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ABSTRACT

The European Union (EU) is advocating an ambitious mix of climate policies, e.g., the carbon Emission Trading System (EU-ETS) or the CO_2 tax that exists in some countries. Even though the benefits of environmental policy are quite undisputed, there is no consensus about the costs in terms of reduced competitiveness and profitability of firms. From the traditional 'static' point of view, profit losses are to be expected since regulation is a restriction on a firm's operations. On the other hand, the so-called Porter hypothesis suggests that due to 'dynamic' effects, environmental policy could actually be profitable for firms. We assess the immediate and dynamic impacts of the Swedish CO_2 tax on profit efficiency among firms within Swedish manufacturing by explicitly looking at efficiency of energy use (recognizing that energy is the input that primarily contributes to CO_2 emissions). The results suggest we can corroborate the Porter hypothesis for three industry sectors - Food, Textile, and Mining - while rejecting it for others. Estimations suggest that the most inefficient sectors are more likely to experience a positive dynamic effect of CO_2 taxation on profitability compared to the more efficient sectors.

JEL-classification: D20, H23, Q52, Q55.

Key words: CO_2 tax, profit efficiency, stochastic frontier analysis, Swedish industry.

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1. Introduction

Anthropogenic climate change is one of the most challenging and urgent global problems requiring a solution. The European Union (EU) advocates an ambitious climate policy strategy in order to make an impact (see, e.g., EU, 2008, 2010), with the intention of setting a good example in a global context. In particular, this has involved pursuing energy and climate policies that cut greenhouse gas emissions. For instance, a price on CO_2 was introduced by the EU Emission Trading System (EU-ETS) in 2005. The EU-ETS will include all major carbon dioxide (CO_2) emitting sectors. However, sectors outside the EU-ETS will not be exempted from climate and energy policy; for these non-trading sectors, introducing or raising CO_2 taxes are an alternative. In this respect, Sweden is a leading country, as it was one of the first nations to introduce a CO_2 tax for households and selected industry sectors in 1990/1991. The CO_2 tax in Sweden has been maintained at a significant level ever since, in comparison to the international standard.[2]

One common argument against environmental regulations is that they may, in addition to simply increasing costs, hamper productivity and competitiveness among firms, and therefore further reduce profits. Viewed from this perspective, the environmental ambitions of the EU and Sweden may have far-reaching negative effects on the opportunity for regulated companies to compete in international markets. On the other hand, the well-known Porter hypothesis (Porter, 1991; Porter and van der Linde, 1995) claims that introducing, or strengthening, the ‘right kind’ of national environmental regulation (economic incentives such as, e.g., taxes and tradable permits) will induce productivity gains and reduce inefficiencies, leading to increased competitiveness and profits, compared with countries with less ambitious environmental goals. Environmental policy could therefore be costless and, by being an early

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[2] However, between 2008 and 2011 the CO_2 tax was phased out for firms inside the EU-ETS system and a larger burden was put on firms not trading emission permits.

mover, the EU and Sweden could actually benefit more than they lose from climate mitigation. This paper addresses this issue by studying the CO_2 tax scheme and its effects on firms' competitiveness and profits within Sweden.

The main purpose is to assess the contemporary *and* dynamic effects of the Swedish CO_2 tax scheme on firm profit efficiency in the manufacturing industry during the years 1990 to 2004. Firms' efficiency may differ due to heterogeneity in production technologies and differences in management of the production processes. The theoretical profit efficiency approach adopted is based on Kumbhakar and Lovell (2000) and Kumbhakar (2001), and efficiency scores are empirically estimated by using a stochastic frontier analysis (SFA) approach suggested by Battese and Coelli (1995) (simultaneously estimating the profit frontier and explaining variation in efficiency). We explicitly apply profit efficiency, modeled as a constant multiple of technical efficiency, as a measure on how efficiently energy inputs are used in production.

Broberg et al. (2013) also analyzes the contemporary and temporal effects of environmental regulation on technical efficiency in Swedish manufacturing.[3] By applying the Battese and Coelli (1995) SFA approach, they use the level of environmental protection investment as a proxy for regulation stringency and tests for effects on efficiency. The results indicate that regulation causes efficiency losses in the five studied Swedish industries during 1999-2004. However, using investments in environmental protection as a proxy for regulation stringency may be problematic. As Broberg et al. (2013) puts it: "We conclude that what seemed like an adequate measure of environmental regulation stringency also has its flaws." For instance, as investments may be voluntary, environmental investments do not necessarily reflect

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[3] This temporal approach using SFA and analyzing the Porter hypothesis was first suggested by Lundgren and Marklund (2010) (which the present paper is a development of).

regulation stringency. Furthermore, separating environmental investments from other types of investments is not obviously straightforward and it therefore might be inconsistencies in the investment data. Also, as pointed out by Broberg et al. (2013), the data survey does not systematically cover investments aimed at reducing CO_2 emissions. The analysis in this paper covers more industries over a longer time period, 1990-2004, and, above all, the regulation stringency is measured by CO_2 taxes actually paid by firms. Furthermore, in our analysis we focus explicitly on profit efficiency, which from a Porter perspective is appropriate, and not production efficiency as in Broberg et al. (2013). Overall, this will provide a more comprehensive and accurate picture of the impact on firm economic performance of Swedish climate policy.

The literature on the Porter hypothesis is extensive. Ambec et al. (2013) provide an overview of theoretical and empirical findings.[4] Theoretically, the hypothesis may be found valid in certain circumstances, e.g., when there are other market imperfections in addition to the environmental problems. However, even though theoretical studies may give important insights, we argue that the task of validating the Porter hypothesis is mainly an empirical one. In this context, Jaffe and Palmer (1997) separate the hypothesis into a *weak*, *narrow*, and *strong* version. The weak version only alludes to environmental regulation stimulating profit maximizing firms to certain types of innovations. Whether these innovations are socially beneficial or not is ignored. The narrow version refers to economic instruments giving maximizing firms greater incentive to innovate compared to command-and-control instruments. Finally, the strong version assumes that firms are not necessarily maximizing profits, and that environmental regulation therefore will make them discover profit potentials and induce them to improve economic performance. Therefore, the strong version of the

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[4] See also Brännlund and Lundgren (2009).

Porter hypothesis is associated with a “win-win” outcome, improving both the environment and firms’ performance and competitiveness.[5]

Lanoie et al. (2011) observe two different types of empirical studies: (a) Studies that test the weak version of the Porter hypothesis by addressing the impact of environmental regulation on firms’ innovation and choice of technology, measured by different types of investments; and (b) studies testing the strong version of the hypothesis by addressing the impact on firms’ economic performance, e.g., productivity. Lanoie et al. (2011) is the first study trying to test all the three versions of the Porter hypothesis, including also the narrow version. Generally, they find strong support for the weak version and, as they put it, “qualified” support for the narrow version (p. 837). However, no support for the strong version of the Porter hypothesis is found. Other studies focusing explicitly on the strong version are Managi et al. (2005), Lanoie et al. (2008), and Broberg et al. (2013), and together they provide findings that are not conclusive. However, uniquely, these studies have in common that they consider temporal dynamics when estimating the effects of environmental policy on different types of economic performance. The dynamic perspective is most crucial to the Porter hypothesis.

In this paper, the strong version of the Porter hypothesis is tested. In contrast to earlier studies, the contribution to this particular type of studies is as follows: (1) We use a unique data set, which includes total CO_2 taxes actually paid at firm level in Swedish industry (the CO_2 tax being an economic instrument in accordance with the narrow version of the Porter hypothesis); (2) contemporaneous *and* dynamic effects of CO_2 taxation on firms’ economic performance is estimated; (3) economic performance is measured by profit efficiency.

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[5] Note that the gain from improved economic performance must outweigh the investment cost.

The paper is structured in six sections, following this introduction. In Section 2 a description of the CO_2 taxation in Sweden is provided. Section 3 outlines the theoretical framework where, based on the profit function, the technology frontier and technical efficiency is modeled in a dual setting. Then the estimation approach to be used, stochastic frontier analysis, is described theoretically. The empirical specifications are provided in Section 4, including the parameterization of the profit frontier and the profit technical efficiency model. Section 5 presents the data, and in Section 6 the results are reported. Finally, Section 7 offers a discussion and conclusions.

2. CO2 taxation in Swedish industry

A historical view and detailed discussion of CO_2 taxation in Sweden is provided in Brännlund (2009). In 1990/1991 Sweden introduced a specific tax on CO_2, explicitly levied on the CO_2-content in fuels. The CO_2-tax partly replaced a general energy tax, and the introduction of it meant a significant increase in the taxation of fossil fuels. Referring to the narrow version of the Porter hypothesis (as suggested in Jaffe and Palmer, 1997), the CO_2-tax can certainly be viewed as “right kind” of regulation. Also, due to a specific deduction system that applies to certain parts of the Swedish industry, or even specific firms or fuels, there is a considerable variation in tax payments which makes it particularly suitable for testing the Porter hypothesis.

The statutory CO_2-tax rate is in Sweden today approximately 1.05 SEK per kg CO_2 emitted (or about 114 EURO/ton or 146 USD/ton),[6] which corresponds, e.g., to 2.44 SEK per liter gasoline for motor vehicles. However, as earlier mentioned the manufacturing sector in Sweden has been, and is, to some degree, excluded from the excise tax on CO_2. The 1993

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[6] 1 Euro = 9.19 SEK, and 1 USD = 7.21 SEK (2014-09-29).

energy tax reform introduced special regulations relieving some of the tax burden on the manufacturing industry. This special treatment has been reinforced ever since. For instance, manufacturing meets lower tax rates on energy products used for heating and in stationary motors.

The manufacturing sectors pay only 21 percent of the 1.05 SEK CO_2-tax base rate. For the use of fossil fuels, some enterprises within these sectors also have the opportunity to apply for tax refunds under certain circumstances. The remaining tax actually paid must be at least 0.5 percent of sales. However, to address energy intensive manufacturing, if the total amount tax paid exceeds 0.8 percent of produced sales value the manufacturer may apply for further tax reductions. In this case a maximum of 24 percent of the tax amount that exceeds 0.8 percent of the sales has to be paid. In addition, there is special treatment of certain fuels used in certain sectors, e.g. some process fossil fuels are exempted from taxation in iron ore mining.[7]

This elaborate tax scheme is quite non-transparent except to the very initiated. However, in this study, we can overlook this problem since we are able to study the “effective” tax rate, i.e., the actual tax payment divided by the amount of emitted kilos of CO_2. This measure implicitly takes into account all the special rules and exemptions associated with CO_2 taxation in Swedish manufacturing.

Figure 1 shows that the official tax rates in households and industry has changed since the introduction of the tax. From 1993 the households have carried most of the increased burden.

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[7] Because the tax system provides the firm with opportunities to apply for tax refund, it could be argued that the firm can adopt its production plans or fuel use to the tax refund rules (se Section 2). That is, to some degree firms may alter the tax rate to a desired level. This would compromise our purpose of testing the Porter hypothesis in a fair way, as the test would risk to underestimate the tax effect on profit efficiency. However, we do not believe there are incentives enough for the firms to actually divert resources to tax planning, since the tax actually paid is modest, ranging between 0.5 percent and a maximum of 24 percent of the tax amount that exceeds 0.8 percent of total sales value. That the incentives for tax planning is not enough is confirmed by industry and governmental officials we have spoken to.

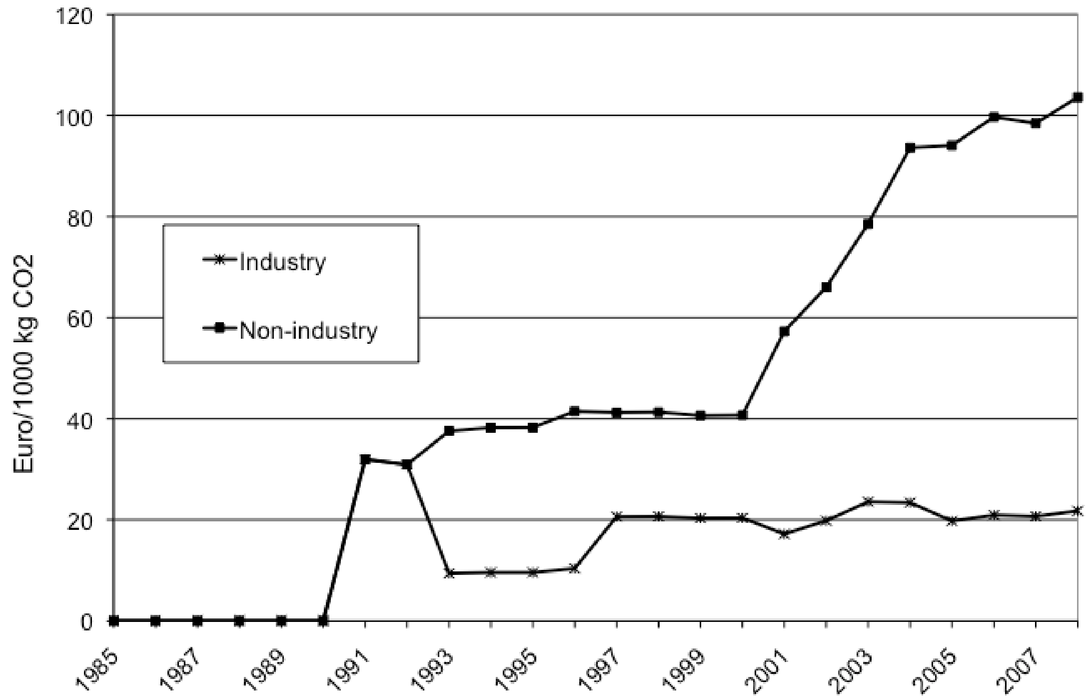

Figure 1. The CO_2 tax in Sweden; industry and households. Source: The Swedish National Tax Board (Rikskatteverket; www.skatteverket.se).

Even though it from Figure 1 looks like industry is exposed to a low level of variation at the aggregate level, the within year variation in actual tax payment among firms is substantial. In Figure 2 this variation is described in a box-plot, where the height of the boxes displays the difference between the 25th and 75th percentiles each year.[8] The horizontal lines within each box show the median tax rate actually paid.[9]

looks like industry is exposed to a low level of variation at the aggregate level

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[8] Note that the 1990 values are imputed, i.e., it is calculated as if the firms were paying the tax according to the scheme.

[9] Firms' actual tax payment is calculated according to the intrinsic special rules and exemptions inherent in the Swedish tax deduction system.

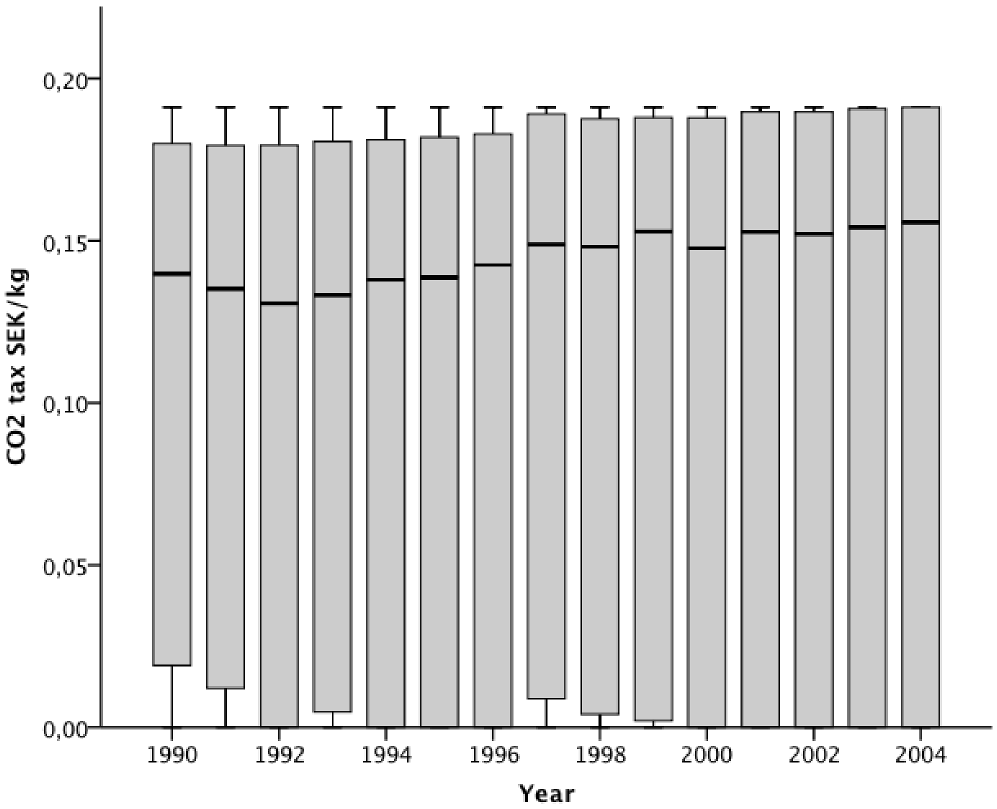

Figure 2. Actual CO_2 tax payment among firms in Swedish manufacturing.

In general the variation in actual CO_2 tax payment among firms has increased somewhat over the years, and the median has increased, but only marginally, ranging between approximately 0.13 and 0.15 SEK/kilo CO_2. More descriptive statistics and discussion related to the CO_2 tax is provided in the data section.

Having established the variation in CO_2 tax payment among firms in the Swedish industry, the theoretical approach to be used to test the strong version of the Porter hypothesis is presented in the next section.

3. Theoretical approach

The Porter hypothesis argues that firms' performances are positively affected by environmental regulation. Performance may be measured in terms of efficiency in production and efficiency is typically decomposed into a technical and an allocative component. However, in testing the Porter hypothesis, which explicitly focuses on the effects on firms' private economic performance, our interest is primarily on the effects on firms' technical efficiency, related to the use of a given input mix in production. Therefore, from the firm's private point of view, we assume allocative efficiency in production. [10]

Technical efficiency is commonly analyzed in a primal setting by specifying and estimating production functions. However, as pointed out by Kumbhakar (2001), there are some estimation issues related to this particular approach. For instance, regressors are assumed exogenous in estimations, but in neoclassical theory inputs are treated as endogenous in firms' optimization behavior. Consequently, estimating primal production functions with inputs as regressors may lead to inconsistent parameter and efficiency estimates. This problem is avoided when analyzing technical efficiency in a dual setting, e.g., by specifying and estimating profit functions.

3.1 Profit technical efficiency

The profit technical efficiency approach adopted is based on Kumbhakar and Lovell (2000), and Kumbhakar (2001). The approach measures the percentage loss in profits due to technical inefficiency in production of output. It is described as follows. First, the underlying production function can be expressed as:

$$y = f(x)e^{-u}, \qquad u \geq 0,\ 0 < e^{-u} \leq 1 \tag{1}$$

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[10] This does not mean that we assume that resources are allocated efficiently in society. For one thing, from the society point of view, it is necessary to consider natural resources, which, e.g., calls for including emissions in the modeling of the firm's production technology.

where y is market output produced, x is a vector of inputs used in production, and u is technical inefficiency in production. Technical inefficiency is, in this case, referred to as being output-oriented, i.e., it describes how output can be increased whilst holding the input mix and quantities constant.

As argued in Kumbhakar and Lovell (2000) only efficiently producing firms survive in the long run, as profit approaches zero in a competitive environment. Allowing for variable profit, it is, therefore, appropriate to apply a short-run framework in which at least one input is modeled as quasi-fixed. Then, the dual variable profit function associated with equation (1), conditional on u, may be written as:[11]

$$\pi(p,w,q,u)=\pi\left(pe^{-u},w,q\right) \tag{2}$$

where p is the output price, $w=(w_1,...,w_N)$ and $q=(q_1,...,q_M)$ are vectors of exogenously given input prices and the quasi-fixed inputs, respectively. Hereafter we refer to $\pi(pe^{-u},w,q)$ as the actual, or observed, variable profit function. As e^{-u} introduces technical inefficiency into the model, the expression in equation (2) may be rewritten as:

$$\pi\left(pe^{-u},w,q\right)=\pi(p,w,q)\cdot h(p,w,q,u) \tag{3}$$

where $\pi(p,w,q)$ is the maximized variable profit function, and $h(p,w,q,u)$ is profit efficiency. By assuming that the underlying production function, $f(x)$, is homogenous of

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[11] Following Kumbhakar and Lovell (2000), we assume profit maximization and use duality theory to establish an equivalence between the production function in Equation (1) and the profit function (see, e.g., Färe and Primont, 1995).

degree r in x, profit efficiency is not dependent on exogenously given prices and quasi-fixed inputs, (p, w, q), but only on output-oriented technical efficiency in production, u. Thus, rearranging equation (3), profit efficiency is defined as:

$$h(u) = \frac{\pi\left(pe^{-u}, w, q\right)}{\pi\left(p, w, q\right)} \leq 1 \tag{4}$$

where the maximized variable profit function describes the profit frontier. Hence, profit inefficiency indicates that there is profit loss attributed to output technical inefficiency, and it is interpreted in terms of percentage loss. Only in the case where $u = 0$, then profit efficiency equals one.

3.2 Stochastic frontier analysis

Our main purpose is to estimate profit frontiers and profit technical efficiency scores, and then to test whether the variation in efficiency depends on CO_2 tax rates. The estimations are based on a single-equation method, and the primary reason for adopting such a method is that it allows for a fairly straightforward single-stage estimating procedure (including both the profit frontier and explaining variation in efficiency). Alternatively, the profit frontier and efficiency scores are estimated in a first stage, and then in a second stage, separately from the first, efficiency is regressed on a set of exogenously given firm-specific variables. However, running the estimations in two separate stages requires contradictory assumptions. Efficient parameter estimates of the profit frontier and profit efficiency requires that efficiency is identically distributed in the first stage. However, the second stage requires the opposite assumption. In the guide to the FRONTIER 4.1 software package, Coelli (1996) maintains that: “*The two-stage estimation procedure is unlikely to provide estimates which are as efficient as those that could be obtained using a single-stage estimation procedure (p. 6)*.”

We use a stochastic frontier analysis approach within a single-stage estimating framework, which was suggested by Battese and Coelli, (1995), and Coelli (1996).[12] Recent studies using the single-stage framework have been reported by, e.g., van der Vlist et al. (2007) and Shadbegian and Gray (2006), although both estimate production functions and not profit functions.

The stochastic profit frontier model may be expressed as:

$$\ell n\left(\pi^{kt}(pe^{-u}, w, q)\right) = \ell n\left(\pi^{kt}(p, w, q; \alpha)\right) + v^{kt} - u^{kt} \tag{5}$$

where $\pi^{kt}(pe^{-u}, w, q)$ is the observed profit of firm k in year t, and $\pi^{kt}(p, w, q)$ represents the deterministic part of the profit frontier. The error term is divided into two components v^{kt} and u^{kt}. Introducing the stochastic part of the frontier, the component v^{kt} arises from random shocks and measurement errors, and these influences are $iid\ N(0, \sigma_v^2)$ and independent of u^{kt}, which is a nonnegative random variable that captures technical inefficiency, and is independently (not identically) distributed such that it is obtained by truncation at zero of $N(z^{kt}\delta, \sigma_u^2)$. If the OLS residuals of the expression in Equation (5) are negatively skewed, $m_3 < 0$, it indicates technical inefficiency, i.e., $u^{kt} > 0$ (Kumbhakar and Lovell, 2000). Finally, σ_v^2 and σ_u^2 are replaced with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$.[13]

Technical inefficiency in equation (5) is defined as:

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[12] For a general discussion of stochastic frontier estimations, see, e.g., Coelli et al. (2005), or Kumbhakar and Lovell (2000).

[13] To test whether there is any technical inefficiency at all a significance test of the γ estimate can be run (see Coelli, 1996, p. 6).

$$u^{kt} = z^{kt}\delta + \upsilon^{kt} \qquad (6)$$

where $z^{kt} = [z_1^{kt},...,z_J^{kt}]$ is a vector of variables that potentially have an effect on efficiency, and δ is a vector of parameters to be estimated. The random variable, $\upsilon^{kt} \sim N(0,\sigma_\upsilon^2)$, is truncated by the variable truncation point $-z^{kt}\delta = \upsilon^{kt} - u^{kt}$.

Profit technical inefficiency is then defined as:

$$-u^{\pi,kt} = -\rho \cdot u^{kt} \qquad (7)$$

where $\rho = 1/(1-r)$, and $u^{\pi,kt}$ is to be interpreted as firm *k*'s percentage profit loss in period t caused by producing output technically inefficient (Kumbhakar, 2001, p. 5). Equation (7) shows that profit technical inefficiency is a constant multiple of technical inefficiency, and the profit frontier, $\pi(p,w,q)$ is a neutral transformation of the observed profit function, $\pi(pe^{-u},w,q)$, which means that shifts of the profit function is independent of prices (Kumbhakar, 2001) (compare equation (4)). This follows from the underlying technology being homogenous.

Finally, profit technical efficiency is expressed as:

$$PE^{kt} = \exp\left(-u^{\pi,kt}\right) = \exp\left(-\rho u^{kt}\right) = \exp\left(-\rho\left(z^{kt}\delta - \upsilon^{kt}\right)\right) \qquad (8)$$

which shows that the smaller the non-negative profit inefficiency variable, $u^{\pi,kt}$, the more profit efficient is firm k at time t. Hence, when $u^{\pi,kt} = 0$, then $PE^{kt} = 1$ and the firm is operating efficiently on the technology frontier.

The expressions in equations (7) and (8) constitute the basis of the test procedures that we conduct. The likelihood function of the model is provided in Appendix C.

4. Empirical approach

4.1 The profit frontier

For estimating purposes, equation (5) is parameterized as a Translog flexible functional form. Specifically, for firm k in period t, in the case of a single output and a single quasi-fixed input, the econometric expression of the variable profit function is:

$$\begin{aligned}\ell n\left(\pi^{kt}(pe^{-u}, w, q)\right) = {} & \alpha_0 + \gamma_q \ell n q^{kt} + \alpha_p \ell n(p^{kt}) + \sum_{n=1}^{N} \alpha_n \ell n w_n^{kt} \\ & + \frac{1}{2}\left[\ell n q^{kt}\right]^2 + \eta_{qp} \ell n q^{kt} \ell n(p^{kt}) + \sum_{n=1}^{N} \eta_{qn} \ell n q^{kt} \ell n w_n^{kt} \\ & + \frac{1}{2}\alpha_{pp}\left[\ell n(p^{kt})\right]^2 + \sum_{n=1}^{N} \alpha_{pn} \ell n(p^{kt}) \ell n w_n^{kt} \\ & + \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{N} \alpha_{nn'} \ell n w_n^{kt} \ell n w_{n'}^{kt} + v^{kt} - u^{kt}\end{aligned} \tag{9}$$

Following Kumbhakar and Lovell (2000, p. 196), profit inefficiency may then be expressed as follows:

$$\ell n h^{kt}(p, w, q, u) = -\left[\alpha_p + \alpha_{pp} \ell n p^{kt} + \sum\nolimits_n \alpha_{pn} \ell n w_n^{kt} + \eta_{qp} \ell n q^{kt}\right] \cdot u^{kt} + \frac{1}{2}\alpha_{pp}(u^{kt})^2 \tag{10}$$

Symmetry is imposed on the profit function in (9) by $\alpha_{n'n} = \alpha_{nn'}$, and linear homogeneity of degree 0 in prices, (pe^{-u}, w), is imposed by the following parameter restrictions, $\sum_n \alpha_p + \alpha_n = 1$, $\sum_n \alpha_{pn} + \alpha_{pp} = 0$, $\sum_{n'} \alpha_{nn'} + \alpha_{pn} = 0$, $\forall n$, and $\sum_n \eta_{qn} + \eta_{qp} = 0$.

As previously notified, the underlying production technology is assumed to be homogenous of degree r in inputs, x. Therefore, the profit function also must satisfy the following parameter restrictions, $\alpha_{pp} = \alpha_{pn} = \eta_{qp} = 0, \forall n$ (see Kumbhakar and Lovell, 2000, p. 197). This means that the expression in (10) collapses to:

$$\ell nh(u)^{kt} = -\alpha_p \cdot u^{kt} \quad , \qquad \alpha_p \geq 1 \tag{10'}$$

which can be compared with the expression in (7).

Assuming that the firms are producing the market product by using the quasi-fixed input factors capital (*K*) and labor (*L*),[14] the variable input factors electricity (*E*) and fossil fuel (*F*), and inserting all the necessary parameter restrictions into equation (9) give the following econometric expression:[15]

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[14] As motivated in Section 3.1, it is appropriate to apply a short-run framework when estimating profit functions, modeling at least one input as quasi-fixed. Then, the most natural choice is the capital stock. Furthermore, as we aim at assessing the effects of CO_2 taxation on energy efficiency use in production, we also model labor as a quasi-fix factor. It may seem controversial to regard the number of employees as exogenously given in the short run. However, this is not that far from the truth concerning the circumstances in Sweden. By the Swedish Employment Protection act (Lagen om AnställningsSkydd, LAS 11§) the term of notice is one to six months depending on time of employment. Furthermore, as a complement to LAS, nearly all industrial firms have collective agreement which is an agreement between employers' and employees' organizations. Not unusual, the collective agreement is additionally to the benefit of the employees. Hence, the term of notice can in certain cases exceed six months in practice. In this respect, both capital and labor (measured as number of employees) are sluggish compared to energy input.

[15] Due to limited data, we have not been able to include biofuel as input in production. These inputs are becoming more and more important, especially in certain industries. However, most of the development likely occurred in the last decade, that is, after the last year of our study.

$$
\begin{aligned}
\ell n\left(\frac{\pi^{kt}}{p^{kt}}\right) = {} & \alpha_0 + \gamma_K \ell nK^{kt} + \gamma_L \ell nL^{kt} + \alpha_E \ell n(\frac{w_E^{kt}}{p^{kt}}) + \alpha_F \ell n(\frac{w_F^{kt}}{p^{kt}}) \\
& + \frac{1}{2}\gamma_{KK}\left(\ell nK^{kt}\right)^2 + \gamma_{KL}\ell nK^{kt}\ell nL^{kt} + \eta_{KE}\ell nK^{kt}\ell n(\frac{w_E^{kt}}{w_F^{kt}}) \\
& + \frac{1}{2}\gamma_{LL}\left(\ell nL^{kt}\right)^2 + \eta_{LE}\ell nL^{kt}\ell n(\frac{w_E^{kt}}{w_F^{kt}}) + \\
& + \frac{1}{2}\alpha_{EE}\left(\ell n(\frac{w_E^{kt}}{w_F^{kt}})\right)^2 \\
& + \alpha_\tau T + \nu^{kt} - u^{kt}
\end{aligned}
\tag{11}
$$

where $1-\alpha_E-\alpha_F=\alpha_p$, $\alpha_{EE}=-\alpha_{EF}=\alpha_{FF}$, and $-\eta_{KE}=\eta_{KF}$.

The profit function in (11) is convex and continuous in prices, non-decreasing in p and non-increasing in w, and concave and continuous in fixed input factors (see, e.g., Bergman, 1997). Finally, technological development is modeled as being linear and Hicks neutral (here denoted by the trend variable *T*).

4.2 The profit efficiency model

The main purpose of this paper is to test whether the CO_2 tax regime in Sweden has had any effects on firms' profit technical efficiency. Therefore, the expression in equation (8) also needs to be explicitly specified, meaning that relevant explanatory z_{kt} variables need to be identified. Here we follow Managi et al. (2005) and Lanoie et al. (2008), and allow for dynamic effects of environmental policy on firm performance. Specifically, the empirical profit efficiency model reads as follows:

$$
\begin{aligned}
-u^{kt} = {} & \delta_0 + \delta_1 tax(CO_2)^{kt} + \delta_2 tax(CO_2)^{kt}_{lag} + \delta_3 Capin^{kt} + \delta_4 Fuelin^{kt} \\
& + \sum_{s=1}^{S-1}\delta_{5s}D^s_{size} + \delta_t g(t) + \upsilon^{kt}
\end{aligned}
\tag{12}
$$

which, following Battese and Coelli (1995), and Coelli (1996), is estimated simultaneously with equation (11).[16] The explanatory variables of particular interest are; (1) $tax(CO2)^{kt}$ which captures the contemporaneous (static) effect of the CO$_2$ tax on profit efficiency; (2) $tax(CO2)^{k}_{lag}$ which captures the dynamic effects. The latter variable is constructed as a moving average of three lags, i.e., $tax(CO_2)^{k}_{lag} = (tax(CO_2)^{kt-1} + tax(CO_2)^{kt-2} + tax(CO_2)^{kt-3})/3$.[17] This construction is chosen to reduce the number of parameters in the ML estimation. To account for firms being of different types, which possibly could have effect on profit efficiency, variables that represent firm characteristics are included; capital intensity, $Capin^{kt} = K^{kt}/L^{kt}$, and fossil fuel intensity, $Fuelin^{kt} = F^{kt}/L^{kt}$.[18] Furthermore, efficiency may vary due to size specific profit frontiers. Therefore, size dummies, D^{s}_{size}, are included. Firms are divided into size quartiles, $s = 1,...,4$, based on number of employees. All firms within a certain size class are compared with the profit frontier of that class, and deviation from the frontier is due to heterogeneity in technology and/or management. Finally, to account for time effects on profit efficiency, e.g., booms, recessions, and other time-specific events that are not related to Hicks neutral technological development in the profit function, we add $g(t) = \delta_{\tau} t + \delta_{\tau 2} t^2$.[19]

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[16] See Appendix C for specification of log likelihood equation.

[17] It should be noted that according to Battese and Coelli (1995) it is straightforward to include right hand side variables in Equation (12) that may appear endogenous to the firms.

[18] Elaborating with tax interaction terms did not provide any significant additional information to our results.

[19] As pointed out in Ambec et al. (2013), the Porter hypothesis argue that tougher environmental regulation leads to investment in R&D, which in turn leads to innovation and productivity increases. This would motivate the inclusion of investment in R&D as a regressor in Equation (12). This means that, since we intend to analyze the effect of CO2 taxation on firms profit efficiency it would be appropriate to add information on investments aiming at reducing CO2 emissions. However, we lack the appropriate data for this exercise, and this problem cannot be addressed within the framework of this study. As is stated in Broberg et al. (2013), data on environmental protection investments collected by Statistics Sweden do not systematically cover this type investments.

The parameters to be estimated in the inefficiency equation given in (12) are $\delta_0, \delta_1, \delta_2, \delta_3$, δ_4, δ_{5s}, and δ_t. Particular focus is then on the significance of the parameters of contemporaneous and dynamic effects of CO_2 taxation, $\hat{\delta}_1$ and $\hat{\delta}_2$, respectively, since they tell us about the validity of the Porter hypothesis. Based on the hypothesis suggesting that there are positive dynamic effects of environmental regulation on profits, the $\hat{\delta}_2$ estimate is expected to take a positive sign. On the other hand, the $\hat{\delta}_1$ estimate can be viewed as capturing static effects of CO_2 taxation. Porter and van der Linde (1995) see the traditional neoclassical view on environmental regulation as being static and too narrow. Therefore, it seems natural not to exclude the possibility of a negative sign for $\hat{\delta}_1$.

4.3 System approaches

As described in previous sections our estimations are based on a single-equation method and, to achieve efficient parameter estimates, a single-stage estimating procedure (maximum likelihood). However, there are other approaches to estimate profit efficiency, such as dual profit system approaches as suggested by Kumbhakar (2001). These systems consist of only cost share equations, or both the profit function and the associated cost share equations. Adopting one of these approaches, the downside is that it is not as straightforward to apply a single-stage estimating procedure. Furthermore, if one considers applying a two-stage estimating procedure, the inefficiency term is assumed identically distributed between firms in estimation with cross sectional data. In estimation with panel data the inefficiency term is assumed time-invariant. Hence, as our purpose is to explain variation in efficiency between firms and over time, these approaches are less attractive to us.

In the presence of both technical and allocative inefficiency the single-equation method adopted in this paper has a short coming – it is not possible to separate the effect of technical inefficiency and the effect of allocative inefficiency on firm profits. To separate these effects a system approach is required (Kumbhakar and Lovell, 2000, p. 195).[20]

5. Data

An overview of the thirteen different sectors in the data set available is provided in Table 1. The data contain information from all firms in the manufacturing sectors in Sweden (SNI 10-37).

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[20] See the shadow price approach in Kumbhakar and Lovell (2000)

Table 1. Swedish manufacturing data.

SNI 2002 (branch code)	**Sector description**
10, 11, 13.1-13.2, 14	Mining
15-16	Food
17-19	Textile
20.1-20.5	Wood
21.11-21.12, 21.21-21.24	Pulp/Paper
22	Printing
23.1-23.3, 24	Chemical
25.1-25.2	Rubber/Plastic
26.1-26.8	Stone/Mineral
27-28	Iron/Steel
29	Machinery
30-33	Electro
34	Motor vehicles

Notes: Industry branch code classification of Swedish manufacturing (SNI 2002) according to Statistics Sweden (www.scb.se).

The data set is a firm level balanced panel covering the years 1990 to 2004.[21] The set contains firms with more than five employees and includes data on output (sales), and input data on quantities and value of labor, electricity and fuels[22], and gross investment. Capital stocks are calculated using gross investment data and the perpetual inventory method together with the assumption that capital stocks are in steady state in 1990.[23] The data also contain detailed

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[21] A sub-set of the unbalanced panel used in Brännlund and Lundgren (2010).

[22] It should be noted that 70-80 percent on average of the fossil fuels is oil of some sort. The rest is natural gas and to some small extent coal. We preferred aggregation like this because it simplifies the econometric estimations. It is possible to separate the different fossil fuels and identify substitution, but often we got non-sensible results (probably because oil is dominating).

[23] The depreciation rate 0.087 is taken from King and Fullerton (1984) and Bergman (1996) who attempt to estimate industry averages for Sweden. We have gross investment data, so the problem when creating capital stocks is to assign a starting value (K_0). We simply do this by assuming that the investment rate in 1990 equals

information on emissions of CO_2 and total payment of CO_2 tax for each firm. We do not have data on marginal taxes paid by each firm. Therefore, we are forced to construct a variable for "effective" CO_2 tax that varies across firms, sectors, and over time, measured as the average tax rate. This means we assume the firms' react the same to a small tax increase as to a large tax increase, which is conflicting with economic theory and evidence. Unfortunately, this is the best we can do with the data we have at hand.

Output price indices[24] are sector-specific, and firm-specific input prices can be calculated from the costs and quantities for electricity and fuels. We assume that output and input prices are exogenous to the firm.

A few descriptive statistics for the different industry sectors are given in Table 2 and Figure 3.[25] As mentioned above, the CO_2 tax varies considerably across sectors, ranging from about 0.04 SEK/kg in the wood product sector to almost 0.15 SEK/kg for Food. These are considerably lower tax rates than the base tax rate for the manufacturing sectors, which is 21 percent of the statutory tax rate of 1.05 SEK/kg. However, as clear from Section 2, manufacturing firms have the opportunity to apply for tax refunds.

The system of tax refund is complicated and may appear as non-transparent. This observation is strengthened by the fact that it from Figure 3 is difficult to discern any particular pattern or relationship between the cost shares of energy and/or fuels and the actual CO_2 tax paid by firms (Figure 3). High use of CO_2 emitting inputs does not necessarily mean high CO_2 tax/kg, or vice versa.

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the depreciation of capital that year for all firms, which admittedly is a bold assumption. By this procedure we are able to "back out" the capital stock for that year. The estimated initial values of capital in 1990 are not crucial for the results, as it is the gross investment that governs the movement of the capital stock. Implicitly, we are assuming there is some relationship between the size of the stock and its flow (gross investments) in 1990. Other ways of assigning initial values for capital stocks, e.g. by using aggregate stocks and weighting with sales to achieve firm stocks, did not alter the results.

[24] Collected from Statistics Sweden; see producer price index section at the website www.scb.se.

[25] For those readers further interested in data issues, please consult Brännlund and Lundgren (2009, 2010) where the same data source is used.

Table 2. Descriptive statistics. Mean values 1990-2004 (base=1990)

	Sector					
Variable	Mining	Food	Textile	Wood	Pulp/paper	Printing
Capital stock (TSEK)	524777	259549	97186	88450	775387	63998
	(1365816)	(509303)	(181651)	(157760)	(1511305)	(102548)
Employees	275	208	148	115	325	142
(number of)	(472)	(227)	(120)	(138)	(308)	(269)
Price electricity	0.292	0.279	0.293	0.296	0.240	0.314
(SEK/Kwh)	(0.126)	(0.080)	(0.093)	(0.096)	(0.087)	(0.096)
Price fossil fuel	0.282	0.286	0.341	0.359	0.235	0.494
(SEK/Kwh)	(0.112)	(0.456)	(0.179)	(0.175)	(0.150)	(0.205)
CO_2 tax	0.074	0.145	0.127	0.041	0.125	0.058
(SEK/Kg)	(0.068)	(0.063)	(0.078)	(0.064)	(0.070)	(0.076)
Nobs.	193	2037	399	1800	1285	945

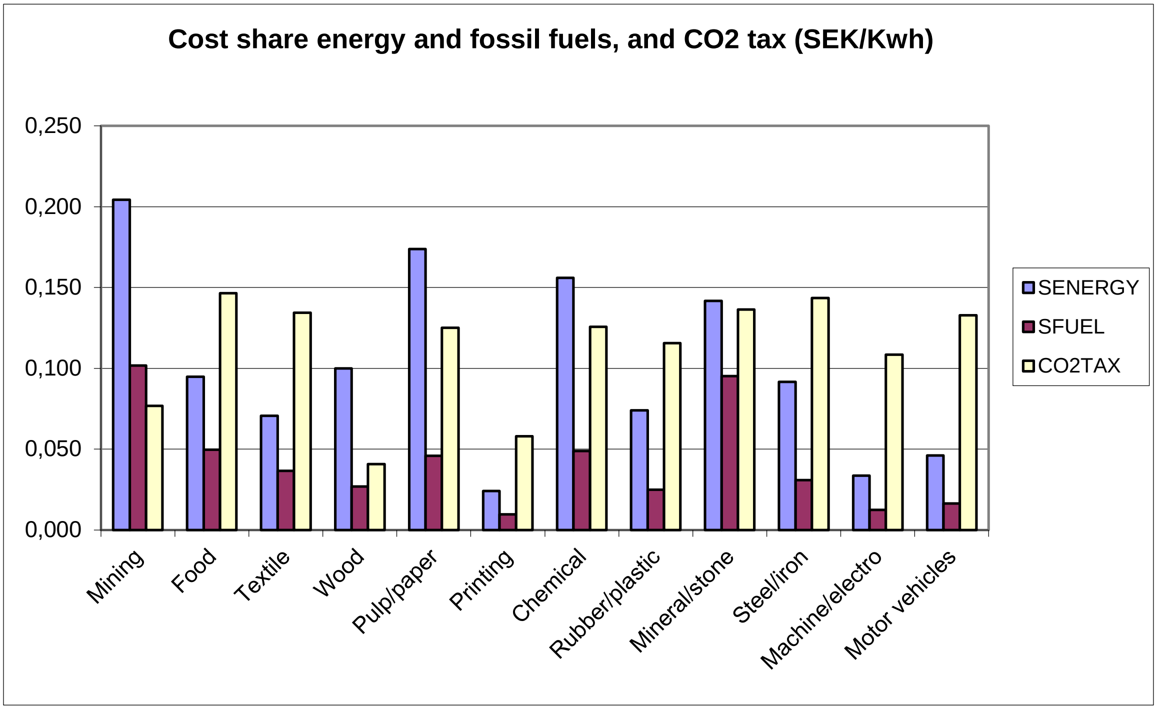
Note: Standard deviation in parenthesis

Table 2. Cont.

	Sector					
Variable	Chemical	Rubber/ plastic	Mineral/ stone	Steel /iron	Machine/ electro	Motor vehicles
Capital stock (TSEK)	631622	113645	108487	191806	238416	581917
	(1717444)	(186114)	(178253)	(479269)	(752930)	(2155773)
Employees	214	140	129	190	228	466
(number of)	(260)	(123)	(122)	(326)	(319)	(1062)
Price electricity	0.259	0.282	0.306	0.292	0.314	0.303
(SEK/Kwh)	(0.105)	(0.074)	(0.096)	(0.086)	(0.093)	(0.091)
Price fossil fuel	0.272	0.369	0.235	0.314	0.395	0.137
(SEK/Kwh)	(0.152)	(0.165)	(0.115)	(0.146)	(0.161)	(0.134)
CO_2 tax	0.123	0.111	0.134	0.137	0.108	0.137
(SEK/Kg)	(0.079)	(0.081)	(0.065)	(0.069)	(0.078)	(0.065)
N obs.	974	917	1042	2753	3649	1098

Note: Standard deviation in parenthesis

Figure 3. Cost share for energy and fossil fuels, and CO_2 tax rate (SEK/Kwh).



In Appendix A we provide additional information about year-by-year mean values at sector level for electricity and fuel prices and the CO_2 tax and its standard deviation.[26] A general pattern is that electricity prices have been trending downward until about 2000, and then turn upward. Fuel prices, on the other hand, trend more or less upward in all sectors. The CO_2 tax varies across sectors but seem quite stable across years. However, the volatility of the CO_2 tax (sdCO2tax in figures) is significant and reveals that there is substantial variation across firms within sectors (and across years).

6. Results

Estimations were performed for all thirteen individual sectors, and two different econometric specifications of the profit function were explored. The profit function and the (in)efficiency part of the error term were estimated simultaneously using maximum likelihood techniques (see Appendix C for the likelihood function). Table 3 contains summarized results. The results we select to present here are the ones with profit function parameters satisfying the

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[26] Note that in Figure 3 and Appendix A we have aggregated the sectors Machines and Electro as they have very similar characteristics when it comes to fuel use and effective tax rates.

desired homogeneity property ($r > 0$) and when SIGMA and GAMMA are statistically significant (i.e., there is inefficiency).[27] Those estimations that do not satisfy these properties cast doubt on the estimated efficiency scores and parameter estimates of the inefficiency equation in (12), and hence we leave them out.

Table 3. Summarized results for the Translog specification.

Sector	Static effect of CO_2 tax δ_1	Dynamic effect of CO_2 tax δ_2	Profit efficiency Score	GAMMA $\gamma = \sigma^2_u/\sigma^2_\varepsilon$	SIGMA $\sigma^2_{\varepsilon=v-u}$	Energy intensive	Number of obs.
Mining	1.399	5.415**	0.539	0.833***	0.150***	Yes	141
Food	-0.625	1.369**	0.567	0.672***	0.338***	Yes	1503
Textile	-3.256	5.463*	0.442	0.947***	0.480***	No	269
Pulp/Paper	-0.850**	-0.990**	0.661	0.503***	0.126***	Yes	951
Printing	0.051	0.377	0.572	0.588***	0.153***	No	639
Chemical	3.337*	-3.889*	0.760	0.445***	0.491***	Yes	688
Stone/ Mineral	2.211***	-1.876***	0.569	0.887***	0.224***	Yes	788
Steel/Iron	-0.248	0.012	0.632	0.514***	0.353***	Yes	1882
Electro	-0.751**	-0.449	0.465	0.935***	0.183***	No	737

*Significant at 10% level. **Significant at 5% level. ***Significant at 1% level.

Our first observation is that there is inefficiency in all the sectors displayed in Table 3a. This is apparent since the GAMMA and SIGMA columns displays statistically significant estimates (which means we are observing inefficiencies). The average profit efficiency scores ranges between 0.442 (Textile) and 0.760 (Chemical), which indicates that profit technical inefficiency is substantial. One reasonable explanation is that this outcome, even though we

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[27] Heterogeneity, especially in some sectors, may cause great variation in efficiency scores. We therefore try to do the sectoral aggregations in a way that this heterogeneity is minimized.

control for size effects and other characteristics, indicates somewhat heterogeneous firms.[28] Furthermore, according to Table 3a, statistically significant and positive dynamic (Porter) effects are found in Mining, Food, and Textile. In these sectors, the static effect is non-significant.[29] Pulp and paper show significant negative effects of the CO_2 tax, both the static and dynamic case, on profit efficiency. This indicates that the CO_2 tax disturbs production in Pulp and paper immediately, and that the firms are not able to take measures, neither immediately nor in the longer term, that neutralize the negative effect of taxation. Chemical and Stone/Mineral show a significant positive static effect, while the dynamic effect is negative; the net effect is, however, negative in Stone/Mineral. A positive static effect indicates that these industries quickly relate CO_2 taxation to resource inefficiency in production, and that they successfully take measures immediately. However, in the longer term these measures come with costs in terms of deteriorated ability to maintain efficiency in production. In Electro CO_2 taxation has a significant negative static impact on profit efficiency, but there is no longer term impact. Profit efficiency in Printing and Steel/Iron seem unaffected by the CO_2 tax.

Other potential effects on profit efficiency, as specified in equation (12), are firm characteristics and a time trend (possibly non-linear). Size matters in some sectors, however, the sign of that effect is ambiguous. Capital intensity seems to be negatively related to efficiency in most sectors (Mining and Textile are exceptions), while the effect of fuel intensity is unclear. Food and Pulp/Paper show an initial negative time trend in efficiency, but

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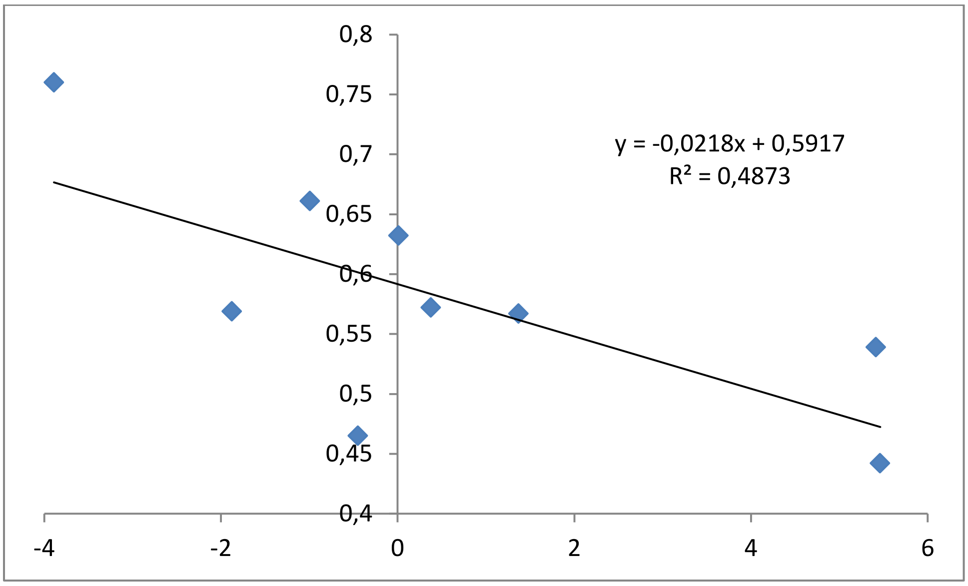
[28] Given that firms produce exactly the same marketed product, differences in efficiency scores between firms will then be due to both technical efficiency (firms produce with more or less productive technologies in each of the firm size categories) and management efficiency (the management of a given technology).

[29] The dynamic effects are restricted to be constant across the different periods. We tried to relax this restriction by interacting the dynamic effect with time in different ways, but no model specification produced converging estimations.

towards the end of the period studied, it turns upward. Other sectors show no clear evidence of time effects.

So is there no detectable pattern in terms of inefficiency and the CO_2 tax across sectors? Without having any ambitions other than to illustrate an interesting question, in Figure 4 we plot the dynamic effect (x-axis) and the efficiency score (y-axis). An ocular inspection (and a trend line) indicates that efficient firms "suffer" (in terms of efficiency) from the tax, while relatively more inefficient sectors improve their efficiency. Without drawing any stronger conclusions, this suggests that there could be an asymmetric effect of taxation on efficiency; i.e., there could be a dynamic Porter effect for the sectors that are most inefficient. However, whether this is a valid conclusion or not needs to be confirmed by more comprehensive and deeper studies.[30]

Figure 4. Dynamic effect δ_2 (x-axis) vs. efficiency score (y-axis), sector level estimates.



6. Discussion and conclusions

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[30] In Figure 4 the Textile sector is situated the most south-east (the most inefficient), and the Chemical sector to the far north-west (most efficient)

According to the strong version of the Porter hypothesis properly crafted environmental regulations have positive dynamic effects on firms' performance in terms of increased productivity and competitiveness. Productivity is determined by the two components, technical efficiency and technological level. In this paper, the main purpose has been to assess empirically the dynamic effects of the Swedish CO_2 tax scheme on manufacturing firms' profit efficiency (a constant multiple of technical efficiency), during the period 1990 to 2004. Particularly, we have assessed the effects of CO_2 taxation on profit efficiency via effects on firms' use of energy input. The task has been accomplished by using a stochastic frontier approach.

Overall, the result shows that the effect of CO_2 taxation on profit efficiency in Swedish industry is not unambiguous. However, on a more general level it seems like the most inefficient sectors become more efficient when they are taxed, and that the most efficient sectors become less efficient (Figure 4). One reasonable explanation in line with the Porter hypothesis is that the increased tax payments make the firms within the inefficient sectors become aware of the inefficiencies and then begin to deal with it. However, the firms within the more efficient sectors do not have this ability to the same extent. To cut the tax costs they instead invest in innovations to develop more productive and less polluting technologies. When firms begin to use newly developed technologies there will be learning costs to consider. During the learning period the firms will operate technically inefficiently below the new technological frontier. That is, innovation-based solutions spurred by taxation cause short-/mid-term costs (in our case two years), which in the analysis appears as increased profit inefficiency. In the defense of the Porter hypothesis, the net effect on productivity may still be positive as technological development can fully offset the decreased profit efficiency. However, this has to be confirmed (or rejected) by future research.

How does our paper relate to previous international literature? Porter and van der Linde (1995) has become one of the most cited articles in the field of research that combines the disciplines of business and environment (Ambec et al., 2013). Both theoretical and empirical studies on various industry sectors have been conducted. However, there are relatively few empirical studies that analyze the impact of what Porter and van der Linde (1995, p 98) argues to be 'properly crafted environmental regulations', i.e., primarily market-based instruments such as pollution taxes and tradable permits (Lanoie et al., 2011). Moreover, Ambec et al. emphasize that previous empirical studies of the Porter hypothesis have not adequately accounted for the dynamic dimension of the hypothesis. This means that environmental regulations are not usually allowed to have lagged impact on productivity and competitiveness and, therefore, it can be questioned whether these studies really test the Porter hypothesis. In this paper, we analyze the effect of a properly crafted environmental instrument (CO2 tax) and allow for lagged effect on profit efficiency (dynamic dimension).

To our knowledge, the only studies that have attempted to measure lagged effects of environmental regulations on firms’ productivity over several years are Managi et al. (2005), Lanoie et al. (2008), and Broberg et al. (2013). The results presented in these studies are not unambiguous. Managi et. al. found no significant effect of environmental regulations on productivity change and technological development in production of the market goods oil and gas in the Gulf of Mexico (this does not necessarily exclude positive effect on technical efficiency change). Lanoie et al. reported that environmental regulations have positive lagged effects on productivity, i.e., technological development (they assume that there is no technical inefficiency) in manufacturing in Quebec, Canada. They also found that the positive lagged effects are stronger in sectors that are more exposed to international competition. [31] Broberg et

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[31] Lanoie et al. (2005, p. 123) measure international competition as: exports + imports / total shipments. They found that the manufacturing sectors in Quebec, Canada, most exposed to international competition are Leather,

al. found indications of environmental regulations leading to losses in the technical efficiency component of productivity in Swedish industry, particularly strong in Pulp and paper. However, whether the results presented in these studies can be used to judge the Porter hypothesis is questionable in one respect; the measures used as proxies for environmental regulations, e.g., cost of complying with command-and-control- types of environmental regulations and investments in pollution control (e.g., end-of-pipe equipment), do not capture properly crafted environmental regulations. According to Porter and van de Linde (1995) command-and-control policies should be seen as a last resort. Broberg et al. use the firms' investments in pollution prevention as a proxy of environmental regulation. However, these investments are not necessarily triggered by market-based policy instruments.

A study that analyzes the impact of a market-based instrument is Brännlund and Lundgren (2010). They report an overall negative impact of CO_2 taxation on profits in Swedish energy intensive industries. However, they only take into account the short-term static effect and the results cannot be used to judge the Porter hypothesis (Porter and van der Linde, 1995 do not rule out short-term costs due to, e,g,, learning effects). Our study complements that of Brännlund and Lundgren. Using a sub-set of their data, we have broadened the picture of the impact of CO_2 taxation and especially its dynamic mid-term effects on efficiency and profits in Swedish manufacturing.

There are several interesting topics of future research in this area. For example, a natural step would be to also allow for allocative inefficiency in production, and analyzing whether CO_2 taxation has impact on this type of efficiency. This would indicate whether taxation has effect on firms input mix in production, e.g., different types of energy inputs, which is a particularly

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Paper and allied products, Primary metals, Machinery, Transportation equipment, Electrical and electronic products, and Chemicals.

important research question in support for climate policy. Furthermore, the EU attaches great importance to tradable permits via its Emission Trading System (EU-ETS). The literature on environmental regulation and its impact on firm performance, in terms of giving incentives to productivity growth is extensive, but rarely consider tradable permits such as the EU-ETS. As data from the first trading period, 2005-2008, is becoming readily available, more applications to the EU-ETS is to be expected (one recent example is Jaraite and Di Maria, 2011). Also, simultaneously assessing how environmental policy such as the CO_2 tax is connected to actual environmental performance of firms and, in turn, its relation to firm profitability, would give a more complete view of how policy and different types of firm performance are linked together.

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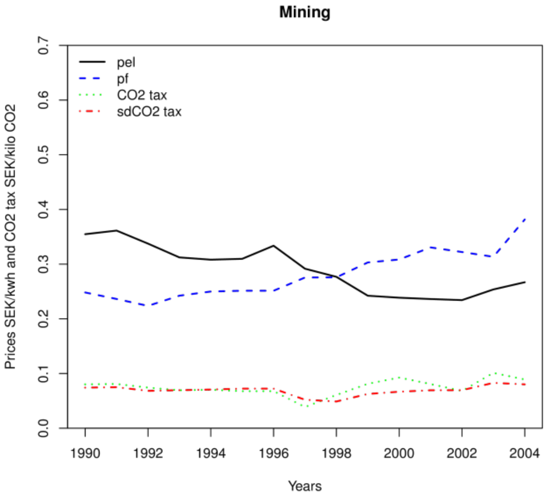
Appendix A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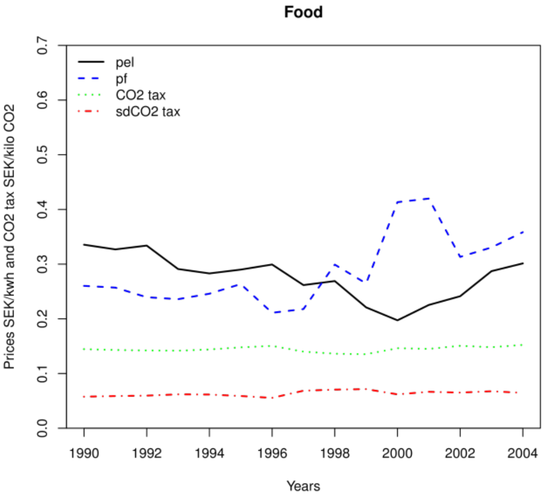
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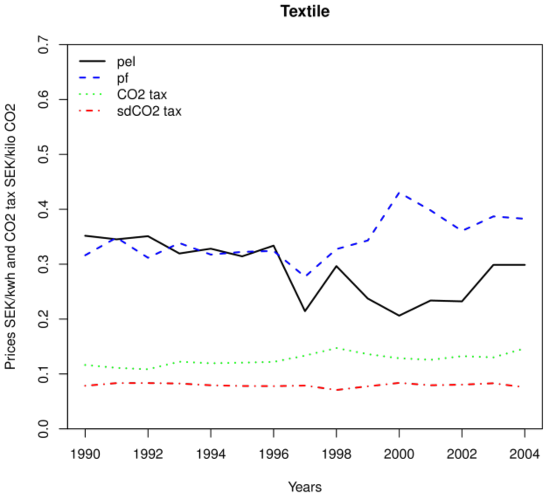
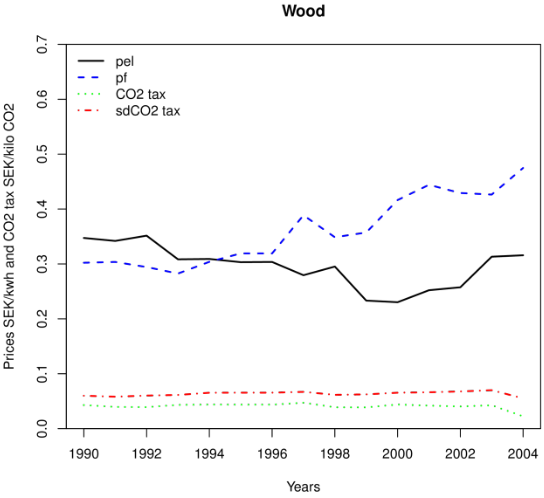
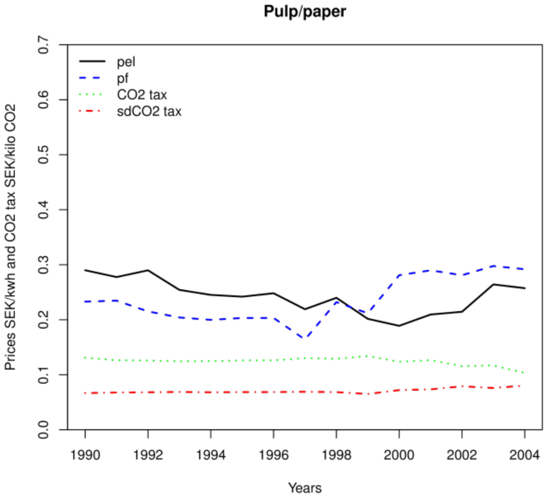
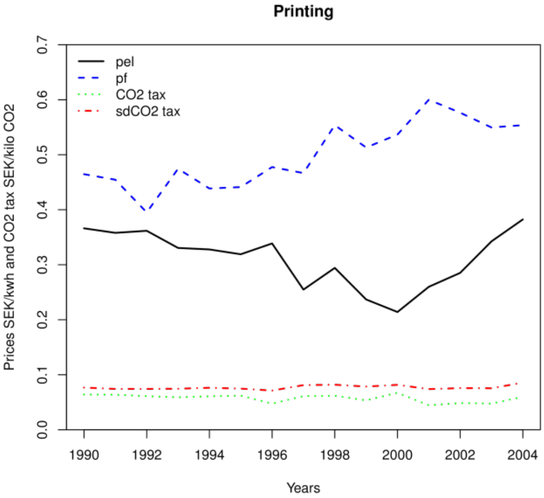
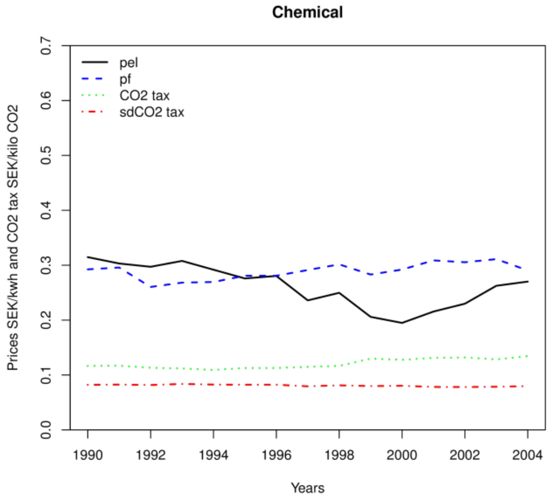
2004
Years

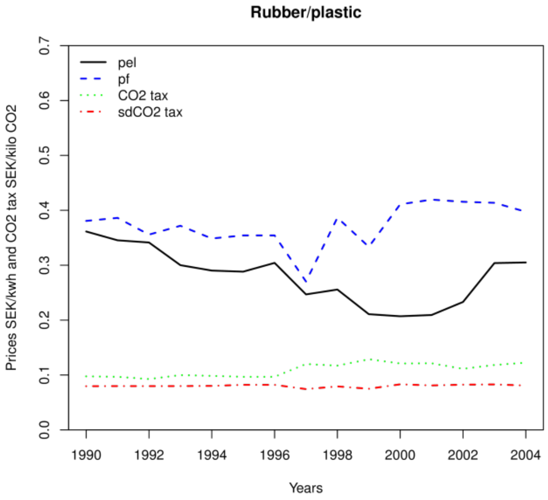

Textile
pel
pf
CO2 tax
sdCO2 tax
Prices SEK/kwh and CO2 tax SEK/kilo CO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1990
1992
1994
1996
1998
2000
2002
2004
Years

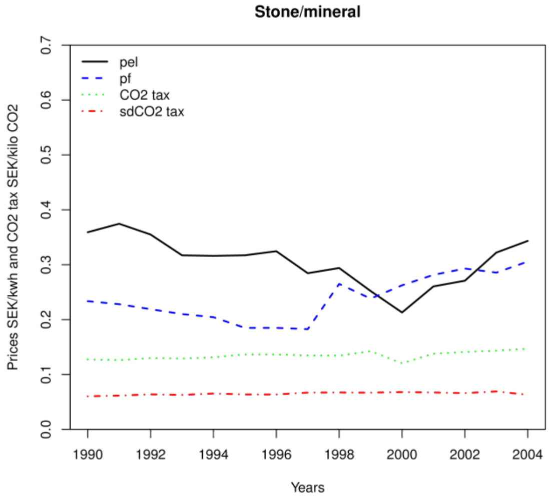

Wood
pel
pf
CO2 tax
sdCO2 tax
Prices SEK/kwh and CO2 tax SEK/kilo CO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1990
1992
1994
1996
1998
2000
2002
2004
Years

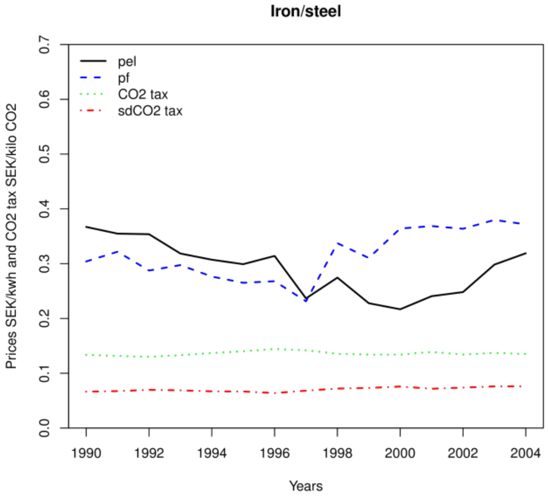

Pulp/paper
pel
pf
CO2 tax
sdCO2 tax
Prices SEK/kwh and CO2 tax SEK/kilo CO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1990
1992
1994
1996
1998
2000
2002
2004
Years

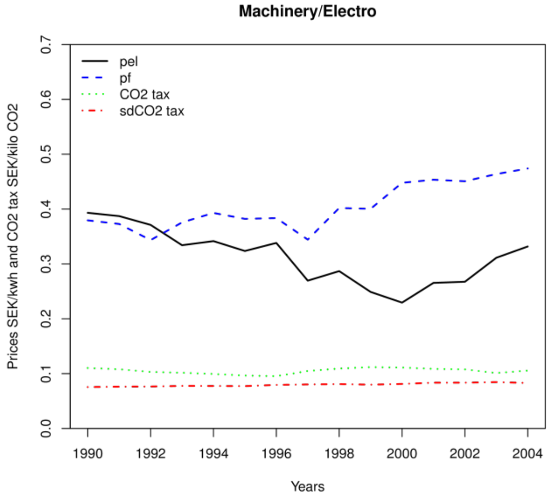

Printing
pel
pf
CO2 tax
sdCO2 tax
Prices SEK/kwh and CO2 tax SEK/kilo CO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1990
1992
1994
1996
1998
2000
2002
2004
Years

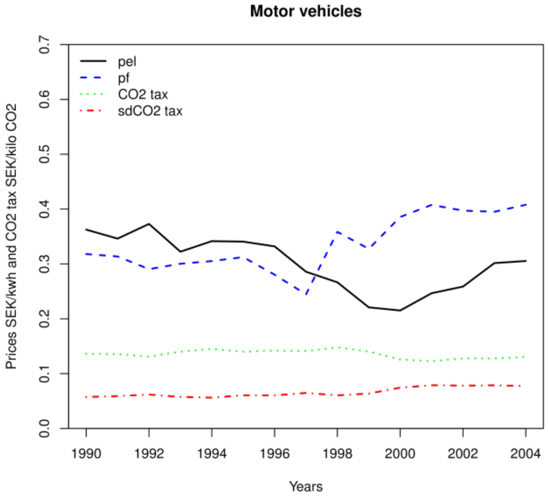

Chemical
pel
pf
CO2 tax
sdCO2 tax
Prices SEK/kwh and CO2 tax SEK/kilo CO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1990
1992
1994
1996
1998
2000
2002
2004
Years


Rubber/plastic
pel
pf
CO2 tax
sdCO2 tax
Prices SEK/kwh and CO2 tax SEK/kilo CO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1990
1992
1994
1996
1998
2000
2002
2004
Years


Stone/mineral
pel
pf
CO2 tax
sdCO2 tax
Prices SEK/kwh and CO2 tax SEK/kilo CO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1990
1992
1994
1996
1998
2000
2002
2004
Years


Iron/steel
pel
pf
CO2 tax
sdCO2 tax
Prices SEK/kwh and CO2 tax SEK/kilo CO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1990
1992
1994
1996
1998
2000
2002
2004
Years


Machinery/Electro
pel
pf
CO2 tax
sdCO2 tax
Prices SEK/kwh and CO2 tax SEK/kilo CO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1990
1992
1994
1996
1998
2000
2002
2004
Years


Motor vehicles
pel
pf
CO2 tax
sdCO2 tax
Prices SEK/kwh and CO2 tax SEK/kilo CO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1990
1992
1994
1996
1998
2000
2002
2004
Years

Appendix B.

Estimation results for Translog (TL) and Cobb-Douglas (CD) specifications with capital and labor as quasi-fixed inputs.

Mining TL

Parameter	**Estimate**	**Error**	**t-statistic**	**P-value**
A0	-0.7798	2.4165	-0.3227	[.747]
A1	1.4223	0.5689	2.5000	[.012]
A2	-1.2789	0.6990	-1.8297	[.067]
A3	-0.1362	0.7032	-0.1937	[.846]
A4	-0.2366	0.6627	-0.3570	[.721]
A11	-0.2719	0.0880	-3.0892	[.002]
A12	0.4002	0.1255	3.1891	[.001]
A13	-0.0431	0.1028	-0.4193	[.675]
A22	-0.5772	0.1981	-2.9131	[.004]
A23	0.1029	0.1473	0.6986	[.485]
A33	0.0467	0.1681	0.2778	[.781]
BT	-0.3394	0.0900	-3.7705	[.000]
D0	-4.7748	0.7998	-5.9698	[.000]
D1	1.3999	1.6835	0.8315	[.406]
D2	5.4154	2.7315	1.9826	[.047]
SD1	0.8175	0.3398	2.4056	[.016]
SD2	1.3707	0.8039	1.7052	[.088]
SD3	-0.1644	0.4034	-0.4074	[.684]
D3	0.0003	0.0001	1.8943	[.058]
D4	-0.0002	0.0003	-0.7401	[.459]
DT	0.5252	0.1634	3.2143	[.001]
DT2	-0.0191	0.0094	-2.0165	[.044]
GAMMA	0.8339	0.0914	9.1245	[.000]
S2	0.1508	0.0290	5.2044	[.000]
Nobs	**Logl**	**BIC**		
141	-24.113	85.973		
AP (1-A3-A4)	1.3728			
r	0.2715			
TE	0.6380			
PE	0.5396			

Mining CD

Parameter	**Estimate**	**Error**	**t-statistic**	**P-value**
A0	1.3366	0.9225	1.4489	[.147]
A1	0.0086	0.0547	0.1580	[.874]
A2	0.8831	0.0765	11.5451	[.000]
A3	-0.2501	0.0997	-2.5093	[.012]
A4	-0.0742	0.0992	-0.7485	[.454]
BT	-0.0203	0.0150	-1.3496	[.177]
D0	-2.8267	0.5743	-4.9222	[.000]
D1	1.9945	1.6629	1.1994	[.230]
D2	4.1342	1.8597	2.2230	[.026]
SD1	0.8260	0.2672	3.0909	[.002]
SD2	1.3815	0.3879	3.5616	[.000]
SD3	0.0169	0.2845	0.0593	[.953]
D3	0.0002	0.0001	2.3666	[.018]
D4	-0.0003	0.0002	-1.3778	[.168]
DT	0.1189	0.1192	0.9974	[.319]
DT2	0.0028	0.0083	0.3393	[.734]
GAMMA	0.5414	0.1556	3.4789	[.001]
S2	0.1431	0.0291	4.9175	[.000]
Nobs	**Logl**	**BIC**		
141	-41.119	85.657		
AP (1-A3-A4)	1.3243			
r	0.2449			
TE	0.6943			
PE	0.6168			

Parameter	**Variable in logs**
A0	Constant in profit function
A1	Capital
A2	Labor
A3	Price electricity
A4	Price fuel
A11	Capital^2
A12	Capital*Labor
A13	Capital*(Price fuel)/(Price electricity)
A22	Labor^2
A23	Labor*(Price fuel)/(Price electricity)
A33	((Price fuel)/(Price electricity))^2

Parameter	**Variable in logs**
BT	Time
D0	Constant in u-function
D1	CO2 tax(t)
D2	MA(-1.-3) CO2 tax
SD1	Small size dummy
SD2	Medium size dummy
SD3	Large size dummy
D3	Capital intensity
D4	Fuel intensity
DT	Time
DT2	Time^2

Food TL

Parameter	Estimate	Error	t-statistic	P-value
A0	-2.4406	1.1128	-2.1932	[.028]
A1	0.6439	0.2404	2.6784	[.007]
A2	0.8631	0.2646	3.2624	[.001]
A3	-0.1408	0.2463	-0.5719	[.567]
A4	-0.1118	0.2454	-0.4556	[.649]
A11	-0.0859	0.0364	-2.3621	[.018]
A12	0.1292	0.0430	3.0009	[.003]
A13	-0.0220	0.0301	-0.7326	[.464]
A22	-0.3585	0.0546	-6.5632	[.000]
A23	0.0518	0.0313	1.6566	[.098]
A33	-0.0689	0.0427	-1.6126	[.107]
BT	0.0113	0.0060	1.8935	[.058]
D0	0.4374	0.4303	1.0164	[.309]
D1	-0.6259	0.5709	-1.0964	[.273]
D2	1.3695	0.5895	2.3234	[.020]
SD1	-0.3934	0.1583	-2.4845	[.013]
SD2	-0.4015	0.1497	-2.6815	[.007]
SD3	-0.2211	0.1285	-1.7207	[.085]
D3	0.0001	0.0001	1.3054	[.192]
D4	0.0003	0.0003	1.3038	[.192]
DT	-0.1316	0.0500	-2.6333	[.008]
DT2	0.0068	0.0026	2.6466	[.008]
GAMMA	0.6726	0.0389	17.2711	[.000]
S2	0.3386	0.0412	8.2162	[.000]
Nobs	**Logl**	**BIC**		
1503	-1437.1	1524.9		
AP (1-A3-A4)	1.2527			
r	0.2017			
TE	0.6366			
PE	0.5679			

Food CD

Parameter	Estimate	Error	t-statistic	P-value
A0	-0.0905	0.3429	-0.2640	[.792]
A1	0.3000	0.0222	13.5390	[.000]
A2	0.6065	0.0345	17.5921	[.000]
A3	-0.1223	0.0304	-4.0230	[.000]
A4	-0.1308	0.0391	-3.3419	[.001]
BT	0.0122	0.0065	1.8621	[.063]
D0	0.4553	0.4727	0.9633	[.335]
D1	-0.5707	0.6138	-0.9299	[.352]
D2	1.1768	0.6454	1.8234	[.068]
SD1	-0.1411	0.1294	-1.0905	[.275]
SD2	0.0008	0.1030	0.0076	[.994]
SD3	0.1104	0.1108	0.9968	[.319]
D3	-0.0001	0.0000	-2.9724	[.003]
D4	0.0003	0.0002	1.3503	[.177]
DT	-0.1437	0.0606	-2.3720	[.018]
DT2	0.0075	0.0031	2.3773	[.017]
GAMMA	0.6431	0.0443	14.5026	[.000]
S2	0.3558	0.0522	6.8122	[.000]
Nobs	**Logl**	**BIC**		
1503	-1468.6	1534.4		
AP (1-A3-A4)	1.2531			
r	0.2020			
TE	0.6494			
PE	0.5821			

Parameter	Variable in logs	Parameter	Variable in logs
A0	Constant in profit function	BT	Time
A1	Capital	D0	Constant in u-function
A2	Labor	D1	CO2 tax(t)
A3	Price electricity	D2	MA(-1.-3) CO2 tax
A4	Price fuel	SD1	Small size dummy
A11	Capital^2	SD2	Medium size dummy
A12	Capital*Labor	SD3	Large size dummy
A13	Capital*(Price fuel)/(Price electricity)	D3	Capital intensity
A22	Labor^2	D4	Fuel intensity
A23	Labor*(Price fuel)/(Price electricity)	DT	Time
A33	((Price fuel)/(Price electricity))^2	DT2	Time^2

Textile TL

Parameter	Estimate	Error	t-statistic	P-value
A0	2.2171	6.6975	0.3310	[.741]
A1	-0.9401	1.1638	-0.8077	[.419]
A2	1.8326	1.3090	1.4000	[.162]
A3	-1.2671	1.1266	-1.1247	[.261]
A4	1.0225	1.1531	0.8868	[.375]
A11	0.0662	0.1598	0.4144	[.679]
A12	0.1035	0.2394	0.4324	[.665]
A13	0.1670	0.1740	0.9600	[.337]
A22	-0.5132	0.3361	-1.5269	[.127]
A23	-0.0835	0.2318	-0.3604	[.719]
A33	-0.3434	0.1745	-1.9678	[.049]
BT	0.6866	0.2914	2.3566	[.018]
D0	-0.6170	1.0889	-0.5666	[.571]
D1	-3.2560	3.0496	-1.0677	[.286]
D2	5.4637	3.0794	1.7743	[.076]
SD1	-0.4900	0.5442	-0.9003	[.368]
SD2	-0.1227	0.5812	-0.2112	[.833]
SD3	0.9117	0.5641	1.6161	[.106]
D3	0.0007	0.0006	1.1131	[.266]
D4	0.0004	0.0010	0.4026	[.687]
DT	-0.1197	0.1969	-0.6079	[.543]
DT2	0.0086	0.0103	0.8407	[.401]
GAMMA	0.9477	0.0333	28.4526	[.000]
S2	0.4800	0.0547	8.7774	[.000]
Nobs	**Logl**	**BIC**		
269	-183.26	255.99		
AP (1-A3-A4)	1.2445			
r	0.1965			
TE	0.5198			
PE	0.4429			

Textile CD

Parameter	Estimate	Error	t-statistic	P-value
A0	-1.6222	1.6612	-0.9765	[.329]
A1	0.2402	0.1151	2.0879	[.037]
A2	0.6430	0.1602	4.0130	[.000]
A3	0.1351	0.0867	1.5586	[.119]
A4	-0.3903	0.1340	-2.9133	[.004]
BT	0.6522	0.2909	2.2417	[.025]
D0	-0.9450	0.8771	-1.0774	[.281]
D1	-0.6037	1.8002	-0.3354	[.737]
D2	3.3892	1.9725	1.7182	[.086]
SD1	0.1639	0.3194	0.5130	[.608]
SD2	0.4492	0.2894	1.5523	[.121]
SD3	0.9398	0.3773	2.4909	[.013]
D3	0.0008	0.0005	1.6616	[.097]
D4	0.0002	0.0008	0.2090	[.834]
DT	-0.2140	0.1735	-1.2332	[.218]
DT2	0.0135	0.0094	1.4338	[.152]
GAMMA	0.8961	0.0507	17.6782	[.000]
S2	0.4101	0.0949	4.3197	[.000]
Nobs	**Logl**	**BIC**		
269	-189.31	245.26		
AP (1-A3-A4)	1.2555			
r	0.2035			
TE	0.5134			
PE	0.4330			

Parameter	Variable in logs
A0	Constant in profit function
A1	Capital
A2	Labor
A3	Price electricity
A4	Price fuel
A11	Capital^2
A12	Capital*Labor
A13	Capital*(Price fuel)/(Price electricity)
A22	Labor^2
A23	Labor*(Price fuel)/(Price electricity)
A33	((Price fuel)/(Price electricity))^2

Parameter	Variable in logs
BT	Time
D0	Constant in u-function
D1	CO2 tax(t)
D2	MA(-1.-3) CO2 tax
SD1	Small size dummy
SD2	Medium size dummy
SD3	Large size dummy
D3	Capital intensity
D4	Fuel intensity
DT	Time
DT2	Time^2

Pulp/paper TL

Parameter	Estimate	Error	t-statistic	P-value
A0	3.6120	0.9484	3.8085	[.000]
A1	-0.6419	0.2527	-2.5398	[.011]
A2	1.1237	0.3310	3.3950	[.001]
A3	-0.2360	0.1907	-1.2372	[.216]
A4	-0.0477	0.1974	-0.2419	[.809]
A11	0.1069	0.0434	2.4624	[.014]
A12	-0.0592	0.0539	-1.0976	[.272]
A13	-0.0631	0.0263	-2.3958	[.017]
A22	0.0190	0.0706	0.2685	[.788]
A23	0.1799	0.0379	4.7493	[.000]
A33	0.0125	0.0256	0.4863	[.627]
BT	0.0189	0.0063	3.0106	[.003]
D0	0.5506	0.2481	2.2196	[.026]
D1	-0.8509	0.3917	-2.1726	[.030]
D2	-0.9906	0.3974	-2.4926	[.013]
SD1	-0.6417	0.1017	-6.3121	[.000]
SD2	-0.4270	0.0946	-4.5135	[.000]
SD3	-0.2072	0.0956	-2.1667	[.030]
D3	-0.0001	0.0000	-2.3655	[.018]
D4	0.0010	0.0002	4.4511	[.000]
DT	-0.0676	0.0362	-1.8654	[.062]
DT2	0.0037	0.0019	2.0073	[.045]
GAMMA	0.5032	0.0882	5.7024	[.000]
S2	0.1260	0.0103	12.2374	[.000]
Nobs	**Logl**	**BIC**		
951	-249.63	331.92		
AP (1-A3-A4)	1.2837			
r	0.2210			
TE	0.7249			
PE	0.6617			

Pulp/paper CD

Parameter	Estimate	Error	t-statistic	P-value
A0	-1.4332	0.1821	-7.8705	[.000]
A1	0.3624	0.0113	32.0590	[.000]
A2	0.5801	0.0175	33.0907	[.000]
A3	-0.0349	0.0114	-3.0544	[.002]
A4	-0.2675	0.0233	-11.4706	[.000]
BT	0.0205	0.0032	6.3672	[.000]
D0	0.8871	0.1845	4.8078	[.000]
D1	-0.6546	0.2863	-2.2866	[.022]
D2	-1.7696	0.3152	-5.6137	[.000]
SD1	-0.5163	0.0613	-8.4178	[.000]
SD2	-0.1967	0.0508	-3.8727	[.000]
SD3	-0.0109	0.0549	-0.1983	[.843]
D3	-0.0001	0.0000	-4.2874	[.000]
D4	0.0008	0.0001	6.4803	[.000]
DT	-0.1414	0.0278	-5.0807	[.000]
DT2	0.0072	0.0015	4.9316	[.000]
GAMMA	0.6942	0.0309	22.4935	[.000]
S2	0.1010	0.0069	14.6920	[.000]
Nobs	**Logl**	**BIC**		
951	-413.21	474.92		
AP (1-A3-A4)	1.3023			
r	0.2322			
TE	0.7246			
PE	0.6573			

Parameter	Variable in logs
A0	Constant in profit function
A1	Capital
A2	Labor
A3	Price electricity
A4	Price fuel
A11	Capital^2
A12	Capital*Labor
A13	Capital*(Price fuel)/(Price electricity)
A22	Labor^2
A23	Labor*(Price fuel)/(Price electricity)
A33	((Price fuel)/(Price electricity))^2

Parameter	Variable in logs
BT	Time
D0	Constant in u-function
D1	CO2 tax(t)
D2	MA(-1.-3) CO2 tax
SD1	Small size dummy
SD2	Medium size dummy
SD3	Large size dummy
D3	Capital intensity
D4	Fuel intensity
DT	Time
DT2	Time^2

Printing TL

Parameter	**Estimate**	**Error**	**t-statistic**	**P-value**
A0	-2.3569	1.3344	-1.7663	[.077]
A1	1.5416	0.4075	3.7830	[.000]
A2	-0.7237	0.4544	-1.5927	[.111]
A3	-0.2693	0.3417	-0.7881	[.431]
A4	0.1897	0.3267	0.5805	[.562]
A11	-0.2288	0.0706	-3.2419	[.001]
A12	0.2394	0.0872	2.7446	[.006]
A13	0.0102	0.0470	0.2163	[.829]
A22	-0.2390	0.1404	-1.7024	[.089]
A23	0.0405	0.0641	0.6308	[.528]
A33	-0.0732	0.0554	-1.3208	[.187]
BT	-0.1947	0.1798	-1.0831	[.279]
D0	-1.8872	0.5538	-3.4078	[.001]
D1	0.0516	0.7086	0.0728	[.942]
D2	0.3774	0.5684	0.6640	[.507]
SD1	-0.0196	0.1718	-0.1141	[.909]
SD2	-0.0112	0.1469	-0.0765	[.939]
SD3	-0.0691	0.1930	-0.3582	[.720]
D3	0.0005	0.0002	2.5214	[.012]
D4	0.0147	0.0067	2.1805	[.029]
DT	0.1738	0.1084	1.6037	[.109]
DT2	-0.0065	0.0054	-1.2208	[.222]
GAMMA	0.5880	0.1166	5.0423	[.000]
S2	0.1534	0.0125	12.2896	[.000]
Nobs	**Logl**	**BIC**		
639	-251.26	335.23		
AP (1-A3-A4)	1.0797			
r	0.0738			
TE	0.5968			
PE	0.5727			

Printing CD

Parameter	**Estimate**	**Error**	**t-statistic**	**P-value**
A0	-2.1482	0.3683	-5.8333	[.000]
A1	0.4765	0.0272	17.4905	[.000]
A2	0.4427	0.0391	11.3339	[.000]
A3	-0.0697	0.0419	-1.6644	[.096]
A4	-0.0720	0.0531	-1.3568	[.175]
BT	0.0312	0.0088	3.5290	[.000]
D0	8.5518	10.033	0.8524	[.394]
D1	0.4757	4.1452	0.1147	[.909]
D2	-1.6532	4.3965	-0.3760	[.707]
SD1	-1.0517	1.3241	-0.7942	[.427]
SD2	0.0302	1.2185	0.0248	[.980]
SD3	-0.9910	1.5839	-0.6256	[.532]
D3	-0.0011	0.0012	-0.8785	[.380]
D4	0.0436	0.0657	0.6634	[.507]
DT	-0.9884	1.1533	-0.8570	[.391]
DT2	0.0381	0.0455	0.8388	[.402]
GAMMA	0.7999	0.1614	4.9563	[.000]
S2	0.4904	0.4146	1.1831	[.237]
Nobs	**Logl**	**BIC**		
639	-258.89	317.03		
AP (1-A3-A4)	1.1418			
r	0.1242			
TE	0.8360			
PE	0.8151			

Parameter	**Variable in logs**
A0	Constant in profit function
A1	Capital
A2	Labor
A3	Price electricity
A4	Price fuel
A11	Capital^2
A12	Capital*Labor
A13	Capital*(Price fuel)/(Price electricity)
A22	Labor^2
A23	Labor*(Price fuel)/(Price electricity)
A33	((Price fuel)/(Price electricity))^2

Parameter	**Variable in logs**
BT	Time
D0	Constant in u-function
D1	CO2 tax(t)
D2	MA(-1.-3) CO2 tax
SD1	Small size dummy
SD2	Medium size dummy
SD3	Large size dummy
D3	Capital intensity
D4	Fuel intensity
DT	Time
DT2	Time^2

Parameter	Estimate	Error	t-statistic	P-value
A0	9.7940	1.3199	7.4203	[.000]
A1	-1.7758	0.3159	-5.6211	[.000]
A2	1.4982	0.4908	3.0523	[.002]
A3	0.5067	0.3149	-1.6088	[.108]
A4	-0.6442	0.3083	2.0899	[.037]
A11	0.2427	0.0520	4.6676	[.000]
A12	-0.0701	0.0710	-0.9875	[.323]
A13	0.0681	0.0443	1.5364	[.124]
A22	-0.1019	0.0948	-1.0750	[.282]
A23	-0.0556	0.0728	-0.7646	[.445]
A33	-0.0271	0.0426	-0.6374	[.524]
BT	0.0647	0.0137	4.7292	[.000]
D0	13.3721	3.4788	3.8439	[.000]
D1	3.3370	1.8839	1.7713	[.077]
D2	-3.8890	2.1681	-1.7937	[.073]
SD1	0.3495	0.2916	1.1984	[.231]
SD2	0.1921	0.2505	0.7667	[.443]
SD3	0.0854	0.2144	0.3983	[.690]
D3	-0.0003	0.0001	-5.9404	[.000]
D4	0.0001	0.0001	1.5862	[.113]
DT	-2.1897	0.5703	-3.8398	[.000]
DT2	0.0896	0.0245	3.6487	[.000]
GAMMA	0.4454	0.1291	3.4491	[.001]
S2	0.4911	0.0910	5.3940	[.000]
Nobs	**Logl**	**BIC**		
688	-588.08	666.489		
AP (1-A3-A4)	1.1375			
r	0.1209			
TE	0.7863			
PE	0.7607			

Parameter	Estimate	Error	t-statistic	P-value
A0	-3.4724	0.3257	-10.6603	[.000]
A1	0.7242	0.0114	63.3549	[.000]
A2	0.1483	0.0264	5.6220	[.000]
A3	0.1070	0.0165	6.5028	[.000]
A4	-0.1133	0.0340	-3.3278	[.001]
BT	0.9525	0.0623	15.2788	[.000]
D0	0.8882	0.1998	4.4460	[.000]
D1	2.6063	0.4512	5.7760	[.000]
D2	-4.3028	0.5065	-8.4959	[.000]
SD1	-0.2621	0.0772	-3.3939	[.001]
SD2	-0.2777	0.0644	-4.3137	[.000]
SD3	-0.3043	0.0619	-4.9156	[.000]
D3	-0.0004	0.0000	-34.3040	[.000]
D4	0.0001	0.0000	9.7209	[.000]
DT	-0.0522	0.0446	-1.1704	[.242]
DT2	0.0032	0.0024	1.3610	[.174]
GAMMA	0.8775	0.0103	85.0666	[.000]
S2	0.2772	0.0114	24.3038	[.000]
Nobs	**Logl**	**BIC**		
688	-1202.4	1267.7		
AP (1-A3-A4)	1.0063			
r	0.0062			
TE	0.5080			
PE	0.5059			

Parameter	Variable in logs
A0	Constant in profit function
A1	Capital
A2	Labor
A3	Price electricity
A4	Price fuel
A11	Capital^2
A12	Capital*Labor
A13	Capital*(Price fuel)/(Price electricity)
A22	Labor^2
A23	Labor*(Price fuel)/(Price electricity)
A33	((Price fuel)/(Price electricity))^2

Parameter	Variable in logs
BT	Time
D0	Constant in u-function
D1	CO2 tax(t)
D2	MA(-1.-3) CO2 tax
SD1	Small size dummy
SD2	Medium size dummy
SD3	Large size dummy
D3	Capital intensity
D4	Fuel intensity
DT	Time
DT2	Time^2

Stone/mineral TL

Parameter	Estimate	Error	t-statistic	P-value
A0	0.6041	0.7239	0.8345	[.404]
A1	0.1538	0.2247	0.6844	[.494]
A2	0.7174	0.2373	3.0233	[.003]
A3	0.6115	0.1608	3.8025	[.000]
A4	-0.6825	0.1515	-4.5045	[.000]
A11	0.0068	0.0361	0.1893	[.850]
A12	0.0211	0.0368	0.5749	[.565]
A13	-0.1260	0.0244	-5.1531	[.000]
A22	-0.0695	0.0444	-1.5664	[.117]
A23	0.1515	0.0323	4.6918	[.000]
A33	0.0640	0.0410	1.5593	[.119]
BT	0.0218	0.0029	7.5152	[.000]
D0	-0.0546	0.1780	-0.3069	[.759]
D1	2.2117	0.5980	3.6985	[.000]
D2	-1.8763	0.6541	-2.8684	[.004]
SD1	-0.3492	0.1105	-3.1612	[.002]
SD2	-0.2283	0.1031	-2.2146	[.027]
SD3	-0.5069	0.1036	-4.8938	[.000]
D3	0.0000	0.0000	-0.9219	[.357]
D4	-0.0001	0.0000	-5.2788	[.000]
DT	0.0052	0.0282	0.1855	[.853]
DT2	0.0014	0.0016	0.9142	[.361]
GAMMA	0.8875	0.0144	61.6919	[.000]
S2	0.2247	0.0123	18.2337	[.000]
Nobs	**Logl**	**BIC**		
788	-778.20	859.435		
AP (1-A3-A4)	1.0710			
r	0.0663			
TE	0.5912			
PE	0.5695			

Stone/mineral CD

Parameter	Estimate	Error	t-statistic	P-value
A0	-0.4588	0.1942	-2.3626	[.018]
A1	0.3498	0.0145	24.1812	[.000]
A2	0.5787	0.0190	30.4173	[.000]
A3	-0.1301	0.0169	-7.7074	[.000]
A4	0.0089	0.0294	0.3039	[.761]
BT	0.0223	0.0026	8.6664	[.000]
D0	0.2195	0.1638	1.3402	[.180]
D1	3.8543	0.4852	7.9438	[.000]
D2	-4.7286	0.5360	-8.8226	[.000]
SD1	-0.5643	0.0746	-7.5610	[.000]
SD2	-0.5188	0.0720	-7.2061	[.000]
SD3	-0.6392	0.0800	-7.9883	[.000]
D3	-0.0001	0.0000	-2.8135	[.005]
D4	-0.0001	0.0000	-11.9005	[.000]
DT	0.0093	0.0262	0.3563	[.722]
DT2	0.0021	0.0014	1.5747	[.115]
GAMMA	0.8888	0.0145	61.5002	[.000]
S2	0.1713	0.0068	25.2016	[.000]
Nobs	**Logl**	**BIC**		
788	-857.20	917.23		
AP (1-A3-A4)	1.1212			
r	0.1081			
TE	0.5847			
PE	0.5479			

Parameter	Variable in logs
A0	Constant in profit function
A1	Capital
A2	Labor
A3	Price electricity
A4	Price fuel
A11	Capital^2
A12	Capital*Labor
A13	Capital*(Price fuel)/(Price electricity)
A22	Labor^2
A23	Labor*(Price fuel)/(Price electricity)
A33	((Price fuel)/(Price electricity))^2

Parameter	Variable in logs
BT	Time
D0	Constant in u-function
D1	CO2 tax(t)
D2	MA(-1.-3) CO2 tax
SD1	Small size dummy
SD2	Medium size dummy
SD3	Large size dummy
D3	Capital intensity
D4	Fuel intensity
DT	Time
DT2	Time^2

Steel/iron TL

Parameter	**Estimate**	**Error**	**t-statistic**	**P-value**
A0	1.7355	0.8532	2.0341	[.042]
A1	-1.1344	0.2380	-4.7658	[.000]
A2	2.0005	0.2631	7.6029	[.000]
A3	0.5929	0.2025	2.9283	[.003]
A4	-1.0222	0.1983	-5.1560	[.000]
A11	0.1941	0.0395	4.9095	[.000]
A12	-0.1278	0.0450	-2.8410	[.004]
A13	-0.1046	0.0296	-3.5335	[.000]
A22	0.0290	0.0575	0.5050	[.614]
A23	0.0668	0.0398	1.6804	[.093]
A33	-0.0239	0.0497	-0.4804	[.631]
BT	0.0323	0.0053	6.1061	[.000]
D0	0.3158	0.3244	0.9734	[.330]
D1	-0.2458	0.8645	-0.2843	[.776]
D2	0.0126	0.7872	0.0160	[.987]
SD1	0.0851	0.1217	0.6990	[.485]
SD2	0.1738	0.1198	1.4506	[.147]
SD3	0.1360	0.1227	1.1081	[.268]
D3	-0.0004	0.0000	-8.3890	[.000]
D4	0.0003	0.0002	1.9501	[.051]
DT	-0.0394	0.0479	-0.8235	[.410]
DT2	0.0022	0.0024	0.9264	[.354]
GAMMA	0.5140	0.0296	17.3834	[.000]
S2	0.3538	0.0194	18.2527	[.000]
Nobs	**Logl**	**BIC**		
1882	-1924.8	2016.2		
AP (1-A3-A4)	1.4293			
r	0.3003			
TE	0.7254			
PE	0.6320			

Steel/iron CD

Parameter	**Estimate**	**Error**	**t-statistic**	**P-value**
A0	-3.5830	0.2594	-13.8148	[.000]
A1	0.3403	0.0190	17.8763	[.000]
A2	0.8034	0.0291	27.5832	[.000]
A3	-0.2697	0.0285	-9.4556	[.000]
A4	-0.1888	0.0403	-4.6904	[.000]
BT	0.0357	0.0055	6.4599	[.000]
D0	0.2113	0.3650	0.5790	[.563]
D1	-0.5525	0.9145	-0.6042	[.546]
D2	-0.1744	0.8056	-0.2165	[.829]
SD1	0.1357	0.1226	1.1067	[.268]
SD2	0.2360	0.1204	1.9594	[.050]
SD3	0.1451	0.1161	1.2507	[.211]
D3	-0.0002	0.0000	-3.6777	[.000]
D4	0.0004	0.0003	1.3475	[.178]
DT	-0.0369	0.0500	-0.7380	[.460]
DT2	0.0019	0.0025	0.7822	[.434]
GAMMA	0.4985	0.0334	14.9434	[.000]
S2	0.3627	0.0275	13.1825	[.000]
Nobs	**Logl**	**BIC**		
1882	-1946.89	2015.48		
AP (1-A3-A4)	1.4585			
r	0.3144			
TE	0.7286			
PE	0.6301			

Parameter	**Variable in logs**
A0	Constant in profit function
A1	Capital
A2	Labor
A3	Price electricity
A4	Price fuel
A11	Capital^2
A12	Capital*Labor
A13	Capital*(Price fuel)/(Price electricity)
A22	Labor^2
A23	Labor*(Price fuel)/(Price electricity)
A33	((Price fuel)/(Price electricity))^2

Parameter	**Variable in logs**
BT	Time
D0	Constant in u-function
D1	CO2 tax(t)
D2	MA(-1.-3) CO2 tax
SD1	Small size dummy
SD2	Medium size dummy
SD3	Large size dummy
D3	Capital intensity
D4	Fuel intensity
DT	Time
DT2	Time^2

Electro TL

Parameter	Estimate	Error	t-statistic	P-value
A0	7.5157	0.2828	26.5773	[.000]
A1	-1.5756	0.0766	-20.5717	[.000]
A2	1.6456	0.1481	11.1091	[.000]
A3	-0.7491	0.1033	7.2513	[.000]
A4	0.6593	0.1061	-6.2107	[.000]
A11	0.1750	0.0240	7.2806	[.000]
A12	0.0345	0.0396	0.8727	[.383]
A13	-0.1424	0.0195	-7.3034	[.000]
A22	-0.2516	0.0650	-3.8731	[.000]
A23	0.1814	0.0280	6.4865	[.000]
A33	0.0640	0.0106	6.0316	[.000]
BT	0.0699	0.0029	23.9718	[.000]
D0	-0.2227	0.1180	-1.8876	[.059]
D1	-0.7515	0.3030	-2.4801	[.013]
D2	-0.4490	0.3093	-1.4517	[.147]
SD1	0.3983	0.0497	8.0094	[.000]
SD2	0.7932	0.0461	17.2187	[.000]
SD3	-0.0695	0.0428	-1.6258	[.104]
D3	-0.0010	0.0000	-24.0064	[.000]
D4	0.0095	0.0013	7.5372	[.000]
DT	-0.0073	0.0231	-0.3175	[.751]
DT2	0.0009	0.0013	0.6960	[.486]
GAMMA	0.9351	0.0094	99.0701	[.000]
S2	0.1832	0.0052	35.2913	[.000]
Nobs	**Logl**	**BIC**		
737	-1158.11	1237.34		
AP (1-A3-A4)	1.0898			
r	0.0824			
TE	0.4962			
PE	0.4659			

Electro CD

Parameter	Estimate	Error	t-statistic	P-value
A0	-0.6017	0.3583	-1.6794	[.093]
A1	0.1916	0.0210	9.1432	[.000]
A2	1.0026	0.0412	24.3339	[.000]
A3	0.0683	0.0347	1.9662	[.049]
A4	-0.1354	0.0476	-2.8458	[.004]
BT	0.0830	0.0071	11.6486	[.000]
D0	-0.1784	0.2984	-0.5978	[.550]
D1	-0.2849	0.7574	-0.3761	[.707]
D2	-0.5486	0.7499	-0.7316	[.464]
SD1	0.1078	0.1141	0.9442	[.345]
SD2	0.3103	0.1168	2.6565	[.008]
SD3	-0.0744	0.0889	-0.8366	[.403]
D3	0.0001	0.0001	0.8826	[.377]
D4	0.0086	0.0044	1.9699	[.049]
DT	-0.0395	0.0556	-0.7103	[.478]
DT2	0.0028	0.0031	0.8803	[.379]
GAMMA	0.7079	0.0366	19.3588	[.000]
S2	0.3136	0.0293	10.7000	[.000]
Nobs	**Logl**	**BIC**		
737	-709.96	769.39		
AP (1-A3-A4)	1.0671			
r	0.0629			
TE	0.6376			
PE	0.6187			

Parameter	Variable in logs
A0	Constant in profit function
A1	Capital
A2	Labor
A3	Price electricity
A4	Price fuel
A11	Capital^2
A12	Capital*Labor
A13	Capital*(Price fuel)/(Price electricity)
A22	Labor^2
A23	Labor*(Price fuel)/(Price electricity)
A33	((Price fuel)/(Price electricity))^2

Parameter	Variable in logs
BT	Time
D0	Constant in u-function
D1	CO2 tax(t)
D2	MA(-1.-3) CO2 tax
SD1	Small size dummy
SD2	Medium size dummy
SD3	Large size dummy
D3	Capital intensity
D4	Fuel intensity
DT	Time
DT2	Time^2

Appendix C

Based on the re-parameterization of the model, replacing σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$, Battese and Coelli (1993) present the loglikelihood function and its partial derivatives for the stochastic production frontier model. Here we reproduce this function, in a profit function setting, by starting with the assumption that the inefficiency stochastic profit model is expressed by:[32]

$$\pi^{kt} = W^{kt}\alpha + v^{kt} - u^{kt} \qquad \text{(B1)}$$

$$u^{kt} = z^{kt}\delta + \upsilon^{kt} \qquad \text{(B2)}$$

where (B1) is the the profit function. Furthermore, W^{kt} is a vector of output and input prices, and quasi-fixed inputs. Then, given that the number of observations for the $k:th$ firm are T^k, $1 \le T^k \le T$, and $\pi^k \equiv (\pi^{k1}, \pi^{k2}, ..., \pi^{kT_k})'$ is the vector of firm $k's$ T^k profit values in (B1), the logarithm of the likelihood function is expressed by (Note that π on the left hand side and π^{kt} on the right hand side denote profit, and π^p denotes the mathematical constant pi, 3.14):

$$\begin{aligned} L(\theta;\pi) = & -\frac{1}{2}\left(\sum_{k=1}^{K} T^k\right)\left\{\ell n 2\pi^p + \ell n \sigma^2\right\} \\ & -\frac{1}{2}\sum_{k=1}^{K}\sum_{t=1}^{T^k}\left\{(\pi^{kt} - W^{kt}\alpha + z^{kt}\delta)^2 / \sigma^2\right\} \qquad \text{(B3)} \\ & -\sum_{k=1}^{K}\sum_{t=1}^{T^k}\left\{\ell n \Phi(d^{kt}) - \ell n \Phi(d^{*,kt})\right\} \end{aligned}$$

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[32] Following Battese and Coelli (1993), we choose to drop the logarithmic prefix to simplify the presentation of the likelihood function and its partial derivatives.

where $\Phi(\cdot)$ denotes the cumulative distribution function for the standard normal random variable. Furthermore, $\theta = (\alpha', \delta', \sigma^2, \gamma)'$, $d^{kt} = z^{kt}\delta / (\gamma\sigma^2)^{1/2}$, $d^{*,kt} = \mu^{*,kt} / \sigma^*$, $\mu^{*,kt} = (1-\gamma)z^{kt}\delta - \gamma(\pi^{kt} - W^{kt}\alpha)$, $\sigma^* = \left[\gamma(1-\gamma)\sigma^2\right]^{1/2}$.

The partial derivatives of the likelihood function in (B3), with respect to α, δ, σ^2, and γ are given by ($\phi(\cdot)$ denoting the probability density function for the standard normal random variable):

$$\frac{\partial L^*}{\partial \alpha} = \sum_{k=1}^{K}\sum_{t=1}^{T^k}\left\{\frac{(\pi^{kt} - W^{kt}\alpha + z^{kt}\delta)}{\sigma^2} + \frac{\phi(d^{*,kt})}{\Phi(d^{*,kt})}\cdot\frac{\gamma}{\sigma_u^*}\right\}\cdot W'^{kt}, \tag{B4}$$

$$\frac{\partial L^*}{\partial \delta} = -\sum_{k=1}^{K}\sum_{t=1}^{T^k}\left\{\frac{(\pi^{kt} - W^{kt}\alpha + z^{kt}\delta)}{\sigma^2} + \left[\frac{\phi(d^{kt})}{\Phi(d^{kt})}\cdot\frac{1}{(\gamma\sigma^2)^{1/2}} - \frac{\phi(d^{*,kt})}{\Phi(d^{*,kt})}\cdot\frac{(1-\gamma)}{\sigma_u^*}\right]\right\}\cdot z'^{kt}, \tag{B5}$$

$$\frac{\partial L^*}{\partial \sigma^2} = -\frac{1}{2}\left(\frac{1}{\sigma^2}\right)\cdot\left\{\left(\sum_{k=1}^{K}T^k\right) - \sum_{k=1}^{K}\sum_{t=1}^{T^k}\left[\frac{\phi(d^{kt})}{\Phi(d^{kt})}\cdot d^{kt} - \frac{\phi(d^{*,kt})}{\Phi(d^{*,kt})}\cdot d^{*,kt}\right] - \sum_{k=1}^{K}\sum_{t=1}^{T^k}\frac{(\pi^{kt} - W^{kt}\alpha + z^{kt}\delta)}{\sigma^2}\right\},$$

(B6)

and

$$\frac{\partial L^*}{\partial \gamma} = \sum_{k=1}^{K}\sum_{t=1}^{T^k}\left\{\frac{\phi(d^{kt})}{\Phi(d^{kt})}\cdot\frac{d^{kt}}{2\gamma} + \frac{\phi(d^{*,kt})}{\Phi(d^{*,kt})}\left[\frac{(\pi^{kt} - W^{kt}\alpha + z^{kt}\delta)}{\sigma_u^*} + \frac{d^{*,kt}(1-2\gamma)}{2\gamma(1-\gamma)\sigma^{2*}}\right]\right\}. \tag{B7}$$