as economically, efficient. In other words, a proportional reduction of the conventional and environmental inputs provides the technically, as well as the economically, efficient factor combination to produce **y**.

However, if plants do not pay the total marginal social costs, then the shadow price on the detrimental inputs for the plants is too low. In Figure 1, the isocost line reflecting a higher price on the environmental input is described as the line **p''-p''**. Then, the economically efficient factor combination for the society is where the isocost line intersects with the frontier at **c**.

We now turn to describing how the BPT frontier is constructed, and show how this reference technique can be compared with the techniques actually employed in order to determine the scope for emission reductions.

4.2.2 Technical and environmental efficiency

Assume we have observations of k ($k = 1,\ldots,K$) plants, which use N ordinary inputs, represented by a vector $x \in \Re^{N}{}_{+}$, and J environmentally detrimental inputs, $z \in \Re^{J}{}_{+}$, to produce M ordinary outputs, $y \in \Re^{M}{}_{+}$. The $K \times N$ input matrix, X, the $Z \times K$ undesirable inputs matrix, Z, and the $M \times \mathrm{K}$ output matrix, Y, represent the data for all K plants. Following Banker *et al.* (1984), these observations can be used to define a production set, S, characterized by a convex hull.

$$S=\{(y,x,z):x \text{ and } z \text{ can produce } y\}. \qquad (4.1)$$

Now, we define the best practice technique frontier as the surface of S. For the case of a production technology using N normal and J environmentally detrimental inputs to produce *M* outputs, following Shephard (1953, 1970) and Färe and Primont (1995), the input distance function can be defined as:

$$D(y,x,z) = \max_{\theta}\left\{\theta : \left(y, \frac{(x,z)}{\theta}\right) \in S, \theta \in R_{+}\right\}. \tag{4.2}$$

In other words, the value of the input distance function measures the maximum amount by which the input vector can be deflated by a factor θ, given the output vector. It measures the minimal proportional contraction of the input vector required to bring it to the frontier of the input requirement set for a given output vector. A value greater than one for the input distance function implies that the observed input vector is inefficient. When the producer operates on the technically efficient frontier, the distance function attains the value of one, that is, $\theta = 1$.

Thus, by definition, the reciprocal of the value of the input distance function provides an input-based Farrell measure of *technical efficiency* (Farrell 1957):

$$TE(y,x,z) = \frac{1}{D(y,x,z)}. \tag{4.3}$$

If *TE* is one, the plant is technically efficient. The measure (1 – *TE*) is the proportion by which improvements in technical efficiency would allow inputs to be reduced without reducing output.

Accordingly, environmental efficiency can be defined in the environmental dimension as follows, when outputs and normal inputs are constant:

$$D_E(y,x,z) = \max_{\phi}\left\{\phi : \left(y, x, \frac{z}{\phi}\right) \in S, \phi \in R_{+}\right\}. \tag{4.4}$$

Then, the *environmental efficiency* measure *EE* will be defined as:

$$EE(y,x,z) = \frac{1}{D_E(y,x,z)}. \tag{4.5}$$

The distance function (D) for each plant can be computed by solving a linear programming problem. In our analysis, we assume CRS. To obtain the input-saving efficiency measure (*TE*) for plant *k*, given output, the following linear programming problem must be solved for each unit. For unit *k*, the optimization problem is:

$$\begin{aligned}
&TE_k = \min \theta \\
&s.t. \\
&-y_k + Y\lambda \geq 0 \\
&\theta\ x_k - X\lambda \geq 0 \\
&\theta\ z_k - Z\lambda \geq 0 \\
&\lambda \geq 0, \theta \leq 1 \\
&y_k \in Y,\ x_k \in X,\ z_k \in Z
\end{aligned} \qquad (4.6)$$

where λ is an $N \times 1$ vector of constants and θ is a scalar that measures the efficiency score for unit *k*. θ will satisfy $\theta \leq 1$, with the value one indicating a point on the frontier and, hence, a technically efficient plant, according to the Farrell (1957) definition. This linear programming problem has to be solved for all *K* units. The intuitive interpretation of the DEA problem is that we take the k^{th} unit and seek to radially contract the input vector (x_k, z_k) as much as possible, while remaining within the feasible input set. The radial contraction of the input vector (x_k, z_k) produces a projection point, (λx_k, λz_k, y_k), on the frontier. The efficiency is the distance between this projection point and the observed data for unit *m*, (x_k, z_k, y_k).

To obtain the input-saving environmental efficiency measure (*EE*) for plant *k* under constant returns to scale, given output and the conventional inputs, the following linear programming problem must be solved for each unit. For unit *k*, the optimization problem is:

$$\begin{aligned}
&EE_k = \min \phi \\
&s.t. \\
&-y_k + Y\lambda \geq 0 \\
&x_k - X\lambda \geq 0 \\
&\theta\ z_k - Z\lambda \geq 0 \\
&\lambda \geq 0, \theta \leq 1 \\
&y_k \in Y,\ x_k \in X,\ z_k \in Z
\end{aligned} \qquad (4.7)$$

ϕ will satisfy $\phi \leq 1$, with the value one indicating a point on the frontier and, hence, an environmentally and technically efficient plant. The intuitive interpretation of the DEA problem is that the k^{th} unit is used to contract the detrimental input vector z_k as much as possible, while remaining within the feasible input set. This contraction of the emission vector, z_k, produces a projection point, $(\lambda z_k, x_k, y_k)$, on the frontier. The environmental efficiency is the distance between this projection point and the observed data for unit *k*, (x_k, z_k, y_k). From the definitions of *TE* and *EE*, it follows that *TE* is always weakly higher than *EE*.

In our application, we include capital, labor, and material as conventional inputs, and emissions of greenhouse gases and acids as environmental inputs. The efficiency measures are calculated with both pollutants jointly.

4.2.3 The cost of reducing emissions

To illustrate the plants' costs of fulfilling the conditions determined by BAT, we use a modification of the method introduced by Pasurka (2001). The method used has its origin in works of Salter (1966) and Johansen (1972), see also Førsund and Hjalmarson (1987). We assume a *putty-clay* technology with constant returns to scale, where the input coefficients are fixed in the short run, when no investments are made. The factors studied within the short-run function are limited to current inputs only. Fixed factors, such as capital, only determine the capacity of the individual plant and do not appear as variables in the short-run function. This means that the only way to achieve the required emission level is to reduce production. As we study the process-oriented, capital-intensive manufacturing industry, we find it reasonable to employ this *putty-clay* assumption. In addition, we assume that the permits given by the environmental authorities specify the total emission level for each pollutant, and the firms have to fulfill all the emission levels in the permits.

The assumption that production reductions are the only way to reduce emissions in the short run may not be realistic for pollutants such as sulfur oxide (SO_2) that can be abated easily with end-of-pipe investments. However, the inefficient firms are obliged to reduce not only emissions of pollutants such as acids, which can be abated through end-of-pipe investments, but also emissions of pollutants that are very costly or impossible to abate, such as carbon dioxide. For the latter type of pollutants, reductions in production seem the only practicable way to reduce emissions in the short run.

Given the above assumptions, the costs for the plants to achieve emission levels in accordance with the frontier technology can be calculated as the loss in the plants' net surplus exclusive of capital costs—that is, income from production minus short-run costs. We assume a fully flexible labor market and disregard transitional unemployment costs.

4.3 Data

We base our study on an extensive database, the Database for Disaggregated Environmental and Economic Data (DEED),[2] which covers the largest and potentially most polluting Norwegian plants. On the international level, similar data are scarce.[3]

The data set consists of an unbalanced panel for each of the following industries: pulp and paper, aluminum, ferro alloys, and inorganic chemicals.[4] Table 1 shows the size of our samples compared with the total industry. The plants in our samples cover a substantial proportion of the production and inputs of the actual industry. This claim mostly holds for emissions as well. The missing observations are the result of a lack of or uncertain emission data. The data set covers about 40 different plants in all four industries each year. In this paper, we use data for the period 1996–2000 to construct the frontier, and data for 2000, the latest data available, to measure the distance to the frontier.

Plant-specific output, intermediate inputs, and capital are measured in current values, and deflated to 2000 prices by industry-specific output and input price indexes and price

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[2] See Larsson and Telle (2003) for further documentation.

[3] For information on time series data in the EU, see Berkhout *et al*. (2001). The Environmental Protection Agency (EPA) provides data for the United States (see the toxic release inventory).

[4] NACE codes 21.1, 27.421, 27.35, and 24.13, respectively.

indexes for investments, respectively. Capital is estimated using a combination of the insurance values of buildings and machinery and the accumulation of net investments. Labor is the number of working hours in the plant. In addition, the emissions of two different pollutants are included. *Greenhouse gases* are an aggregate of CO_2, methane (CH_4) and nitrous oxide (N_2O), measured in thousands of tonnes of CO_2-equivalents. *Acidifying substances* are an aggregate of SO_2, nitrogen oxides (NO_x), and ammonium (NH_3), measured in tonnes weighed by the acidifying component (H^+). We perform the DEA analysis using OnFront 2.2 (Färe and Grosskopf 2000).

Table 1 The coverage of our sampled plants compared with the respective industries in 2000.

Industry		Plants	Production (million euro)	Labor (1000 h)	Energy (million euro)
Pulp and paper	Industry	39	1965	9641	177
	Sample	17	1357	7052	133
	Coverage	0.44	0,69	0.73	0.75
Aluminium	Industry	12	2474	8311	262
	Sample	7	2445	7923	2621
	Coverage	0.58	0.99	0.95	1.00
Ferro alloy	Industry	19	6057	3576	106
	Sample	11	5947	3507	106
	Coverage	0.58	0.98	0.98	1.00
Inorganic chemistry	Industry	29	747	3607	91
	Sample	10	733	2624	68
	Coverage	0.34	0.60	0.72	0.74

Source: Statistics Norway (2003). Exchange rate (1 euro=8.1 NOK) from Bank of Norway (2004)

4.4 Potential emissions reductions

4.4.1 Technical efficiency

Table 2 shows the calculated technical efficiencies, as defined in equation (4.3). The efficiencies vary across industries, and the average technical efficiency is 88%. In the aluminum industry, almost all plants operate on the frontier with an average efficiency of 99%, whereas the other three industries have an overall efficiency potential of between about 10% and 20%. In Table 3, these efficiency measures are transformed into emission reduction potentials. If all plants operated on the technically efficient frontier, greenhouse gases and acids would be reduced by 11% and 16%, respectively. The highest potential for reductions is for acids in the ferro alloy industry.

4.4.2 Environmental efficiency

The environmental efficiency measure calculates the distance to the frontier in the environmental dimension, as defined in equation (4.5). The environmentally detrimental inputs include both greenhouse gases and acidifying substances. Table 2 reveals substantial environmental inefficiencies. On average, for all industries, the efficiency score is 60%. This shows that there is a large scope for emission reductions. Table 3 summarizes the potential emission reductions if all plants operated on the frontier. If all plants reduced their emissions in accordance with best practice environmental techniques, emissions of greenhouse gases and acids would fall, on average, by 36% and 54%, respectively. Again, the potential for emission reductions is smallest in the aluminum industry. For the other industries, the potential is vast, with reductions of up to 83% possible for acid equivalents in the ferro alloy industry.

To sum up, our analysis shows that there is substantial potential for emission reductions if all plants are instructed to implement the emission levels that accord with their industry's best-applied technology. Hence, our results may be taken to indicate that we can expect reductions in emissions as the BAT requirement of the IPPC directive is implemented in Norway. However, such an application of the IPPC directive might turn out to be very costly. In the next section, we present estimates of such costs.

Table 2 Average technical and environmental efficiencies, in percentages.

	All industries	Pulp and paper	Inorganic chemistry	Ferro alloy	Primary aluminum
Technical efficiency	88	88	90	81	99
Environmental efficiency	60	58	62	41	92

Table 3 Average emission reductions if all plants were technically or environmentally efficient, in percentages. Figures are weighted with emissions.

		All industries	Pulp and paper	Inorganic chemistry	Ferro alloy	Primary aluminum
Technical efficiency	Greenhouse gases	11	12	12	20	2
	Acids	16	6	11	25	1
Environmental efficiency	Greenhouse gases	36	37	42	64	10
	Acids	54	20	39	83	5

4.5 The costs of emission reductions

The results presented in Table 4 show significant variations in costs across industries. When the emission standard is based on *technically efficient emissions*, the average unit costs for the plants of reducing greenhouse gases range from eight euro per tonne for ferro alloy to 90 euro per tonne for aluminum. For acids, the difference is significantly larger. For aluminum, almost all plants are technically efficient and there is little potential for emission reductions for any of the pollutants. Therefore, abatement of these emissions would be relatively costly.

When the emission standard is based on *environmentally efficient emissions*, the average unit costs for the plants of reducing emissions are higher than in the case of technically efficient emissions for both greenhouse gases and acids. Again, there is great variation in the average costs across industries. Once more, emission reductions appear especially costly in the aluminum industry.

Table 4: Average abatement costs per unit of pollutant. Profit weighted with emissions, in euro

		All industries	Pulp and paper	Inorganic chemistry	Ferro alloy	Primary aluminum
Technical efficiency	Greenhouse gases euro/tonne	17	70	12	8	90
	Acids euro/kg	99	660	58	45	5740
Environmental efficiency	Greenhouse gases euro/tonne	23	121	14	9	90
	Acids euro/kg	140	1192	66	49	5823

Abatement costs differ not only between industries, but also between plants. In Figures 2–5, we have constructed the marginal abatement cost curve for society by arranging our calculated costs per unit of emissions for each plant in ascending order. In the same graphs, we have plotted the accumulated costs for the society. We represent the costs as the reduction of the short-run net surplus.

Figure 2. **Social abatement costs for accumulated greenhouse gases and greenhouse gas emissions per tonne, measured with technical efficiency**

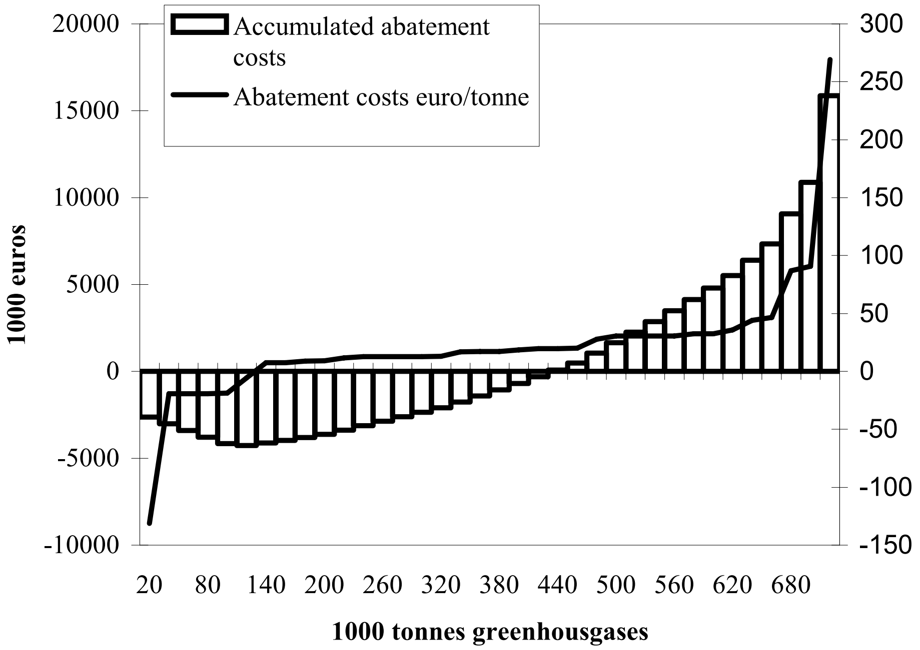


Figure 3. **Social abatement costs for accumulated greenhouse gases and greenhouse gas emissions per tonne, measured with environmental efficiency**

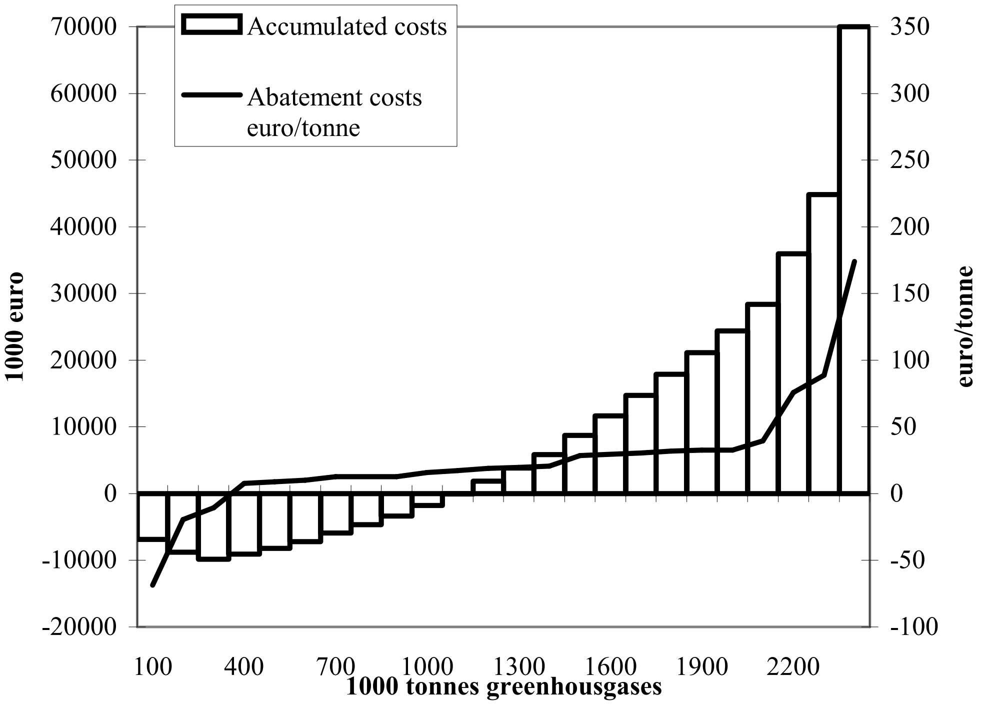


Figure 4. **Social abatement costs for accumulated acid equivalents and acid emissions per tonne, measured with technical efficiency**

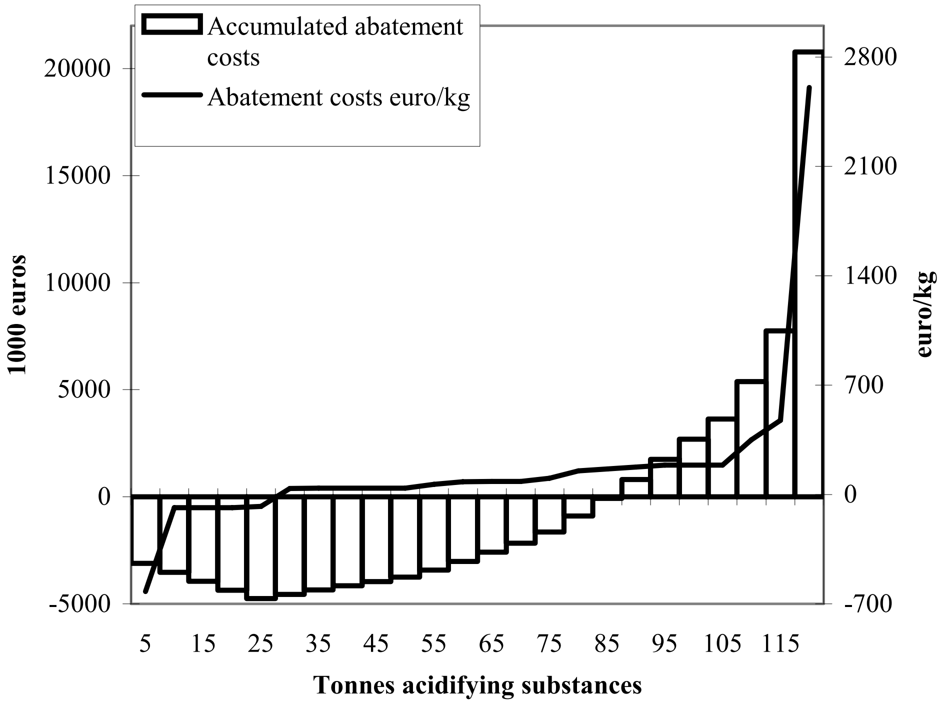
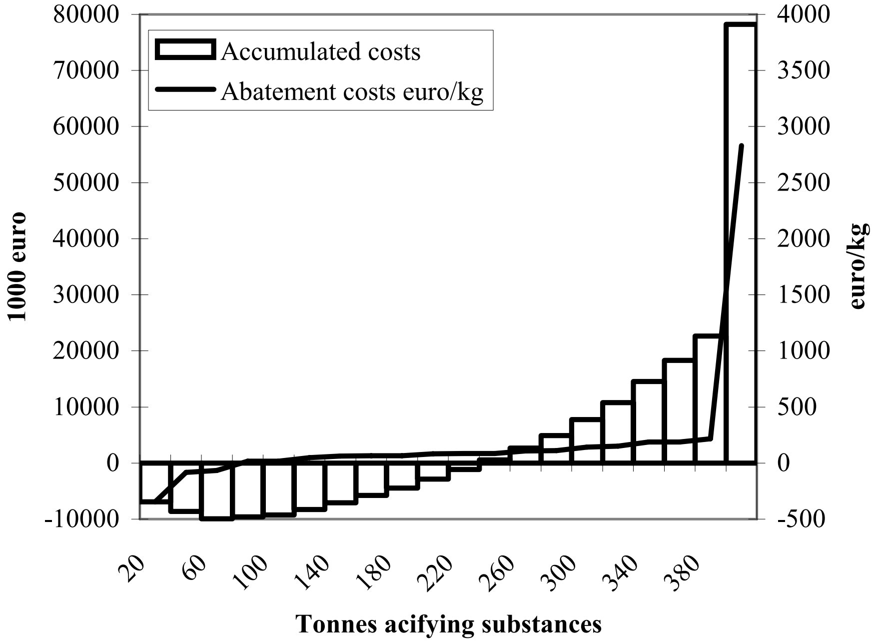


Figure 5. **Social abatement costs for accumulated acid equivalents and acid emissions per tonne, measured with environmental efficiency**



First, for the *technical efficiency measure*, if all plants adhere to emission caps that correspond to the emissions of the efficient plants, the potential reduction is about 718 000 tonnes of greenhouse gases, or about 11% of the total emissions of greenhouse gases from these industry branches. The abatement costs vary from negative values (when there are benefits for both the firm and society) to 1 200 euro per tonne of emitted greenhouse gases. For acids, the potential reduction is 16% of total emissions and the average cost of such a reduction is almost 100 euro/kg.

In the short run, some plants make losses. If these losses are permanent, the plants will eventually have to close down. However, the losses could be temporary; for example, losses resulting from market failures. In our analysis, we have analyzed only one year, so we cannot investigate the reason for the losses in these plants. If all the plants with losses in the pulp and paper and inorganic chemical industry closed down, there would be a 4% reduction of the total emissions of greenhouse gases from these industries. This equals the emission reduction that would occur if all plants were emitting the same amount as the technically efficient plants. When we sum up the costs for society in an accumulated social cost curve, we find that up to 54% of the potential reduction in emissions of greenhouse gases, or 6% of the total emissions of greenhouse gases, could be achieved at zero social cost. However, to reduce emissions the extra 20% necessary to reach the level of the frontier is very costly. For greenhouse gases, the cost of abating the last percentage of the potential reduction is about 1 200 euro per tonne.

The abatement cost profile for acids is similar to the one for greenhouse gases, with a wide range between the plants with the lowest and those with the highest abatement costs. A reduction of 9% of total emissions could be achieved if the plants making economic losses were closed down. 70% of the potential reduction in emissions of acids, or 11% of the total emission of acids from these industry branches, could be abated without incurring social costs. However, the cost of abating the last percentage of the potential reduction in order to reach the frontier is almost 16 000 euro/kg.

Second, for the environmental efficiency measure, if all plants adhere to emission caps that correspond to the emissions of the efficient plants, the potential reduction is about 2.4 million tonnes for greenhouse gases, or about 36% of the total emission of greenhouse gases. Again, the calculations show that about 45% of the potential, or 16% of the total emissions, could be abated without any costs to society. The emissions of acids could be reduced by 44% with nearly half of this reduction achievable without social costs.

To sum up, the costs of achieving emission standards according to the BAT requirements differ significantly across industries and plants. Large emission reductions can be achieved without incurring social costs. However, the costs of having all plants emit in accordance with their industry's best practice seem to be very high, at least for the last units abated. Our analysis indicates that shifting from a system that focuses on cost efficiency to one based on the BAT principle involves substantial costs.

4.6 Concluding discussion

The IPPC directive states that new establishments need permits to operate. The directive requires the emission permits to accord with each industry's BAT, thus achieving the highest practicable level of protection for the environment. In addition, this directive states that existing establishments must operate in accordance with the requirements by no later than 2007. Norway began to implement the directive via its environmental regulations and policies in 1999 (Ot. Prp. 59 1998–99, Ministry of Environment 2002).

In this paper, we have investigated how the implementation of the IPPC directive may influence emissions and costs in the most energy-intensive industries in Norway. We have applied two different interpretations of BAT by defining BAT, first, with respect to all factor input dimensions, and, second, with respect to environmental technologies only.

The results show that, if all plants implement their industry's best practice technology, overall emissions of greenhouse gases and acids will decline. The most conservative estimate indicates an average reduction of 11–16% compared with the 2000 emission level. However, emissions of acids could be cut by about 54% if environmental techniques already in practice within each plant's sub-industry were implemented in all plants. The aluminum industry seems to be the most efficient of the Norwegian industries, with little scope for emission reductions, whereas the ferro alloy industry has the greatest potential for emission reductions. Furthermore, the costs of reducing emissions are highly heterogeneous. Some plants face very low abatement costs in reducing emissions. For others, emission reductions may even be profitable. These types of plants have net short-run losses. On the other hand, for plants at the other end of the abatement curve, it may be very costly to reduce emissions. Hence, making the implementation of BAT compulsory for all plants at a given point in time may inflict considerable costs.

We have considered *technical* and *environmental* efficiency, with only limited concern for economic efficiency. Mostly for emissions of acids, and certainly for emissions of greenhouse gases, the environmental costs caused by emissions are similar across all plants. Hence, to achieve cost efficiency marginal abatement costs should be similar across plants. A BAT principle like that of the IPPC, which requires plants to meet the same emission targets regardless of costs, will therefore not be cost efficient and a given level of emissions could therefore be achieved at lower costs. Such arguments of cost efficiency were one of the main reasons why a strict BAT principle was explicitely rejected when the Norwegian anti-pollution law was launched in 1981 (Bugge, 1999). Although the IPCC includes some modifications to reduce economic inefficiency that follows from the BAT-principle, our results indicate that the implementation of the IPCC directive's BAT principle does not result in similar abatement costs across all sampled plants. This observation might be taken to indicate that the overall reduction of emission could be achieved at lower overall costs or, alternatively, that emissions could be further reduced at the same overall costs.

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Chapter 5

Testing the Multiproduct Hypothesis on Norwegian Primary Aluminium Industry Plants.

Abstract:

Although most of the production activities involve multiple outputs, econometric models of production or cost functions normally involve only one single homogeneous output. The aim of this paper is to test the hypothesis that a multiproduct specification for Norwegian primary aluminium production is superior to a model with a single homogeneous product. To do this, we use a Multiproduct Symmetric Generalized McFadden (MSGM) cost function. This functional form is globally concave and flexible in the sense that it provides a second order differentiable approximation of any arbitrary cost function, which is twice continuously differentiable and linear homogeneous in input prices. In an empirical application on a panel data from ten Norwegian primary aluminium plants, we find support for our hypothesis. We present estimates on price elasticities, returns to scale and scope, technical change and product specific demand elasticities. Our results indicate economies of scope, i.e. it is more profitable to produce more than one output, and provide evidence for the sensitivity of the factor demands when the product-mix changes.

Keywords: Cost function, Multiple output, Global concavity, Returns to scale, Economies of scope, Price elasticity, Output elasticity, Panel data, Primary aluminium industry.

5.1 Introduction

Although the production activities of most firms are associated with multiple outputs, most of the econometric models of production or cost functions involve only one single homogeneous output. The single output assumption has traditionally been the case in production function analyses of aluminium production (see for example Lindquist 1995), event though aluminium plants may produce a whole range of different products. The objective of this paper is to test the hypothesis that a multiproduct specification for Norwegian primary aluminium production is superior to a model with a single homogeneous product. If that hypothesis is not rejected (which is the case here) we proceed with estimation of scale and scope economies. Because of the rather few industry studies based on multiple output production functions our knowledge about the existence of economies of scope is quite limited.

When several outputs are produced from a single production process, it is a technological phenomenon of intrinsic jointness. There are a variety of reasons for this, for example economising of some shareable inputs or economies of scope, jointness due to output interactions and uncertainty on the demand side. Economies of scope may be due to fixed inputs, which are utilised in the production of all outputs. This seems to be the case in the aluminium industry.

The use of a single output model is based on the assumption that the transformation function is separable in outputs and inputs, but such a strong *a priori* assumption may lead to inaccurate empirical conclusions. The cost function framework, described below, enables us to actually test for the difference between a single output and a multi-output approach.

One of the most problematic aspects of estimating cost functions is to maintain the conditions implied by the economic theory. Diewert (1971) defined a flexible functional form for a cost function as one that could provide a second order differentiable approximation to an arbitrary twice continuously differentiable cost function. His functional form satisfies the property of linear homogeneity in prices, at any point in an admissible price domain. The most popular functional forms in empirical studies are the translog (Christensen, Jorgensen and Lau, 1971) and the Generalized Leontief (Diewert, 1971). One problem with these functional forms, however, is that the conditions required by the economic theory may not be fulfilled in applied analyses. Violations of the monotonicity and concavity conditions are common in empirical studies, although it is often possible to avoid these problems by imposing restrictions on the functional forms. However, this leads to a significant loss of flexibility. Diewert and Wales (1987) proposed a flexible functional form in which the curvature conditions could be tested, *the Symmetric Generalized McFadden cost function* (SGM). An advantage of the SGM over other flexible functions is that the curvature conditions required by the economic theory can be easily imposed on the parameters of the cost function without limiting the flexibility of the model.

The purpose of this paper is to analyse the Norwegian primary aluminium industry with the use of the Multiproduct Symmetric Generalized McFadden (MSGM) cost function, developed by Kumbhakar (1994). This functional form is an extension of the single product SGM cost function, introduced by Diewert and Wales (1987). Our model is also modified to include capital as a quasi-fixed input, in the same way as in Kumbhakar (1989). A similar approach has also been used by Peeters and Surry (2000), but on time series. The MSGM model allows us to independently test important economic relationships that characterise the production processes. This includes testing whether a single or a multiproduct functional form is the most appropriate to use, thereby providing measures of economies of scale and scope. The model also allows us to test and impose the required concavity condition globally, if the unconstrained model does not meet them. For these reasons, this flexible form is attractive for analyses of plant level production processes.

The paper is organised as follows: In the next section, a theoretical description of the MSGM model is provided. In Section 3, a description of the data is presented. Section 4 considers an application of the model in order to test for a single versus a multiproduct form for the cost function. Furthermore, we estimate the appropriate elasticities, the overall returns to scale, the economies of scope and the product-specific demand elasticities for ten Norwegian primary aluminium plants, each plant producing more than one commodity. In the last section, we summarise and discuss our results.

5.2 The multiproduct symmetric generalized McFadden cost function

5.2.1 *The basic model*

Assume that the production technology of a firm is represented by $y=F(v, k, t)$, where y is a (mx1) vector of outputs, v is a (nx1) vector of inputs, and k represents the quasi-fixed variable capital in period t. Since capital is assumed to be quasi-fixed, this function can, in contrast to the models in the previous chapter, be regarded as a representation of the short run production possibilities. Under certain regularity conditions, the true cost function in period t, which is the dual to the production function, can be written as $C^*(y, w, k, t)$, given a positive input-price vector w. Thus, $C^*(y, w, k, t)$ is the solution to the following problem:

$$C^*(y,w,k,t) = \begin{array}{l} \min(w'v) \\ s.t.\, y = F(v,k,t) \end{array} \tag{5.1}$$

The cost function $C^*(\cdot)$ will satisfy various conditions depending on which restrictions we impose on the production function $F(\cdot)$. We assume that the function is continuous and twice differentiable with respect to its arguments. Since function $C^*(\cdot)$ is unknown, our problem is to find an approximation for the cost function, $C(\cdot)$, which has similar characteristics as the general form of the cost function. In order to apply the multiproduct symmetric generalized McFadden (MSGM) framework, we require that the cost function is linearly homogeneous and concave in w.

Consider the following cost function, $C(\cdot)$, as an approximation of the true function $C^*(\cdot)$:

$$\begin{aligned} C(w,y,k,t) = \quad & g(w)\left\{\sum_{r=1}^{m}\beta_r y_r\right\} + \sum_{i=1}^{n}\alpha_i w_i + \sum_{i=1}^{n}\alpha_{it} w_i t + \sum_{i=1}^{n}\alpha_{ik} w_i k + \sum_{i=1}^{n}\alpha_{ii} w_i \left\{\sum_{r=1}^{m}\beta_r y_r\right\} + \\ & \sum_{i=1}^{n}\beta_{ik} w_i k\left\{\sum_{r=1}^{m}\beta_r y_r\right\} + \sum_{i=1}^{n}\beta_{it} w_i t\left\{\sum_{r=1}^{m}\beta_r y_r\right\} + \sum_{i=1}^{n}\sum_{r=1}^{m}\sum_{s=1}^{m}\beta_{irs} w_i y_r y_s + \\ & \left\{\sum_{i=1}^{n}\alpha_{itt} w_i t^2\right\}\left\{\sum_{r=1}^{m}\beta_r y_r\right\} + \left\{\sum_{i=1}^{n}\alpha_{ikk} w_i k^2\right\}\left\{\sum_{r=1}^{m}\beta_r y_r\right\} \end{aligned} \tag{5.2}$$

where n is the number of variable inputs and m is the number of outputs. The $g(w)$ function is defined as:

$$g(w)= w'Sw/2\theta'w\,, \tag{5.3}$$

with S being an n x n symmetric negative semi-definite matrix of parameters estimated in the model, with $s_{ij}=s_{ji.}$ θ is a vector of predetermined non-negative constants and not all zero. The following restrictions are made: One of the parameters in β_r $(r=1...m)$ is normalised to unity. We also need some restrictions on the elements of S. These are: $S'w^* = 0$ for some w^*, where $w_i > 0$, for all i. For example, if w^* is chosen to be a unit vector (the normalising point) and $S'w^* = 0$, then $\sum_{j=1}^{n} s_{ij} = 0$ for all i. If the estimated S matrix is negative semi-definite, then $C(\cdot)$ defined in (5.2) and (5.3) will be globally concave in input prices w.

On the other hand, even if the estimated S matrix is not negative semi-definite, it can be imposed on the cost function without destroying its flexibility by applying a correction method. To do this, we follow the technique used by Wiley, Smith and Brambel (1973). We redefine S as $\tilde{S}$ = -Γ Γ', where Γ is an N-1 by N-1 lower triangular matrix:

$$\begin{aligned} &\tilde{S} = -\Gamma\Gamma', \qquad \Gamma = [\gamma_{ij}] \qquad (i, j = 1,....,n-1) \\ &\gamma_{ij} = 0 \quad \text{for}\, i > j \end{aligned} \tag{5.4}$$

Using Shephard's lemma, the conditional demand functions are:

$$\begin{aligned} v_i = \frac{\partial C}{\partial w_i} = &\left[\sum_{r=1}^{m} \beta_r y_r\right] \left[\frac{\sum_{j=1}^{n} s_{ij} w_j}{\sum_{j=1}^{n} \theta_j w_j} - \frac{\theta_i}{2} \frac{\sum_{j=1}^{n} s_{ij} w_i w_j}{\left(\sum_{j=1}^{n} \theta_j w_j\right)^2} \right] + \alpha_i + \alpha_{it} t + \alpha_{ik} k + \\ &\alpha_{ii}\left[\sum_{r=1}^{m} \beta_r y_r\right] + \beta_{ik} k \left[\sum_{r=1}^{m} \beta_r y_r\right] + \beta_{it} t \left[\sum_{r=1}^{m} \beta_r y_r\right] + \\ &\sum_{r=1}^{m} \sum_{s=1}^{m} \beta_{irs} y_r y_s + \alpha_{ikk} k^2 \left[\sum_{r=1}^{m} \beta_r y_r\right] + \alpha_{itt} t^2 \left[\sum_{r=1}^{m} \beta_r y_r\right] \end{aligned} \tag{5.5}$$

5.2.2 *Testing of hypotheses*

As Kumbhakar (1994) points out, the MSGM cost function defined above is general enough to include some interesting cases. The MSGM cost function represents the unrestricted model, and we can test the multiproduct hypothesis by restricting the product specific parameters β_r and β_{irs}.

In our data, we have divided the output into three product categories: (I) primary aluminium plus products directly connected to the production of this good, (II) alloys and castings, and (III) products made of aluminium. Further details on the data are given in the next section. Our model enables us to test different aggregation levels. First, we test the hypothesis that the production can be characterised by a single product SGM cost function. For this we apply the following restrictions on the parameters of the MSGM cost function:

$$\beta_r = 1 \text{ for all r,} \qquad \text{and}$$

$$\beta_{irs} = \text{constant for all r and s.} \tag{5.6}$$

Second, we test the hypothesis that output consists of two product groups. We have chosen to test the aggregation of category (II) and (III). This implies that the following restrictions on the parameters are made:

$$\beta_2 = \beta_3 = 1, \qquad \text{and}$$

$$\beta_{i2s} = \beta_{i3s} \text{ for all s.} \tag{5.6'}$$

5.2.3 *Economies of scale and scope*

The traditional concept of scale economies for a single product firm refers to the behaviour of total costs as output expands. Formally, economies of scale are measured by the elasticity of scale of the production function. In the case of price-taking behaviour the elasticity of scale is equal to the inverse of the elasticity of cost with respect to output, i.e. the ratio between marginal cost and average cost. Economies of scale are present if the scale elasticity exceeds one, i.e. when the average cost is larger than the marginal cost:

$$RTS = \frac{AC}{MC} = \frac{C(y)}{y\,dC/dy} > 1 \tag{5.7}$$

The multiproduct generalisation of this concept is the overall returns to scale (see for example Baumol et al., 1982). It is defined as the elasticity of output with respect to cost measured along a ray in the output space:

$$ORTS = \frac{C(\cdot)}{\sum_i y_i MC_i} \tag{5.8}$$

where MC_i is the marginal cost of product *i.* ORTS measures the responsiveness of costs to a scale change, while the composition of output remains fixed. It can be interpreted as the ratio of total costs to revenue that would be generated from following the marginal cost-pricing rule.

A “shortcoming” of the economies of scale assumption is that the product mix is unlikely to stay constant when total output increases. A measure of the effect of a change in the output mix is the estimate of economies of scope, suggested by Baumol et al. (1982), and Bailey and Friedlander (1982), which is defined as:

$$ESCP = \frac{\sum_i C(0,...,y_i,..,0)}{C(y)} \tag{5.9}$$

If economies of scope are present, for a given output mix, a firm that produces all the outputs will have lower costs than the sum of costs for single output firms.

The own and cross-price elasticities are defined as:

$$\varepsilon_{ij}^{sr} = \frac{\partial v_i}{\partial w_j}\frac{w_j}{v_i} \tag{5.10}$$

The last elasticity to be defined is the elasticity of input demand with respect to output:

$$\eta_i^r = \frac{\partial v_i}{\partial y_r} \frac{y_r}{v_i} \tag{3.11}$$

5.2.4 Technical change and factor baised technical change

Several measures of technical change can be derived out of the model. Usually, the measure overall technical change (TC) is calculated as cost reduction over time:

$$TC = -\frac{1}{C}\frac{\partial C}{\partial t} = -\left[\sum_{i=1}^{n}\alpha_{it}w_i + \sum_{i=1}^{n}\beta_{it}w_i\sum_{r=1}^{m}\beta_r y_r + 2t\sum_{i=1}^{n}\alpha_{itt}w_i\sum_{r=1}^{m}\beta_r y_r\right]\frac{1}{C} \tag{5.12}$$

If TC is positive then technical change has been cost reducing over time.

The rate of technical change can also be analysed for each factor input. The factor specific technical change is measured as

$$TC_i = -\frac{\partial v_i}{\partial t}\frac{1}{v_i} = -\left[\alpha_{it} + \beta_{it}\sum_{r=1}^{m}\beta_r y_r + 2ta_{itt}\sum\beta_r y_r\right]\frac{1}{v_i} \tag{5.13}$$

If TC_i is positive there has been factor *i* saving technical progress. To calculate if factor saving technical progress has been greater than the over all technical change, we define factor based technical change as the change of cost share s_i:

$$FTC_i = \frac{\partial s_i}{\partial t} = \frac{\partial \ln p_i x_i - \partial \ln C}{\partial t} = TC - TC_i \tag{5.14}$$

If FTC_i is negative, the factor *i* saving technical progress have been larger (measured in percent) than the total saving technical progress. However, first we can test if there has been factor biased technical change or if the technical change has been neutral by restricting some variables. If the following conditions hold in (5.2) and (5.5) the technical change has been factor neutral:

$$\begin{aligned} \alpha_{it} &= \alpha_t \\ \beta_{it} &= \beta_t \\ \alpha_{itt} &= \alpha_{tt} \end{aligned} \tag{5.15}$$

These conditions can be tested with a log-likelihood test.

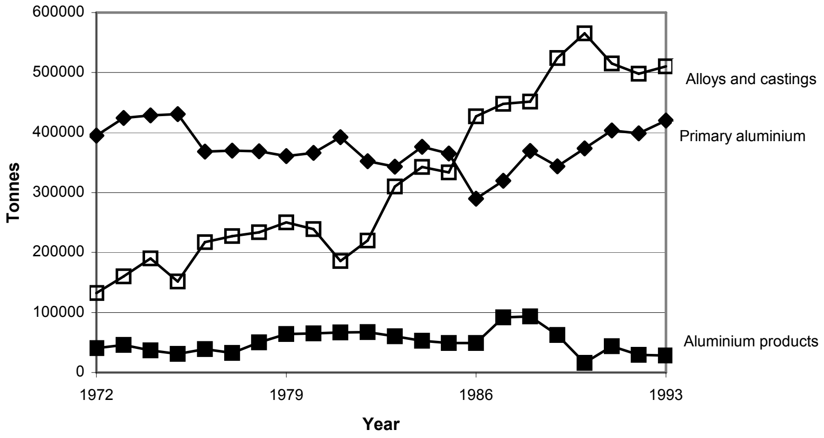
5.3 Data description

The empirical results are based on a panel of annual observations from ten Norwegian primary aluminium plants. It is an unbalanced panel that covers the period 1972 to 1993. Plant specific data for the production volume and value are not available after 1993. Seven plants are observed for the whole period, while the other three are observed for three to eleven years. This data set is an extension of the data used in Chapter 3 in this thesis. In total 173 observations are used.

Even though the primary aluminium industry in Norway is one of the most homogeneous industries, the ten aluminium plants in the industry produce in fact up to ten different products. Each product demands different amount of inputs. For estimation purposes, we have divided the outputs into three categories; (i) primary aluminium plus products directly connected to the production of this good, (ii) aluminium alloys and aluminium castings and (iii) products made out of aluminium. All categories are measured in produced tonnes.

As we can see in Figure 1 below, primary aluminium was the main product in this branch of industry until the mid 1980s. The production has been rather stable at about 400 thousand tonnes per year. However, the strong growth in the production of alloys and castings during the 1980s made this the largest product group. The third group, comprising aluminium products, was a small and rather stable product group during the period.

Figure 1. The production of aluminium in Norway 1972-1993



The data are obtained from the Manufacturing Statistics database of Statistics Norway, supplemented to a minor extent by data from the Norwegian National Accounts. The endogenous inputs are *(L)* labour measured in (1000) hours worked, (*E*) electricity measured in kWh, (*F*) other fuels measured in kWh, and (*M*) other intermediate inputs measured in constant 1991-prices. The capital stock (K) is the most difficult factor to measure. The manufacturing statistics have only one measure of capital, the insurance value of capital. The weakness of the insurance value is that firms have had different insurance policies over time due to costs. Instead, the perpetual inventory method has been chosen, accumulating the historical investments from an initial benchmark value. To calculate a benchmark value for capital we have used the mean gross profit, i.e. the income minus the variable costs for the establishment, as an instrument variable for the user cost of capital. The capital has then been calculated as the gross profit divided by the user price of capital, defined as the investment price index multiplied by the sum of the discount rate and the depreciation rate. As discount rate we have chosen the interest rate of five-years Government bonds. The starting value (K_M) has been set as the median observation for each plant. Capital measure is the sum of two categories: a) buildings and b) machinery and equipment.

$$K_M = \frac{1}{T}\sum_{t=1}^{T}\frac{(p_t y_y - \sum_{j=,l,m,e} w_{jt} x_{jt})}{w_{Kt}} \tag{5.16}$$

$$w_{Kt}=w_{int}(\delta_t+ r_t^{*}) \tag{5.17}$$

$$w_{invt}= (w_{bt}\,\bar{k}_{bt}+ w_{mt}\,\bar{k}_{mt})/ (\,\bar{k}_{bt}+ \bar{k}_{mt}) \tag{5.18}$$

$$r_t^{*} = (1-r_t)/(1-i_t)-1, \tag{5.19}$$

$$\delta_t = (\delta_b\,\bar{k}_{bt}+ \delta_m\,\bar{k}_{mt})/ (\,\bar{k}_{bt}+ \bar{k}_{mt}) \tag{5.20}$$

$$\begin{aligned}
K_t &= (1-\delta_t)^{t-M} K_M - \sum_{\tau=1}^{t}\left((1-\delta_{mt})^{\tau-M} inv_{b\tau} + (1-\delta_{mt})^{\tau-M} inv_{m\tau}\right) \qquad \forall t < M \\
K_t &= (1-\delta_t)^{t-M} K_M + \sum_{\tau=M+1}^{t}\left((1-\delta_{mt})^{\tau-M} inv_{b\tau} + (1-\delta_{mt})^{\tau-M} inv_{m\tau}\right) \qquad \forall t > M
\end{aligned} \tag{5.21}$$

where:

inv_t = gross investments time t.

w_{invt} = weighted price index for investment goods.

w_{bt} = price index for building investments.

w_{mt} = price index for investments in machinery and equipment.

w_{kt} = user price of capital

$\bar{k}_{bt}$ = the average insurance value for buildings.

$\bar{k}_{mt}$ = the average insurance value for machinery and equipment.

r_t^{*} = the real rate of the long run interest rate.

r_t = the nominal interest rate.

i_t = inflation.

δ_b = the depreciation rate for buildings.

δ_m = the depreciation rate for machinery and equipment.

The depreciation rate for buildings is assumed to be 4 %. For machinery and equipment the depreciation rate is 8 %.

The time trend *t* is assumed to capture the nature of technical change. Statistics are summarised in Table 1. As we can see, not all the plants produce all the products. There are also large differences in size between the different plants. The smallest plants only existed for a limited time.

Table 1 Summary statistics of aluminium production in Norway 1972-1993

Variables	Mean	Std Dev	Min	Max
Costs (in 1000 kr)	2,157,310	1,569,420	27,180	6,378,100
Labour (in 1000 hours)	1,262,880	722,270	4,550	3,004,249
Electricity (MWh)	1,638,250	890,040	61	3,544,658
Fuel (MWh)	79,180	6,900	74	307,282
Material (1991 year prices)	519,460	300,040	1,477	1,238,870
Capital (1991 year prices)	1,261,230	922,450	481	5,340,395
Prime aluminium (tonnes)	47,740	39,120	0	146,390
Alloys and castings (tonnes)	41,340	15,340	0	171,760
Aluminium products (tonnes)	6,450	15,340	0	60,090
Wages (1991=1)	0.52	0.29	0.13	1.17
Price of electricity (1991=1)	0.57	0.31	0.12	1.67
Price of fuel (1991=1)	0.61	0.32	0.07	1.28
Price of material (1991=1)	0.73	0.24	0.29	1.07

Figure 2 Variable input coefficients in Norwegian aluminium production 1972-1993

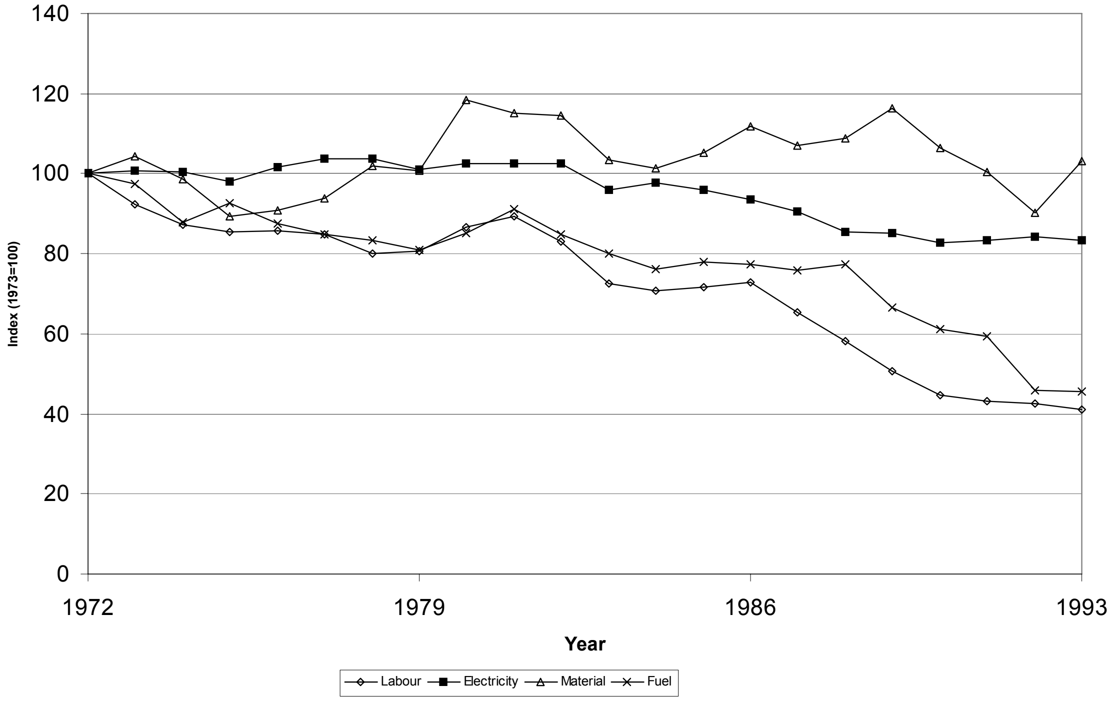


Figure 2 shows the variable input coefficients. The material input coefficient was relatively stable during the years, while the use of labour and fuel showed a strongly diminishing trend. The labour input per tonne produced was reduced by more than 50 per cent during the observation period, from 22 to 9 hours per produced tonne. The use of electricity also declined somewhat, but not as much as the use of labour and fuel. In the beginning of the period the input coefficient of electricity was stable. However, during the last part of the period a decline is observed.

5.4 The estimation procedure and empirical results

Our MSGM cost function (5.2), presented in Section 5.2 in the most general form, is applied with four conditional input demand functions (5.5) derived by Shephard's lemma and with three product groups.

Since we have panel data, one may expect autocorrelated disturbances due to the existence of unobserved characteristics over time. We therefore include an autoregressive AR(1) coefficient ρ_i, specified for each equation. We also use a dummy coefficient μ_p for each plant in order to capture the heterogeneity in the cost function. The error term of the cost function is then specified as:

$$u_{ipt} = \rho_i \, u_{ipt-1} + \mu_p + \eta_{ipt} \tag{5.22}$$

where $p = 1, \ldots, 10$, and $t = 1, \ldots, 22$ are indices for plant and time (year), respectively. μ_p captures plant specific effects, which we assume to be invariant over time. Plant specific effects are assumed to be fixed. The error term η_{ipt} is white noise and we assume further that it has a probability distribution that is invariant over time. We have corrected and tested the models for negative semi-definiteness, according to the method explained in Section 3.2.1.

With the above modifications, we have estimated the system by using the full information maximum likelihood regression technique (FIML). Appendix A1 reports the parameter estimates of all models. In Table 2 we summarise the values for the unrestricted three product-groups specification, as well as the restricted specifications defined in (5.6) and (5.6'). We have tested the restricted models against the unrestricted model with a likelihood ratio test. Since the data set only consists of 10 plants, we apply a small-sample corrected likelihood ratio test defined as:

$$\chi^2(r) = -\frac{2(T-k-1+\frac{r}{2})}{T}(L_R - L_U)\,, \tag{5.23}$$

where L_R and L_U are the log-likelihood values for the restricted and the unrestricted model, respectively. T is the sample size, k the number of parameters in the unrestricted model, and r is the number of restrictions (see Mizon, 1977).

Table 2 Summary statistics from the estimation of the models

Model	Three products	Two products	Single product
Maximum likelihood-value	1239.41	1215.16	1196.92
Test statistic		33.71	57.48
No. of restrictions		13	22
R^2_c-adj	0.992	0.993	0.993
R^2_l-adj	0.969	0.967	0.965
R^2_e-adj	0.988	0.988	0.987
R^2_f-adj	0.959		
R^2_m-adj	0.923	0.928	0.923
ρ_c	-0.897	-0.93	-0.92
ρ_l	-0.859	-0.93	-0.93
ρ_e	-0.786	-0.83	-0.82
ρ_f	-0.946	-0.92	-0.92
ρ_m	-0.808	-0.71	-0.68

The likelihood ratio tests reject at the 1 % level the restricted two-product model and the single product form in favour of the more general multiproduct specification (the critical values are 27.7 and 40.3, respectively). The goodness of fit is high, with all adjusted R^2 over 0.92. The ρ-values are negative and high, but presumably these corrections will avoid autocorrelations in the estimates. There is a trade-off between autocorrelation and the loss in the explanatory power of the system.

In order to test whether there is still autocorrelation in the system after adjusting with the ρ-values, we have used the Godfrey Lagrange multiplier test (Godfrey, 1978a and 1978b). According to the test statistics, the null-hypothesis of no autocorrelation cannot be rejected at the five per cent level, except for the cost equation in the single product model (see Table 3).

Table 3 Autocorrelation test

Equation	3 Products	2 Products	1 Product
Cost	2.420 (0.120)	2.876 (0.09)	4.651 (0.03)
Labour	1.842 (0.175)	0.666 (0.41)	0.949 (0.33)
Electricity	0.226 (0.635)	0.067 (0.80)	0.008 (0.93)
Fuel	0.181 (0.671)	0.001 (0.97)	0.009 (0.92)
Material	1.145 (0.284)	0.210 (0.65)	0.207 (0.65)

Probability for autocorrelation in parentheses

Next, we examine several economically relevant characteristics. We begin with the multiproduct overall returns to scale (ORTS), defined in (5.8). The overall returns to scale (ORTS) seem to be increasing over time, see Figure A1 in the appendix. However, the variations in the estimates are very high, so no definitive conclusions can be drawn from these results (see Table 4). Even though the primary aluminium industry is characterised by large-scale production, the estimates of the returns to scale are remarkably high. The variation may be a result of the characteristics of the data set, where some small units are not observed during the entire period.

Table 4 Estimates of economies of scale and scope, 1991

Elasticities	3 goods		2 goods		1 good	
	Value	Std. dev.	Value	Std. dev.	Value	Std. dev.
ORTS	2.32	2.44	2.55	2.58	1.86	0.24
ESCP	2.09	0.26	2.55	0.16	-	-

If economies of scope are present for a given output mix, a firm producing all the outputs will face lower costs than the sum of costs for firms producing only one of the products. In most of the studies of the primary aluminium industry, the assumption is that only one homogeneous product is produced, but in this study the hypothesis of a single homogeneous output is rejected. The results of our model indicate significant and stable economies of scope for the firms over time. The standard deviation in Table 4 shows that the estimates of ESCP are more significant than the estimates of ORTS. A value of economies of scope around 2 during the whole period means that the cost of producing only one product is twice as high as producing all the products. The precise estimates of the scope elasticity in contrast to the large variability in the estimation of the scale elasticity indicate that it is very important to apply a multiproduct estimation framework that takes the economies of scope into account.

Next we test the non-neutral technical change conditions stated in (5.15) Table 5 shows the likelihood value for the model with neutral technical change against the unrestricted model. The unrestricted model with factor specific technical change cannot be rejected at any level of significance.

Table 5 Test of neutral technical change, 1991

Model	Unrestricted	Restricted model
Maximum likelihood value	1239.41	1203.79
Test statistics		35.40
No. of restrictions		9

Concerning technical change, Table A1 shows that the estimates of the time parameters are not significant, except for labour. However, as reported in Table 6, our estimates on overall technical change defined in (5.12), has a significant positive estimate 2.4 percent annual growth. In our estimates of factor specific technical change in labour saving

Thus, technical change is dominated by labour saving technical progress. However the statistical significance of factor based technical growth, as defined in 3.15, is weak.

Table 6 Estimates of technical progress, 1991

Elasticities	3 goods		2 goods		1 good	
	Value	Std. dev.	Value	Std. dev.	Value	Std. dev.
TC	0.024	0.008	0.025	0.007	0.029	0.007
TCL	0.033	0.017	0.039	0.013	0.057	0.014
TCE	0.019	0.012	0.020	0.009	0.023	0.009
TCF	0.019	0.098	0.024	0.054	-0.004	0.045
TCM	0.018	0.157	0.013	0.018	0.003	0.015
FTCL	-0.028	0.016	-0.017	0.016	-0.028	0.012
FTCE	0.008	0.007	0.001	0.008	0.007	0.006
FTCF	0.024	0.075	0.012	0.048	0.033	0.046
FTCM	0.022	0.054	0.026	0.023	0.026	0.013

In Table 7, the own-price and the cross-price elasticities are reported. The price elasticities are defined as in (5.10). According to our estimates, all the own-price elasticities are negative and smaller than one in absolute values. This is in line with the findings of Lindquist (1995), who used a dynamic translog approach on the same data set for the Norwegian primary aluminium industry. Our estimates are, however, higher than those reported in Chapter 3 in this thesis. The main reason for the differences between the estimation results is that here we have applied a multiproduct framework. Moreover, in this study we have an extended data set and a different approach dealing with capital, where we used a dynamic model for capital, which also can affect the results.

Table 7 Input price elasticities, 1991

Elasticities	3 goods		2 goods		1 good	
	Value	Std. dev.	Value	Std. dev.	Value	Std. dev.
ε_{LL}	-0.33	0.08	-0.29	0.09	-0.44	0.17
ε_{EE}	-0.20	0.05	-0.19	0.05	-0.23	0.11
ε_{FF}	-0.23	0.10	-0.25	0.12	-0.20	0.14
ε_{MM}	-0.06	0.10	-0.05	0.07	-0.21	0.51
ε_{LE}	0.15	0.07	0.15	0.07	0.08	0.11
ε_{LF}	-0.05	0.03	-0.04	0.03	-0.05	0.03
ε_{LM}	0.02	0.03	0.02	0.03	0.04	0.04
ε_{EL}	0.11	0.04	0.11	0.04	0.06	0.09
ε_{EF}	0.05	0.03	0.04	0.03	0.09	0.08
ε_{EM}	-0.04	0.03	-0.02	0.03	-0.09	0.07
ε_{FL}	-1.05	0.82	-0.81	0.92	-1.10	0.99
ε_{FE}	1.79	1.26	1.62	1.47	2.12	1.97
ε_{FM}	0.04	0.49	0.09	0.52	0.76	0.93
ε_{ML}	-0.02	0.03	-0.02	0.02	-0.06	0.18
ε_{ME}	0.02	0.02	0.02	0.02	0.06	0.07
ε_{MF}	0.02	0.04	0.04	0.02	0.02	0.22

The only cross-price elasticities above one are between fuel and labour, and fuel and electricity. With respect to the differences in performance between the models, we cannot detect any significant differences in our elasticity estimates across the models. However, the standard deviations in the single output model are much higher on average. Therefore, our conclusion is that the multiproduct models give more efficient estimates.

We now discuss how an increase in product *i* will affect the demand for each input. The substitution effects caused by the shift in the product mix may explain the shift in factor use. The partial demand elasticities with respect to output are only calculated for the unrestricted model. The results are reported in Table 8. A change in the output of primary aluminium has the greatest effect on labour demand. A one per cent change in output leads to a 0.6 per cent change in labour demand.

The effect on the demand for labour of a change in output can also be seen in the development over time, as illustrated in Figure A6. Figure 2 shows that the labour input has been reduced in connection with the shift in production from primary aluminium to alloys and castings. On the other hand, the greatest impact of a change in the production of alloys and castings is on the demand for fuel and material. The graphs in Figures A8 and A9 in the appendix show that the trend for these elasticities is increasing.

Table 8 Input demand elasticities with respect to different outputs

Variable\Output	Primary aluminium	Alloys and castings	Aluminium products
Labour	0.628	0.183	0.020
Electricity	0.201	0.282	0.034
Fuel	0.333	0.664	0.092
Material	0.348	0.557	0.040

5.5 Conclusions

In this study we have used the Multiproduct Symmetric Generalized McFadden (MSGM) cost function on the primary aluminium industry in Norway to investigate the extent of economies of scale and scope in this industry. The main advantage of this functional form is that global concavity can be imposed on the cost function without destroying the flexibility of the model estimation. Furthermore, this functional form permits zero values on one or more outputs. We have tested three different specifications of the MSGM cost function, and our hypothesis that the multiproduct specification is superior to the single output model is clearly accepted. The main results can be summarised in the following way.

- Technical change is dominated by labour saving technical progress. Except for labour, all other estimates on factor biased technical change are not significant.
- There are no significant economies of scale. The returns to scale values are very high, on average above 2, but with large standard deviations.

- Economies of scope are large, about 2, and estimated with high significance. It is relatively more profitable to produce more than one product. Our estimates of the economies of scope are much more significant than the estimates of the economies of scale. The precise estimates of the scope elasticity, in contrast to the large variance in the estimation of the scale elasticity, indicate that it is very important to apply a multiproduct estimation framework that takes the economies of scope into account.

- Our estimates indicate that input demand is not sensitive to factor prices, except for the cross-price elasticities between fuel and labour, and fuel and electricity. The elasticity estimates are robust between the three model specifications. However, higher standard deviations, on average, for the single product specification indicate that the multiproduct approaches are more efficient.

- The production mix has a considerable influence on the factor demand. Plants have shifted their production from primary aluminium to alloys and castings. These changes in the output mix have lead to a less labour intensive production and more material and fuel intensive outputs. These results would have been impossible to detect in a model with one homogeneous good.

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Appendix A1

Table A1 Parameter estimates

Model	Three products		Two products		Single product	
Parm.	Estimate	t-value	Estimate	t-value	Estimate	t-value
β_1	0.800	2.59	0.933	14.27	1*	-
β_2	0.867	2.63	1*	-	1*	-
λ_{ll}	-2.470	-3.85	-2.371	-5.73	-3.404	-11.00
λ_{le}	3.745	3.30	3.675	6.83	2.372	7.09
λ_{lf}	-0.146	-0.57	-0.197	-0.83	-0.016	-0.09
λ_{ee}	1.221	0.71	0.875	0.64	-1.456	-2.92
λ_{ef}	0.653	2.36	0.712	4.13	0.687	5.17
λ_{ff}	0*	-	0*	-	0*	-
α_l	1.009	2.92	1.135	3.62	1.330	4.42
α_e	0.093	0.53	0.124	0.70	0.163	0.83
α_f	-0.030	-0.29	-0.050	-0.55	-0.079	-0.89
α_m	0.156	0.58	0.079	0.36	0.059	0.30
α_{ll}	0.019	0.14	0.013	0.11	-0.038	-0.34
α_{ee}	27.890	2.34	25.202	6.47	21.011	6.84
α_{ff}	0.052	0.04	0.053	0.04	-0.277	-0.30
α_{mm}	9.446	1.58	8.648	2.32	6.243	2.10
α_{lk}	0.975	2.33	0.907	2.32	0.863	2.42
α_{ek}	0.293	0.90	0.282	1.06	0.350	1.44
α_{fk}	-0.070	-0.98	-0.066	-1.01	-0.076	-1.12
α_{mk}	0.226	0.69	0.166	0.61	0.148	0.61
α_{lt}	-0.045	-2.28	-0.048	-2.68	-0.053	-3.01
α_{et}	-0.012	-0.75	-0.017	-1.12	-0.022	-1.47
α_{ft}	0.005	1.01	0.005	1.35	0.006	1.40
α_{mt}	-0.019	-0.92	-0.017	-1.00	-0.017	-1.08
α_{lkk}	-8.332	-1.15	-6.987	-1.39	-6.106	-1.48
α_{ekk}	-3.736	-0.62	-4.488	-1.23	-5.059	-1.56
α_{fkk}	1.071	0.78	0.919	1.08	0.938	1.19
α_{mkk}	-4.218	-0.76	-3.469	-0.89	-3.094	-1.02
α_{ltt}	0.005	0.01	-0.018	-0.05	0.128	0.44
α_{ett}	-0.021	-0.05	0.030	0.09	0.121	0.43
α_{ftt}	0.053	0.59	0.051	0.81	0.044	0.85
α_{mtt}	0.209	0.49	0.268	0.91	0.333	1.56

Table A1 Parameter estimates (cont.)

Model	Three products		Two products		Single product	
Parm.	Estimate	t-value	Estimate	t-value	Estimate	t-value
β_{11l}	28.394	0.98	24.580	0.99	44.247	1.84
β_{11e}	-36.799	-1.33	-44.379	-1.86	-27.447	-1.24
β_{11f}	0.145	0.03	0.292	0.05	-0.628	-0.11
β_{11m}	2.239	0.09	-3.554	-0.15	1.853	0.09
β_{12l}	55.242	1.71	50.555	1.93	*	-
β_{12e}	-27.196	-0.82	-29.264	-1.11	*	-
β_{12f}	-0.453	-0.07	-0.228	-0.04	*	-
β_{12m}	9.635	0.35	4.102	0.18	*	-
β_{22l}	43.700	1.21	41.097	1.54	*	-
β_{22e}	-40.110	-1.01	-43.706	-1.53	*	-
β_{22f}	0.849	0.13	1.075	0.17	*	-
β_{22m}	9.025	0.31	0.610	0.02	*	-
β_{13l}	31.200	0.70	*	-	*	-
β_{13e}	-37.652	-0.62	*	-	*	-
β_{13f}	-3.241	-0.34	*	-	*	-
β_{13m}	-1.663	-0.03	*	-	*	-
β_{23l}	76.941	1.49	*	-	*	-
β_{23e}	-21.746	-0.45	*	-	*	-
β_{23f}	6.296	0.72	*	-	*	-
β_{23m}	10.443	0.19	*	-	*	-
β_{33l}	109.622	1.19	*	-	*	-
β_{33e}	-100.781	-0.62	*	-	*	-
β_{33f}	0.418	0.03	*	-	*	-
β_{33m}	-6.357	-0.09	*	-	*	-
α_{lkk}	0.394	0.36	0.544	0.74	0.363	0.69
α_{ekk}	1.149	0.93	1.435	2.28	1.360	2.61
α_{fkk}	-0.227	-0.88	-0.186	-1.39	-0.168	-1.55
α_{mkk}	0.509	0.49	0.455	0.74	0.371	0.80
α_{ltt}	-0.001	-0.03	0.000	0.03	-0.004	-0.42
α_{ett}	-0.006	-0.44	-0.005	-0.51	-0.008	-0.89
α_{ftt}	-0.003	-0.76	-0.003	-1.31	-0.002	-1.42

Table A1 Parameter estimates (cont.)

Model	Three products		Two products		Single product	
Parm.	Estimate	t-value	Estimate	t-value	Estimate	t-value
d_1	-0.001	-0.10	-0.009	-0.20	0.030	0.22
d_2	-0.019	0.32	0.009	0.12	0.007	0.04
d_3	0.013	0.26	0.067	1.23	0.045	0.33
d_4	0.052	0.74	0.056	0.76	0.048	0.31
d_5	0.042	0..84	-0.004	-0.06	0.079	0.55
d_6	0.013	0.13	-0.098	-1.56	0.055	0.30
d_7	-0.039	-0.39	-0.012	-0.09	-0.205	-0.98
d_8	-0.048	-0.60	0.004	0.03	0.031	0.07
d_9	0.013	0.06	0.019	0.09	-0.049	-0.21

* = Restricted parameters

Figure A1 Economies of scale (ORTS) and economies of scope (ESCP)

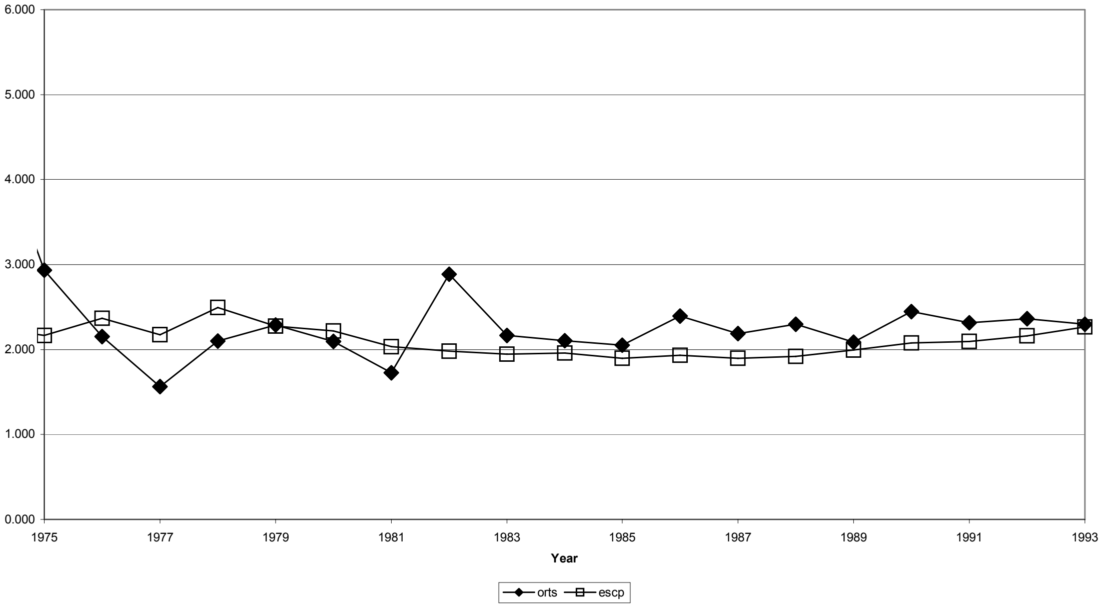

Figure A2 Price elasticities of labour w.r.t. labour (ELLL), electricity (ELLE), fuel (ELLF), and other intermediate inputs (ELLM)

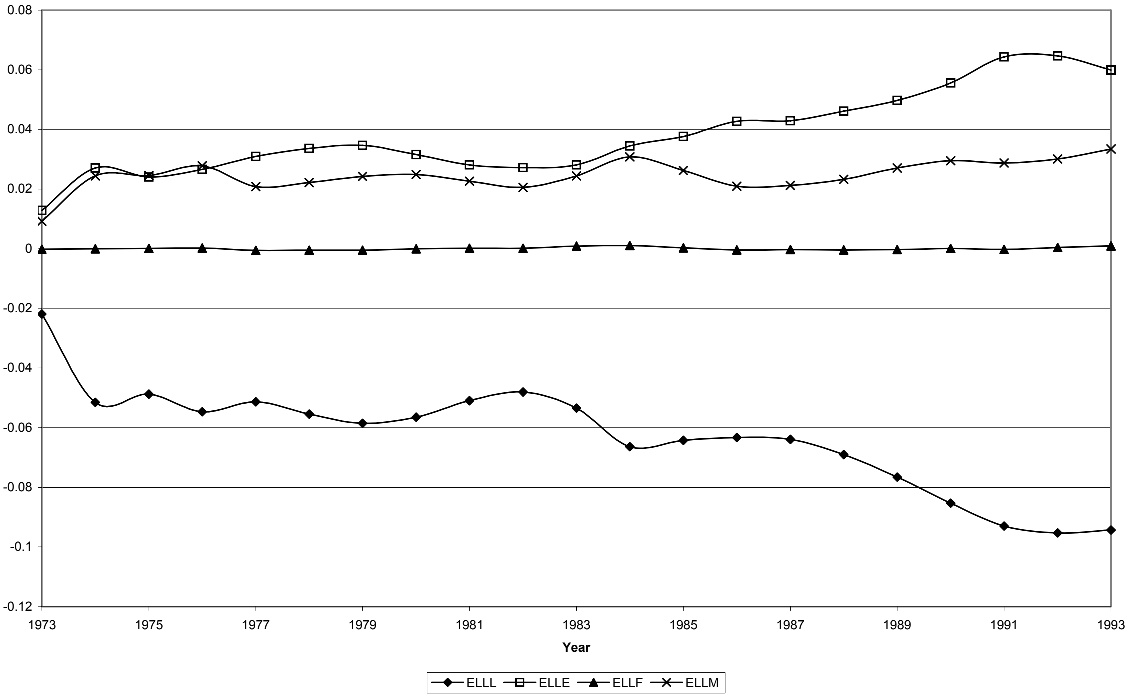

Figure A3 Price elasticities of electricity w.r.t. labour (ELEL), electricity (ELEE), fuel (ELEF), and other intermediate inputs (ELEM)

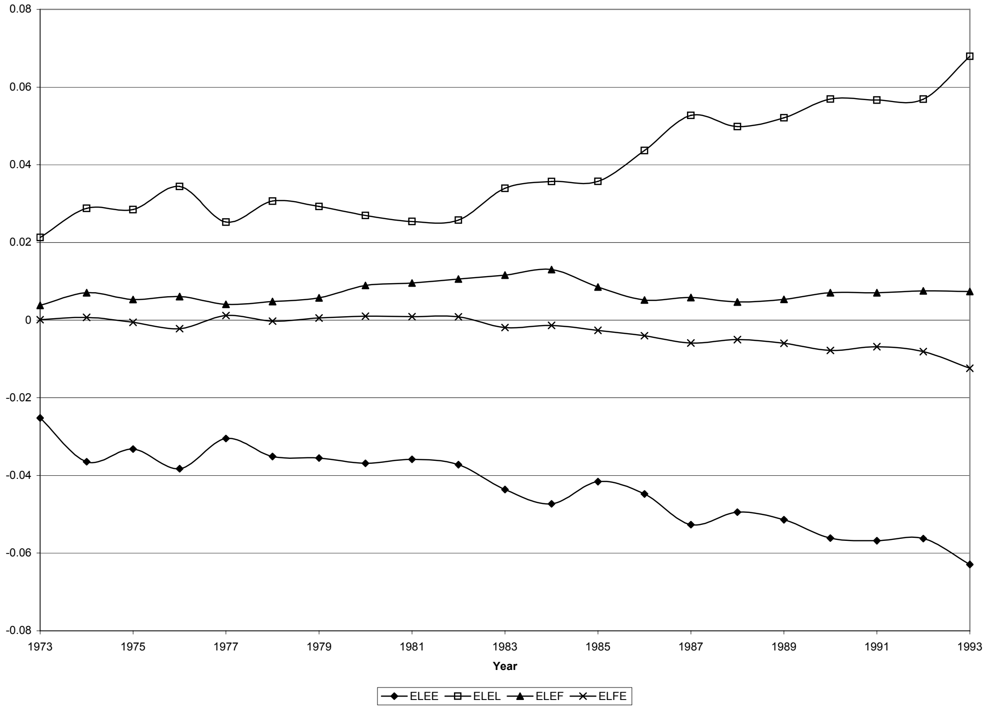

Figure A4 **Price elasticities of fuel w.r.t. labour (ELFL), electricity (ELFE), fuel (ELFF), and other intermediate inputs (ELFM)**

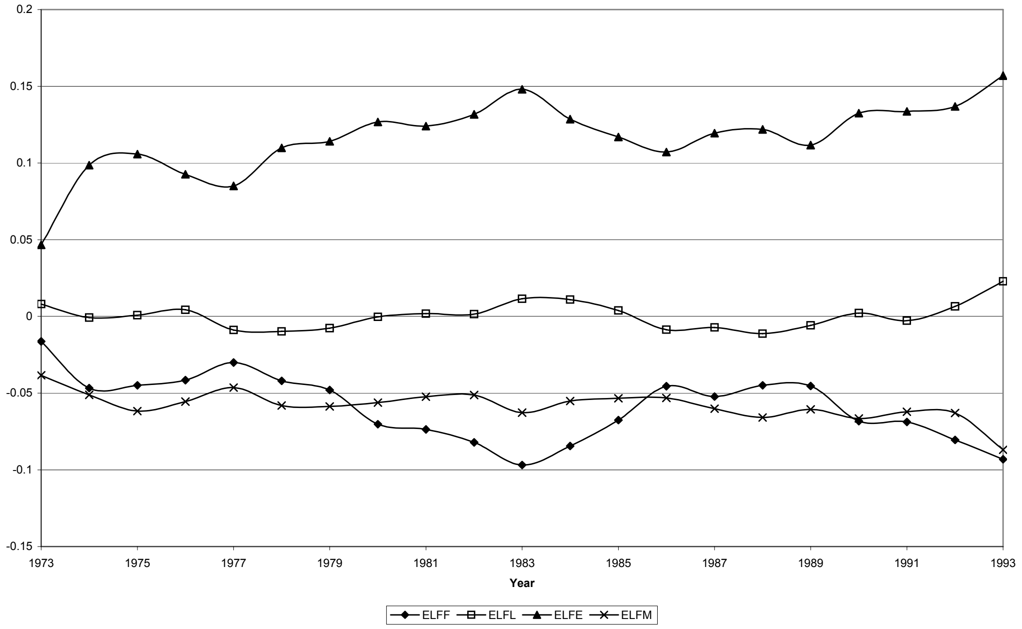

Figure A5 **Price elasticities of material w.r.t. labour (ELML), electricity (ELME), fuel (ELMF), and other intermediate inputs (ELMM)**

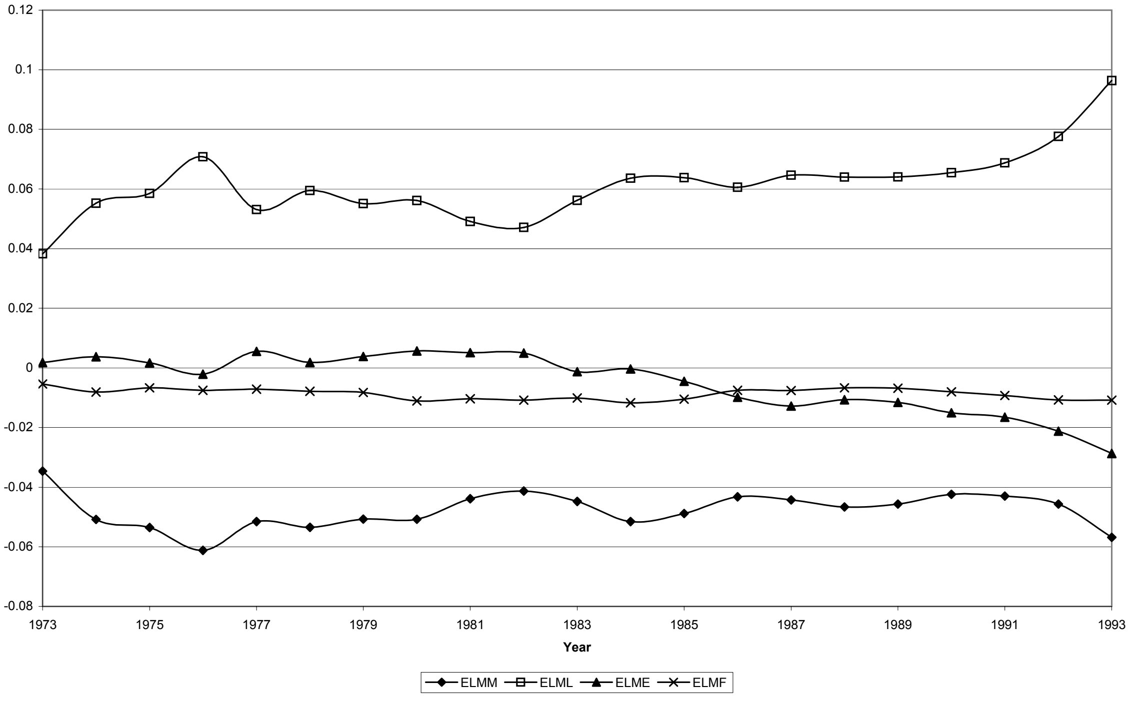

Figure A6. Demand for labour with respect to output: Primary aluminium (ELLY1), aluminium alloy (ELLY2), aluminium products (ELLY3)

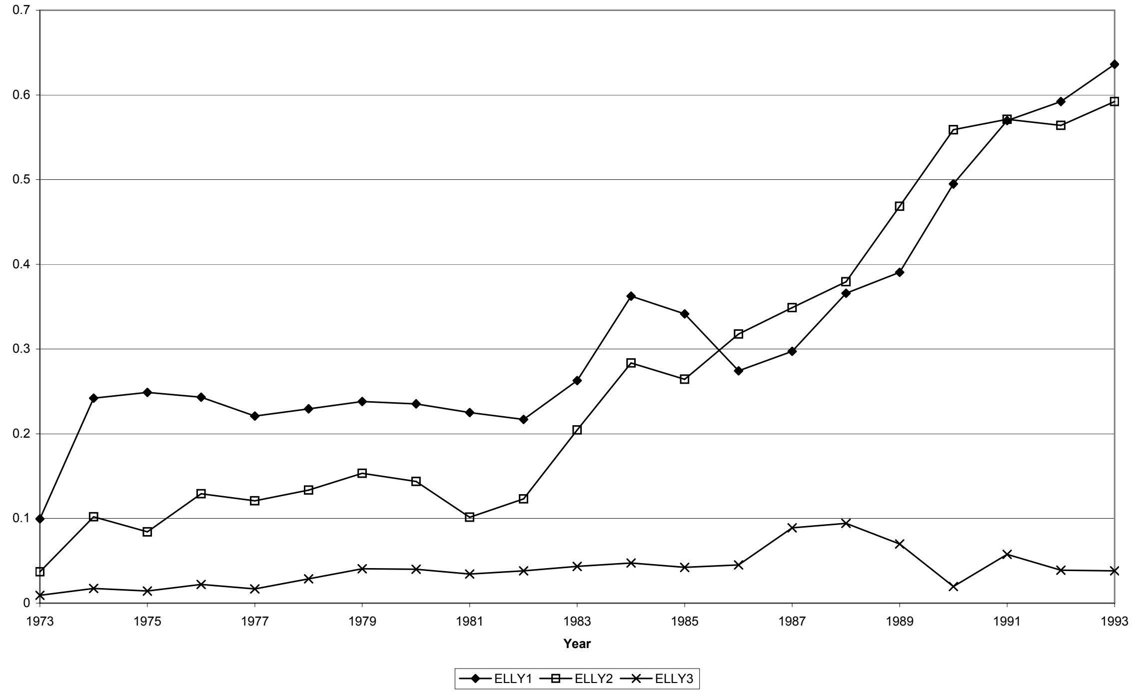

Figure A7. Demand for electricity with respect to output: Primary aluminium (ELEY1), aluminium alloy (ELEY2), aluminium products (ELEY3)

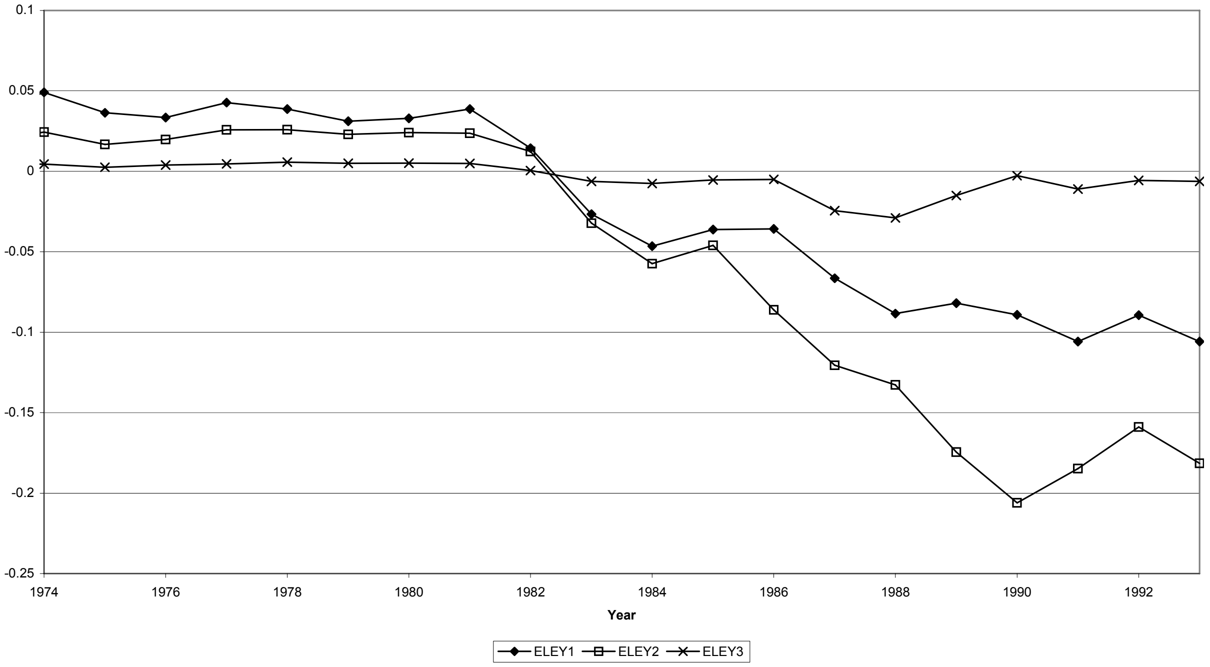

Figure A8 **Demand for fuel with respect to output : Primary aluminium (ELFY1), aluminium alloy (ELFY2), aluminium products (ELFY3.)**

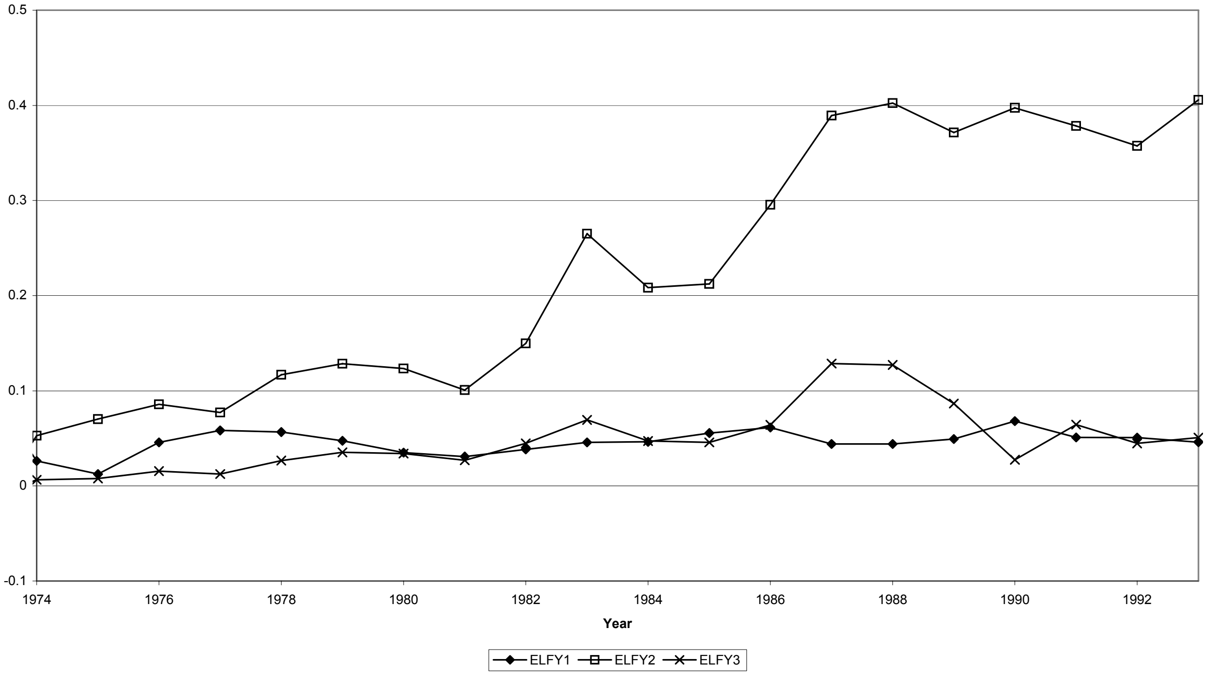

Figure A9 **Demand for other intermediate materials with respect to output: Primary aluminium (ELMY1), aluminium alloy (ELMY2), aluminium products (ELMY3).**