The impact of pollution abatement investments on technology: Porter hypothesis revisited

Jean Pierre HUIBAN

INRA, UR 1303 ALISS,

65 bd de Brandebourg, 94205 Ivry Cedex, France

Camilla MASTROMARCO

Dipartimento di Scienze dell'Economia,

University of Salento,

Ecotekne, via per Monteroni, 73100 Lecce, Italy,

email: camilla.mastromarco@unisalento.it

Antonio MUSOLESI

GAEL UMR 1215, INRA- University of Grenoble,

1241, rue des résidences, Domaine Universitaire,

38400 Saint Martin d'Hères, France

email: Antonio.Musolesi@grenoble.inra.fr

Michel SIMIONI

Toulouse School of Economics,INRA-GREMAQ and IDEI

Manufacture de Tabacs, 21 allées de Brienne,

31000 Toulouse, France

email:simioni@toulouse.inra.fr

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Abstract

This paper revisits the Porter hypothesis by pursuing two new directions. We first compare two likely models and use a test between non nested models to choose among them. A first model assumes that pollution abatement capital enters the production function as an input while a second assumes that it is an external factor of production affecting firm's efficiency. The model selection procedure indicates that pollution abatement capital appears to be an input of production. Then we pay attention not only on the average pollution abatement effort effect but we also focus on its variability across firms and over time. Our findings suggest that the traditional view about the effect of environmental regulation on productivity and the Porter hypothesis may coexist. This evidence supports the idea that a well-designed environmental regulation affects positively the firm performances *in some instances*.

JEL classification: C23, D24, Q50.

Keywords: Porter hypothesis, pollution abatement investment, stochastic frontier analysis, time-varying efficiency, Vuong test, French food processing industry.

1 Introduction

Pollution clearly appears as an undesirable output of production. Because producing cleanly is more expensive than polluting, environmental regulation may be necessary in order to push firms to make investments devoted to pollution reduction and to pursue a sustainable process of economic development. A standard view among economists is that environmental regulation aiming to reduce pollution is a detrimental factor for firms' competitiveness and productivity (see e.g. Viscusi, 1983, Jorgenson and Wilcoxen, 1990, Greenstone, 2002). From the early nineties, however, this view has been challenged by numerous economists. In particular, Porter (1991) and Porter and Van der Linde (1995) argued that more stringent but properly designed environmental regulations do not inevitably hamper firms competitiveness but they could enhance it. This new paradigm has become known as the "Porter hypothesis". Since then, such a hypothesis has received much attention. It has initially been criticized with respect to a lack of an underlying theory (e.g. Palmer *et al.*, 1995) and for being inconsistent with the empirical evidence (e.g. Jaffe *et al.*, 1995), while, today there exists a more solid theory but also a rather mixed empirical evidence, suggesting that *"further research is clearly needed in this area"* (Ambec *et al.*, 2013, p. 10).

This paper aims to contribute to the empirical literature in two ways. First, with respect to an econometric modeling perspective, we aim to introduce in the Porter hypothesis literature some reasoning and modeling which have been developed by the econometric literature on productivity and efficiency analysis about the role of external factors of production, in the end extending the approach proposed by Coelli *et al.* (1999). Indeed, while most of the existing studies add the chosen proxy of pollution abatement efforts into a production function/ TFP equation as an additional factor of production, we argue that it is not possible to exclude a priori that it can enter a production function as an external factor, i.e. as a variable that cannot (at least totally) be controlled by the producer but that may has an influence in the production process (see e.g. Badin *et al.*, 2010). Building on Coelli *et al.* (1999) and adopting a translog technology, originally introduced by Christensen *et al.* (1973), we compare two models. In the first one, the pollution abatement effort enters as an additional input of production. This model encompasses the first model proposed by Coelli *et al.* (1999) where the external factor influences the shape of the technology. The second one assumes that pollution abatement effort affects the degree of technical inefficiency (see also Greene, 2005, for a description of such a kind of models). Since these two models are not nested, we then perform the Vuong (1989) test in order to select the most likely one.

Secondly, from an empirical and policy oriented perspective we focus on one relevant aspect of the Porter hypothesis which has been neglected by the existing empirical literature. Indeed, as also stressed by Ambec (2013), the Porter hypothesis does not say that properly designed environmental regulations always enhance firms' performance but it says that they do *"in some instances"*. We thus pay attention not only on the average pollution abatement effort effect but also focus on its variability across firms and over time. These two contributions allow us to provide new insights on the Porter hypothesis literature.

In order to perform the econometric analysis, we build a new a rich firm-level panel data set concerning the French food processing industries and covering the period 1993-2007, the French food processing industry being particularly relevant for such a kind of analysis. The Food industry is not only relevant in terms of size, representing in France a large part of manufacturing, (about 550,000 employees in 2011, i.e. 18% of manufacturing employment) but is also relevant because it is one of the most polluting sector with respect to several indicators, especially when looking the effects of total final consumption of the produced goods (European Environmental Agency, 2006). This has been shown by several studies. Marin *et al.* (2012) using the NAMEA (National Accounting Matrix with Environmental Accounts) data show that food and especially animal-based food productions have a dominant role in the total environmental impact by consumption. Vieux *et al.* (2012) note that the contribution from the food processing industries to the total green house gas emission range from 15 to 31%. Moreover, in 2007, the food processing industry was found to be the third greatest spender on pollution abatement investments in France (167 million €), only exceeded by the energy (437 million €) and chemicals, rubbers and plastics (204 million €) industries.

The estimation results provide some relevant insights. First, the model selection procedure indicates that the model where the pollution abatement capital enters the production process as an input is preferred to both the model where such a variable affects the inefficiency and to the one where it only influences the shape of the production function as in Coelli et al. (1999). Say differently, this means that the pollution abatement capital appears to be an input of production rather than an external factor. Secondly, while the average pollution abatement capital elasticity equals 0.018, its estimated density is bimodal, with a negative and a positive mode. Moreover, the area under the density for positive values of the elasticity is greater than the same area for negative values, indicating that most firms have a positive elasticity while a small number of firms have a negative one. To the best of our knowledge, this is the first empirical paper suggesting that the traditional view about the effect of environmental regulation on productivity and the Porter hypothesis may coexist and supporting the idea that a well-designed environmental regulation affects positively the firm performances *"in some instances"*. Third, we document a positive shift of both pollution abatement capital elasticity and efficiency over time.

The present paper is organized as follows. Section 2 gives a brief review of the related literature. Section 3 presents the econometric methodology while the description of the data and some descriptive statistics are provided in section 4. Section 5 details the results and section 6 concludes.

2 Related literature

With respect to the specific goal of the paper, it seems worth discussing and linking two separate literatures.

2.1 Environmental regulation and economic performance

According to a standard view among economists, at least until the nineties, pollution abatement effort due to environmental regulation may be benefic for environmental performance but would negatively affect the firms' economic performances since it forces firms to allocate the production inputs to pollution reduction, which pushes them away from the optimal production choices. This in turn could lead firms to delay their investments (Viscusi, 1983) or relocate their activities in countries imposing less stringent pollution regulations (Greenstone, 2002). At the national level, Jorgenson and Wilcoxen (1990) suggest that environmental regulation explains part of the sharp decline in the rate of economic growth during the 1970's and 1980's.

From the early nineties, however, this traditional paradigm has been challenged by what has become known as the "Porter hypothesis" (Porter, 1991; Porter and Van der Linde, 1995). Porter and Van der Linde (1995, p. 98) indeed suggest that: "Strict environmental regulation can trigger innovation (broadly defined) that may partially or more than fully offset the traditional costs of regulation".

Since then, the Porter hypothesis has attracted a great deal of attention, theoretically as well as empirically (for a recent survey, see e.g., Ambec *et al.* 2013). From a theoretical point of view, after some initial criticisms (e.g. Palmer *et al.*, 1995), the literature has provided alternative argumentations supporting such a hypothesis. These are firms' behaviors departing from the assumption of profit maximization (e.g., Ambec and Barla, 2006), market failure (e.g., André *et al.*, 2009), organization failure (e.g., Ambec and Barla, 2002) and R&D spillovers (e.g., Mohr, 2002).

Empirically, Jaffe and Palmer (1997) first distinguished among the "weak" and the "strong" version of the Porter hypothesis. According to the weak version, properly designed environmental regulation may stimulate innovation. This is has been validated by many previous studies (Lanjouw and Mody, 1996, Jaffe and Palmer, 1997, Brunnermeier and Cohen, 2003, Popp, 2006, Arimura *et al.*, 2007). The strong version makes a step further suggesting that in many cases this innovation more than offsets the regulatory costs, in the end enhancing firms' competitiveness and economic performances (most often measured with the firms' productivity). For this respect, while most of the studies reviewed by Jaffe *et al.* (1995) find a negative effect of environmental regulation on productivity and firms' performances, some more recent works suggest a positive effect (see e.g. Berman and Bui, 2001, Alpay *et al.*, 2002, Yang and Yao, 2012). In summary, while there is a well established consensus on the weak version, the empirical evidence on the strong version is much more mixed and requires further investigations.[1]

[1]Some recent works study simultaneously both the weak and the strong versions (e.g., Hamamoto, 2006, Lanoie *et al.*, 2011, Van Leeuwen and Mohnen, 2013).

2.2 Accounting for external factors

The second strand of the literature which is relevant for this paper is that focusing on external (or environmental) factors.[2] External factors may be broadly defined as *"External or environmental factors that cannot be controlled by the producer but may influence the production process"* (Badin *et al.*, 2010). Concerning more generally the production process, it has been also suggested that *"producer performance is influenced by three very different phenomena: the efficiency with which management organizes production activities, the characteristics of the environment in which production activities are carried out, and the impact of good and bad luck, omitted variables, and related phenomena which would be collected in a random error term in a regression-based evaluation of producer performance. The first phenomenon is endogenous, while the second and third are exogenous."* (Fried *et al.*, 2002).

Stochastic Frontier Analysis provides a useful framework to deal with this issue. Battese and Coelli (1995) introduced a class of model where the external factors influence directly the inefficiency, while Greene (2005) suggested adopting the least restrictive variant of the Battese and Coelli model. Coelli *et al.* (1999) propose testing the Battese and Coelli's (1995) model against a more conventional specification where the external factors are supposed to affect the shape of the production technology. The subsequent literature has used the Battese and Coelli's (1995) model in many and diversified contexts such as the efficiency of universities (Kempkes and Pohl, 2010), the productive efficiency of developing countries (Henry *et al.*, 2009), the effect of the business environment on inefficiency (Roudaut, 2006), just to cite few recent papers.

Concerning specifically the role of pollution abatement efforts, almost all the

[2]Hereafter we refer to external factors to avoid confusion with the environment, defined in terms of ecological units and natural resources.

existing studies added the chosen proxy for pollution abatement efforts as an additional explanatory variable in a production function / total factor productivity equation. Broberg *et al.* (2013), adopting the Battese and Coelli (1995) approach is, to the best of our knowledge, the sole work introducing pollution abatement investments as determinants of technical inefficiency.

3 Econometric Methodology

The most common approaches in the stochastic frontier literature model the impact of external factors either into the structure of the technology or into the technical efficiency (Coelli *et al.*, 1999). We follow and extends these trends and consider two alternative models to include pollution abatement investments, Z_{it}, into production process.

3.1 Input model

In the first model, we extend Coelli *et al.* (1999) by assuming that Z_{it} enters a stochastic frontier production function as an additional factor of production (we label this model to as *input model)*:

$$Y_{it} = F(t, K_{it}, L_{it}, Z_{it})\tau_{it}w_{it}. \tag{1}$$

where the output of a firm i at time t, Y_{it}, is determined by the levels of labor input and physical capital, L_{it} and K_{it}. It is also affected by pollution abatement investments, Z_{it}, while t captures technological change over time. The w_{it} are assumed to be independent and identically distributed random errors, which capture the stochastic nature of the frontier while τ_{it} denotes efficiency with $0 < \tau_{it} \leq 1$. When $\tau_{it} = 1$, the firm produces on the efficient frontier.

A maintained hypothesis along the paper is that the technology has a translog form with non neutral technological progress. The translog form can be interpreted as a second order Taylor series approximation of an unspecified underlying production function and achieves local flexibility (also called Diewert flexibility) implying that the approximating functional form provides perfect approximation for the underlying function and its first two derivatives at a particular point (Fuss *et al.,* 1978). It has also been shown that it outperforms other Diewert-flexible forms (Guilkey *et al.,* 1983). Equation (1) can be written as:

$$\begin{aligned} y_{it} &= \alpha + \beta_\tau t + \beta_k k_{it} + \beta_l l_{it} + \beta_z z_{it} + \\ &+\gamma_\tau \frac{t^2}{2} + \gamma_k \frac{k_{it}^2}{2} + \gamma_l \frac{l_{it}^2}{2} + \gamma_z \frac{z_{it}^2}{2} + \\ &+\delta_{\tau k} t k_{it} + \delta_{\tau l} t l_{it} + \delta_{\tau z} t z_{it} + \delta_{kl} k_{it} l_{it} + \delta_{kz} k_{it} z_{it} + \delta_{lz} l_{it} z_{it} + \\ &- u_{it} + v_{it} \end{aligned} \tag{2}$$

where lower case letters indicate variables in natural logs, i.e., $y_{it} = \ln(Y_{it})$, and so on, $u_{it} = -\ln(\tau_{it})$ is a non-negative random variable, and $v_{it} = \ln(w_{it})$, distributed as $N(0, \sigma_v)$. It is worth to note that we do not exclude, *a priori*, the possibility that pollution abatement capital enters the production function as a full production inputs rather than restricting its effect to the shape of the technology as in Coelli *et al.* (1999). This, for two reasons. First, we cannot exclude that such variable can be assimilated to a production input which is under the control of the producer choosing the optimal level of pollution abatement investment given some external constraints (such as environmental regulation) and within its maximization program. Secondly, this model nests the model estimated by Coelli *et al.* (1999) which assumes that external variables affect only the shape of the production technology, and can be easily tested by imposing the following restriction:

$$\gamma_z = \delta_{\tau z} = \delta_{kz} = \delta_{lz} = 0 \tag{3}$$

The inefficiency term u_{it} can be modelled as a time invariant truncated-normal random variable, i.e. $u_{it} = u_i$ and $u_i \overset{iid}{\sim} TN\left(\mu, \sigma_u^2\right)$. The time invariance of the inefficiency component is, however, a problematic assumption. One multiplicative form which has been proposed consists of variations on:

$$u_{it} = \ell(t,T) \times u_i$$

where $u_i \overset{iid}{\sim} TN\left(\mu, \sigma_u^2\right)$. Concerning $\ell(t,T)$, we consider a variant of the Battese and Coelli (1992) model, as proposed by Greene (2005) which can be written as:

$$\ell(t,T) = \exp(\sum_{t=2}^{T} \gamma_t d_t) \tag{4}$$

where d_t denote year dummies.[3] The time invariance can be relaxed also by considering a second specification, which we label as additive (see e.g, Battese and Coelli, 1995, Coelli *et al.*, 1999, Mastromarco and Zago, 2013), for the inefficiency:

$$u_{it} \overset{iid}{\sim} TN\left(\mu_{it}, \sigma_u^2\right), \text{ with } \mu_{it} = \mu + \sum_{t=2}^{T} \gamma_t d_t \tag{5}$$

3.2 Efficiency model

An alternative model, considered in this paper, following the efficiency frontier literature (see, e.g., Battese and Coelli, 1995, Coelli *et al.*, 1999; Kempkes and Pohl,

[3]By construction, a constant term in eq. (4) capturing the effect of the first year cannot be identified simultaneously with the mean of the truncated normal so the value of the constant term is set to zero.

2010, Henry *et al.*, 2009, and Roudaut, 2006), assumes that pollution abatements investments is an external factor of production affecting the technical efficiency (hereafter, *efficiency model*):

$$Y_{it} = F(t, K_{it}, L_{it})\tau_{it}(Z_{it})w_{it}. \tag{6}$$

By writing equation (6) in translog form we have:

$$\begin{aligned} y_{it} \;&=\; \alpha + \beta_\tau t + \beta_k k_{it} + \beta_l l_{it} + \gamma_\tau \frac{t^2}{2} + \gamma_k \frac{k_{it}^2}{2} + \gamma_l \frac{l_{it}^2}{2} + \delta_{\tau k} t k_{it} + \delta_{\tau l} t l_{it} + \delta_{kl} k_{it} l_{it} + \\ &\quad - u_{it} + v_{it} \end{aligned} \tag{7}$$

where v_{it} is the usual random error term, i.e. $v_{it} \overset{iid}{\sim} N(0, \sigma_v^2)$. We consider two alternative specifications for the inefficiency term u_{it}, a multiplicative one and an additive one, as for the input model. The multiplicative model can be written as:

$$u_{it} = \ell(t, T, Z_{it}) \times u_i,$$

where

$$u_i \overset{iid}{\sim} TN\left(\mu, \sigma_u^2\right) \text{ and } \ell(t, T, Z_{it}) = \exp(\sum_{t=2}^{T} \gamma_t d_t + \theta Z_{it}), \tag{8}$$

while the additive model can be written as:

$$u_{it} \overset{iid}{\sim} TN\left(\mu_{it}, \sigma_u^2\right) \text{ and } \mu_{it} = \mu + \sum_{t=2}^{T} \gamma_t d_t + \theta Z_{it} \tag{9}$$

3.3 Vuong test

In summary, we have four models: input model with multiplicative inefficiency component, input model with additive inefficiency component, efficiency model with multiplicative inefficiency component, and efficiency model with additive inefficiency component. They are estimated by maximum likelihood. Since they are non nested, in order to choose the most preferred specification, we perform the modified likelihood-ratio test proposed by Vuong (1989) to compare non-nested models. To define the test, consider two models where $\widehat{f}(y_i, x_i)$ denote the predicted probability of observing y_i and x_i based on the first model, and $\widehat{g}(y_i, x_i)$ the predicted probability for the second model. Vuong (1989) proposes the following test statistics in order to test the null hypothesis that the two models are undistinguishable:

$$V = \frac{M^{-1/2}\ LR_M}{\hat{\omega}_M}$$

where M is the number of observations, LR_M is the usual likelihood-ratio statistics computed as the difference between the log-likelihood of the first model and the log-likelihood of the second model, evaluated at their maximum values, and

$$\hat{\omega}_M^2 = \frac{1}{M}\sum_{m=1}^{M}\left[log\frac{\widehat{f}(y_m, x_m)}{\widehat{g}(y_m, x_m)}\right]^2 - \left[\frac{1}{M}\sum_{m=1}^{M} log\frac{\widehat{f}(y_m, x_m)}{\widehat{g}(y_m, x_m)}\right]^2$$

The Vuong statistics is asymptotically distributed as standard normal distribution. If V is greater than a critical value at a given significance level, say 1.96 for a 5% significance level, then the first model is favored. If V is smaller than a critical value at a given significance level, say -1.96 for a 5% significance level, then the second model is favored. Otherwise, neither model is preferred.

4 Data

4.1 The ANTIPOL and the EAE surveys

Plant-level data for the French food processing industries on pollution abatement investments are collected annually in a survey conducted by the French ministry of Agriculture, called *Enquête Annuelle sur les Dépenses pour Protéger l'Environnement* (ANTIPOL), since the early 1990s. It covers plants with at least 100 employees. To our knowledge, this paper represents the first attempt to use this survey for academic purposes. The ANTIPOL survey provides information on two key indicators:

- Physical investments devoted to pollution abatement.

- Knowledge investments devoted to pollution abatement.

Physical investments are defined as *"the purchase of buildings, land, machinery or equipment to limit the pollution generated by the production activity"* while knowledge investments are defined as *"the internal activities or the purchase of external services improving the knowledge to reduce the pollution"*. For both investments, the available information is disaggregated into specific fields: *"water"*, *"waste"*, *"air and climate"*, *"noise"*, *"land"*, *"landscape and biodiversity"*, *"others"*.

We build a plant-level measure of pollution abatement investments as the sum of both kinds of investments for all the fields. Then, this plant-level measure is aggregated at the firm-level. Finally, a firm-level pollution abatement capital stock is built using the perpetual inventory method using a depreciation rate of 15%. This is a standard rate adopted in the literature for both investments in pollution abatement (Aiken *et al.*, 2009) and investments in knowledge such as R&D (Hall *et al.*, 2010).

The EAE is a firm-level survey covering almost all firms with 20 or more employees. It provides a measurement for the value-added, deflated by its annual industry price index and for the standard inputs of production, labour measured with the number of firm employees by annual average in full-time equivalents, and capital measured with the amount of fixed assets deflated by the annual price index for equipment goods.

The two data bases are merged providing us the variables we need to estimate a production function. In order to make the merge, the plant-level data obtained from the ANTIPOL survey have been aggregated at the firm level, in the end obtaining an unbalanced panel data set composed of 8391 observations and 1130 firms observed during the 1993-2007 periods.

4.2 Description of the panel

Let us first focus on firm pollution abatement investment behaviour in the panel. The share of firms that have made a pollution abatement investment at least one year during the period 1993-2007, in the 1130 firms constituting the unbalanced panel, is equal to 85.22%. Fig.1 reports the percentages of pollution abatement non investing firms in the different sectors of the French food processing industry.[4] Pollution abatement investment behaviours are different across sectors. All firms invested at least once in the highly polluting starch and vegetable fats and oils manufacturing sector, while only two thirds of firms did it in the beverage sector.

Consider now the trends in pollution abatement investments. The annual share of investors increases from 51.95% in 1993 to 65.16% in 2007, as shown in Fig. 2.

[4]French food industry can be decomposed in 10 sectors when considering the NACE classification at the 3-digit aggregated level.

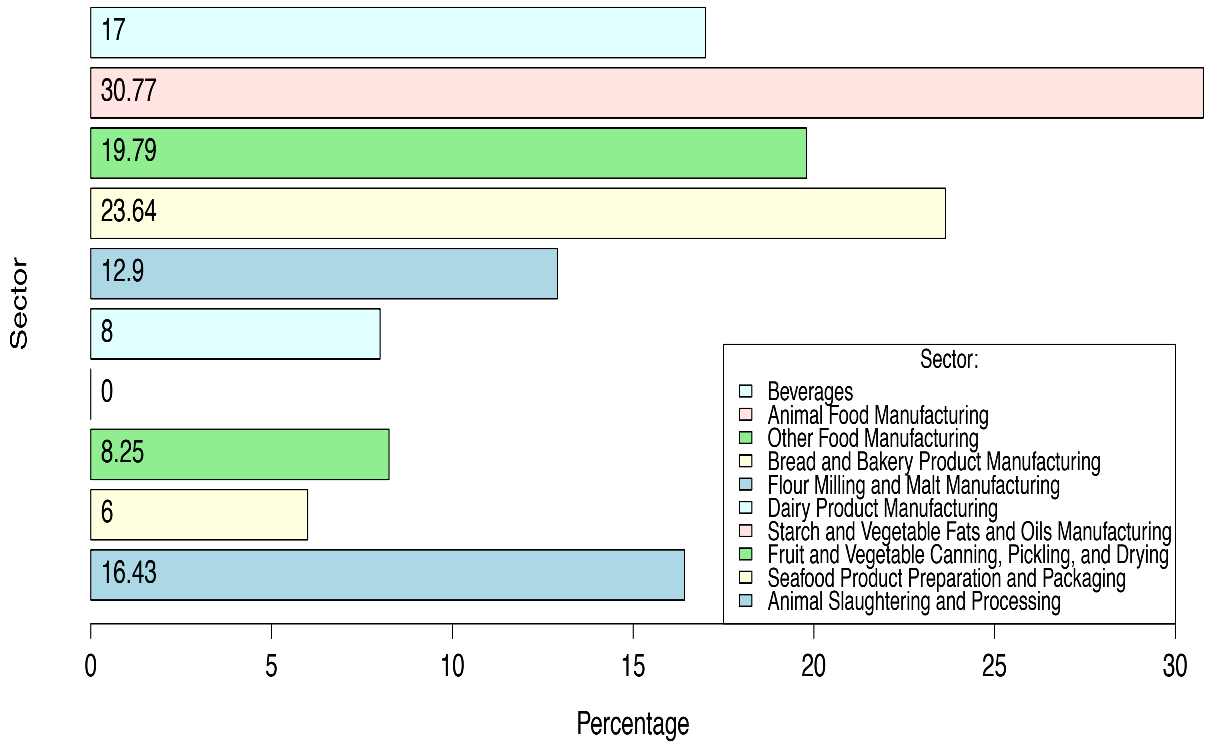

Figure 1: Percentages of pollution abatement non investing firms in food processing industry sectors

Such an increase is mostly due to a level shift occurred from 2000 to 2001 when the share of firms investing to reduce pollution moves from 53.06% to 68.82%. This is likely due to stricter environmental constraints. In 2000, indeed, the European Union promulgated a relevant directive, i.e., the EU water framework directive, aimed to achieve a good status for all waters and introducing new standards for managing Europe's waters (see e.g., Kallis and Butler, 2001). The treatment of waste water is one of the most important fields for pollution abatements, concerning in average more than 50% of the total pollution abatement investments of the French food industry. At the same time, when focusing only on the firms investing in pollution abatements, it can be noticed that the average amount of investments decreases from 320.932 KEuros in 1993 to 247.261 KEuros in 2007 and that such a decrease occurs in the 2000s, as shown in Fig. 2.

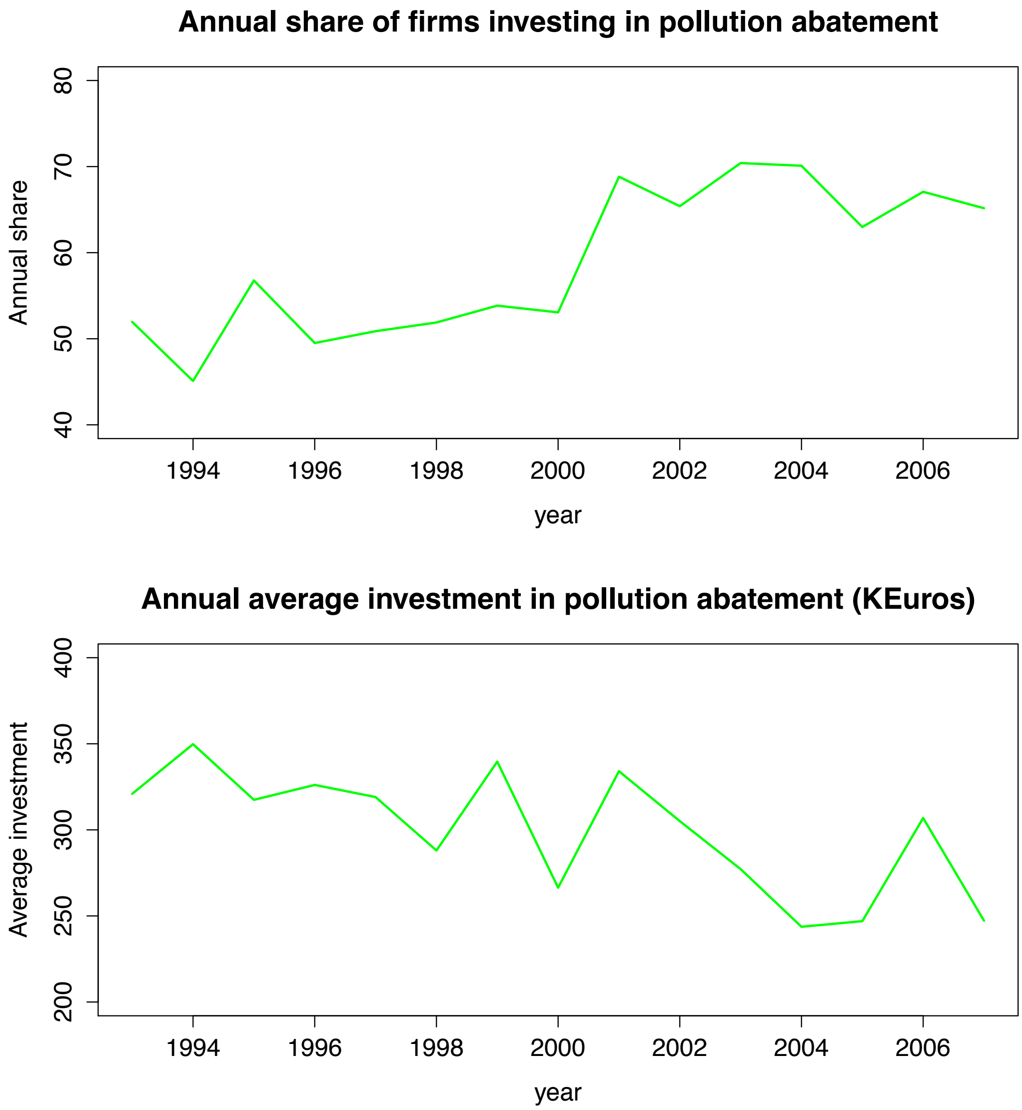

Figure 2: Trends in pollution abatement investments

Table 1 presents some descriptive statistics for the variables used to estimate the production function: value added, labour (number of workers), physical capital stock, and pollution abatement capital stock. This table shows that average pollution abatement capital stock is about one-fiftieth of average physical capital stock.

Variable	Label	Mean	Std. dev.	Min	Max
Value-Added (K Euros)	VA	27605.71	52847.71	100.16	609216
Labour (Number of workers)	L	418.03	534.38	100	6677
Capital stock (K Euros)	K	47756.40	104830.80	.5	2314025
Pollution Abatement Capital stock (K Euros)	KPA	980.53	2575.60	0	41456.53

Table 1: Summary statistics

Since a fraction of firms has never invested to reduce pollution, the corresponding stock of capital presents many zeros (18.21% of the total number of observations). But all the explanatory variables are expressed in logarithms when using a Translog specification. To include all the observations for the variable KPA, we follow Battese (1997), using $\ln(KPA + D)$ where $D = 1$ if $KPA = 0$, and $D = 0$ if $KPA > 0$, as explanatory variable instead of $\ln(KPA)$ which is not defined when $D = 1$. Battese (1997) also introduces the variable D as a shifter of the constant term. As we introduce sectoral dummies to capture unobserved heterogeneity across sectors, we do not introduce the dummy D. Indeed, sectoral dummies can capture the effect of omitted variables that explain the heterogeneity of pollution abatement investment behaviours across sectors, making the dummy D redundant.

A final step before moving to the econometric section, Figure 3 plots the estimated densities of labour productivity suggesting that firms investing to reduce pollution are more productive than the others and the one sided Kolmogorov-Smirnov test clearly indicates $(p - value < 0.001)$ that the cumulative distribution function of labour productivity for firms engaged in pollution abatements activities lies below that of labour productivity for firms do not engaged in such an activity. The next section aims to provide a closer look to this descriptive pattern.

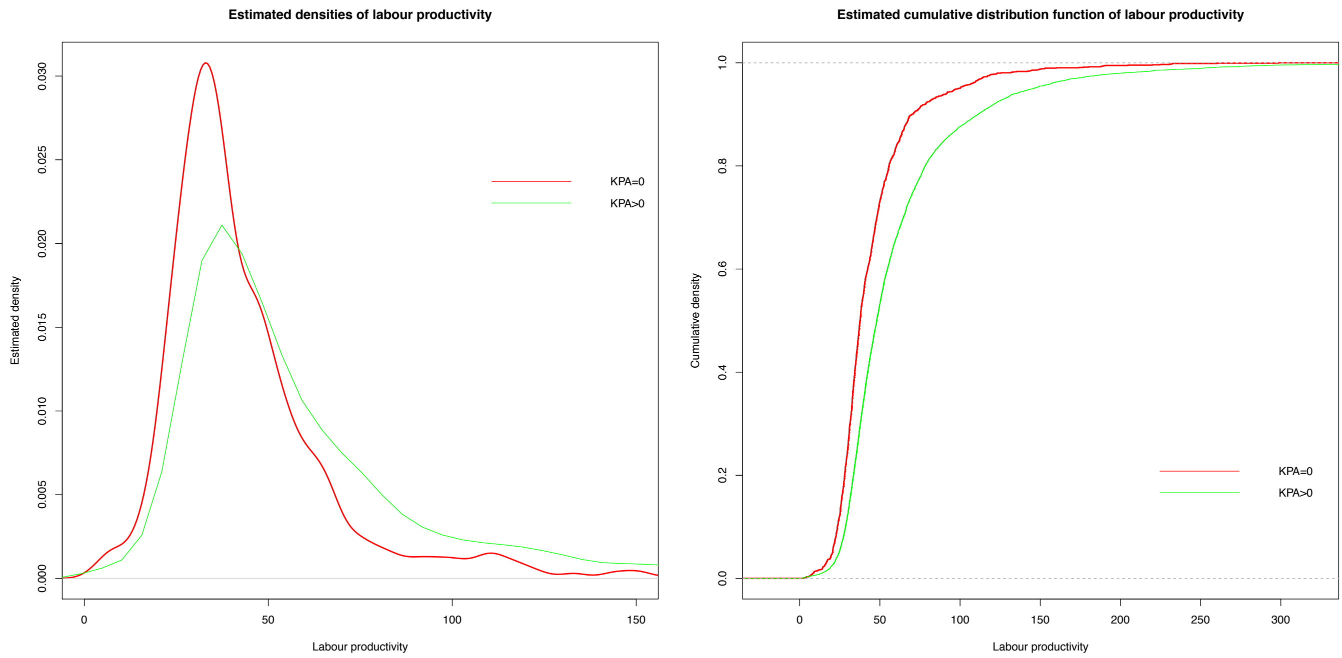

Figure 3: Estimated density of labour productivity

5 Estimation results

5.1 Model selection

We estimate the four specifications proposed above. Then we perform the Vuong test in order to select the most likely model.[5] Results of the Vuong test: values of the test statistics and their associated p-values, are reported in Table 2. First, Vuong tests clearly indicate that the multiplicative specification of efficiency is preferred to the additive specification, for both the input and efficiency models. Signs of the Vuong test statistics are negative and p-values are very small. Second, Vuong test shows that the input model is preferred to the efficiency model when comparing them in the multiplicative case. Sign of the test statistics is positive and the associated p-value is much smaller than usual significance levels. To sum up,

[5]Sectorial fixed effects, defined at the Nace3 level, have been included in the translog specification. These sectoral dummy variables account for unobserved environmental and technological factors that have different effects on production in different sectors.

we select the multiplicative input model as the most likely model at the result of the model selection procedure.

Table 2: Model selection results

Null Hypothesis	Vuong Test Statistics	P-value
Additive vs Multiplicative (Input model)	-24.458	< 0.001
Additive vs Multiplicative (Efficiency model)	-24.531	< 0.001
Input model vs Efficiency model (Multiplicative case)	5.3142	< 0.001

It is also interesting to note that the input model not only appears to be more likely than the efficiency model but also that in the latter, the estimate of the parameter associated to pollution abatement capital, θ from equation (8), is very close to zero ($-0.419e-5$) and is far to be significant at standard levels ($p-value = 0.307$).

We then proceed to a test of the null hypothesis that pollution abatement capital affects only the shape of the production technology as in the Coelli *et al.* (1999) model, i.e. we test the null hypothesis defined by equation (3). The likelihood ratio test statistics whose value is 18.616 with a p-value equals to 0.001, allows us to reject such an hypothesis. Pollution capital abatement enters the production function as a full input.

These results have relevant policy oriented implications, indicating that environmental policies aimed to push firms to invest to reduce pollution do not simply shift the shape of the production function or the firm's efficiency but they will full affect the technology of the firms.

5.2 Elasticities

The estimated values of the parameters of the preferred model, i.e. the multiplicative input model, allows computing the output elasticities with respect to the inputs. These elasticities vary across firms and over years. Figure 6 gives their estimated densities using nonparametric kernel estimators. On average, capital and labor elasticities are equal to 0.255 and 0.780 respectively.

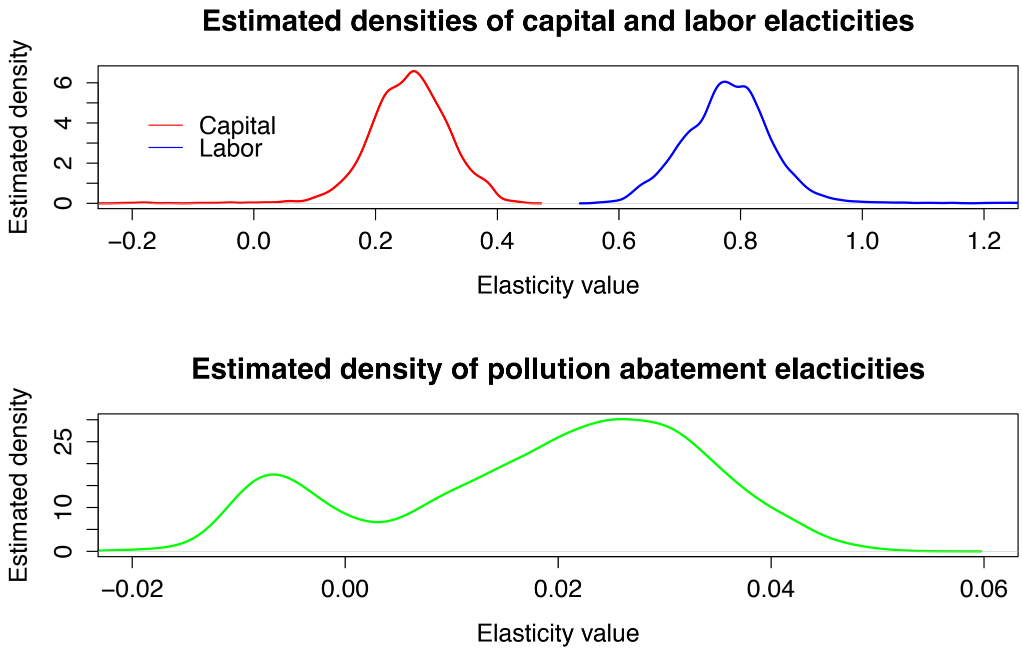

Figure 4: Estimated densities of elasticities

One of the main result of the paper is given by the estimated density of pollution abatement capital elasticity. It is worth noting that while the average pollution abatement capital elasticity is equal to 0.018, the density is bimodal. This density appears to be a mixture of two underlying densities, a first one with a negative mode and a second one with a positive mode. Moreover, the area under the density for positive values of the elasticity is greater than the same area for negative values, indicating that most firms have a positive elasticity while a small number of firms have a negative one. This result has two interpretations. First, it suggests that the traditional view about the effect of environmental regulation on productivity and the Porter hypothesis may coexist. Second, it reinforces the view that a well-designed environmental regulation does not always affect positively the firm performances, but it does in many cases, as also stressed by Ambec *et al.* (2013).

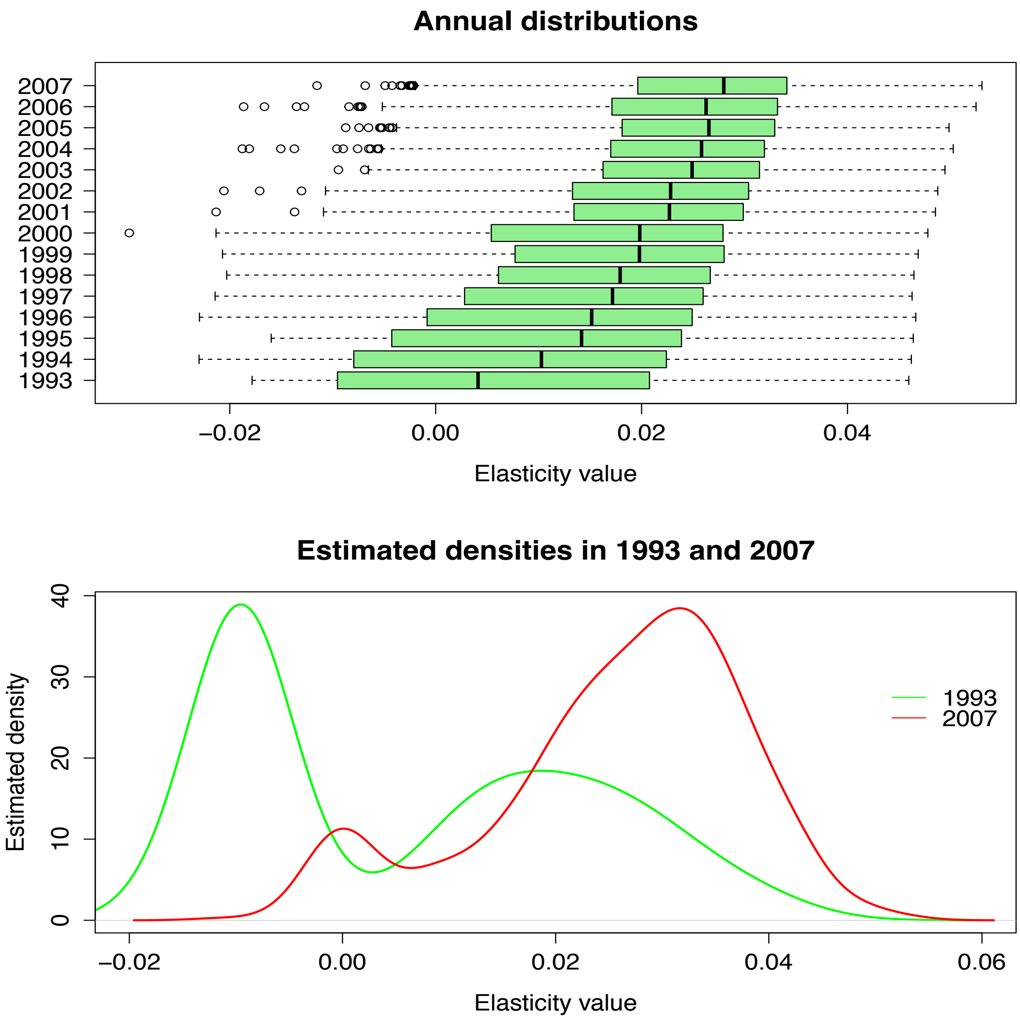

Figure 5: Evolution of pollution abatement elasticity distributions over time

A closer look at the annual distributions of pollution abatement elasticities (see figure 5) shows a positive trend. The median increases over time from 0.004 in 1993 to 0.0280 in 2007. The interquartile range decreases over time, and the annual distributions of elasticities shrink, the standard deviation decreasing from 0.017 in 1993 to 0.012 in 2007. Less and less of firms exhibit a negative pollution abatement elasticity. The comparison of the estimated densities in 1993 and 2007 strengthens this view. The two densities are always bimodal. Nevertheless, there is a shift from 1993 to 2007. Almost all firms have a positive elasticity in 2007 while the number of firms with positive elasticity is roughly the same as the number of firms with a negative one in 1993. Moreover, the first mode moves from -0.011 in 1993 to about zero in 2007. To sum up, this result reinforces the idea that a well-designed environmental regulation does not always affect positively the firm performances, but it does in many cases and we observe that this positive effect concerns an increasing over time number of firms.

The comparison with previous works is not straightforward since they provided very mixed evidence about the sign of the effect of pollution abatement effort on productivity and, at the same time, this paper represents to the best of our knowledge the first work focusing on the heterogeneity across firms and over time of the estimated elasticity of pollution abatement efforts.

5.3 Distributions of efficiency over time

A natural outcome of the estimation of the multiplicative input model is the time-varying efficiency scores. They can be computed as $\exp\left(-\mathrm{E}\left(u_{it}|\varepsilon_{i1},\ldots,\varepsilon_{iT_i}\right)\right)$ where $\varepsilon_{it}=v_{it}-u_{it}$, using an extension of the Jondrow *et al.* (1982) estimator of efficiency score to the input model with multiplicative efficiency. Figure 6 reports the annual distributions of these scores. The evolution of these distributions seems to be characterized by different patterns for three periods. The distributions display a slight increase over the 1993-1999 period. The median (resp. mean) of efficiency scores increases from 0.551 (resp. 0.569) in 1993 to 0.580 (resp. 0.604) in 1999, while the dispersion decreases (the standard deviation is equal to 0.234 in 1993 and 0.204 in 1999). This period is followed by a stagnation of efficiency score distributions from 2000 to 2002. Finally, we observe a sharp increase in efficiency scores over the 2003-2007 period. The median (resp. mean) of efficiency scores grows from 0.569 (resp. 0.560) in 2003 to 0.673 (resp. 0.692) in 2007, with a decrease in the dispersion (the standard deviation is equal to 0.210 in 2003 and 0.166 in 1999). The observed stagnation during the early 2000s has been documented in Bontemps *et al.* (2013).

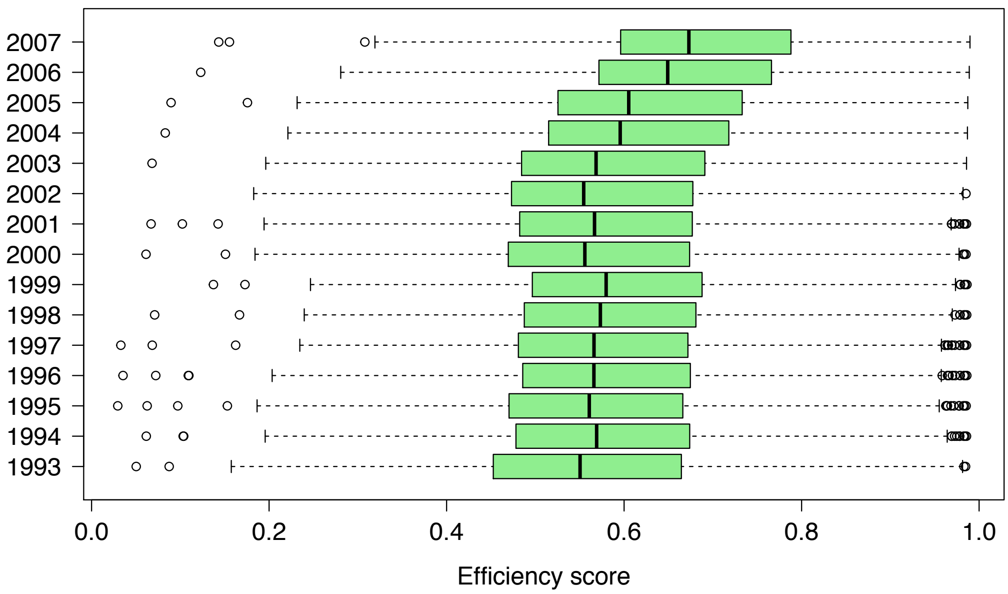

Figure 6: Annual distributions of efficiency scores

6 Summary and conclusions

This paper revisits the strong version of the Porter hypothesis, i.e. the possible existence of a positive causal relation between well designed environmental regulations and productivity, by exploiting for the first time an original and rich survey on pollution abatement investments conducted on the French food industries.

This paper contributes to the existing empirical literature in two main directions. First, following and extending the econometric literature on productivity and efficiency analysis, we argue that two alternative specifications can be adopted to model the role of pollution abatement investments into productivity. One model assumes that pollution abatement capital enters the production function as an input while the other assumes that it is an external factor of production affecting firm's efficiency. Since these two models are not nested, we performed the Vuong (1989) test in order to select the most likely one. Secondly, as also stressed by Ambec et al. (2013), the heterogeneity of the effect of well designed environmental regulations on productivity is a key, but not yet tested, underlying assumption of the Porter hypothesis. Therefore we paid much attention not only on the average effect of pollution abatement investments on productivity but also focused on its variability across firms and over time.

The results from the estimation and testing have relevant implications. First, they clearly indicate that pollution abatement capital does not influence firms' efficiency but it enters the production function as an input. This seems to be important with respect to a policy oriented perspective indicating that policy makers should consider environmental policies aimed to push firms to invest to reduce pollution not as a mean simply shifting the shape of the production function or the firm's efficiency but as a factor fully affecting the technology of the firms. Secondly, we find that the average elasticity of output with respect to pollution abatement capital is positive and equals 0.018. More interesting, the estimated density of such elasticity appears to be bimodal, with a negative and a positive mode. Moreover, the area under the density for positive values of the elasticity is greater than the same area for negative values, indicating that a large fraction of firms has a positive elasticity while a small part of firms has a negative one. This result appears to be fully consistently with the following statement "Strict environmental regulations do not inevitably hinder competitive advantage against rivals; indeed, they often enhance it" (Porter, 1991, p.168). It also suggests that studying firms heterogeneity may be a key for a better understanding of the Porter hypothesis. Third, we documented a positive shift of both pollution abatement capital elasticity and efficiency over time. The latter being pushed in our model by unobservable common time effects introduced in the model as proposed by Greene (2005).

To sum up, we hope that this paper may stimulate further works. It would be of great interest, indeed, understanding if our main results can be generalized to other sectors and countries or if they are specific to the French food processing industry.

References

[1] Aiken, D. V., Fare, R., Grosskopf, S. and Pasurka C. A.. (2009), "Pollution Abatement and Productivity Growth: Evidence from Germany, Japan, the Netherlands, and the United States," Environmental and Resource Economics, 44, 11-28.

[2] Albornoz, E. , Cole, R. J. , R. Elliot and M. G. Ercolani (2009), "In Search of Environmental Spillovers", The World Economy 32, 1, 136–63.

[3] Alpay, E., Buccola, S., Kerkvliet, J., 2002. "Productivity Growth and Environmental Regulation in Mexican and U.S. Food Manufacturing." *American Journal of Agricultural Economics* 84(4): 887-901.

[4] Ambec, S., Cohen, M. A., Stewart, E. and P. Lanoie, (2011). "The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness?," Review of Environmental Economics and Policy, 7, p.2-22.

[5] Berman, E. and L.T.M. Bui (2001), "Environmental Regulation and Productivity: Evidence from Oil Refineries", The Review of Economics and Statistics 83(3), 498-510.

[6] Badin, L., C., Daraio, L., Simar, Léopold (2010), "Optimal bandwidth selection for conditional efficiency measures: A data-driven approach," European Journal of Operational Research, Elsevier, vol. 201(2), pages 633-640.

[7] Battese, G. E. (1997) : "A Note on the Estimation of Cobb-Douglas Production Function when Some Explanatory Variables have Zeros", Journal of Agricultural Economics 48, 250-252.

[8] Battese, G. E., and Coelli, T. J. (1992) : "Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India", Journal of Productivity Analysis 3:1/2 (June), 153-69.

[9] Battese, G.E., and Coelli, T.J. (1995) 'A Model for Technical Efficiency Effects in a Stochastic Frontier Production Function for Panel Data', Empirical Economics, 20, pp. 325-32.

[10] Christensen, L. R., D. W. Jorgenson and L. J. Lau (1973), 'Transcendental logarithmic production frontiers', Review of Economics and Statistics, 55 28-45.

[11] Christmann, P. and G. Taylor (2001), Globalization and the Environment: Determinants of Firm Self-regulation in China, Journal of International Business Studies, 32(3): 439-458.

[12] Coelli, T., Perelman, S., Romano, E., (1999) "Accounting for Environmental Influences in Stochastic Frontier Models: with Application to International Airlines", Journal of Productivity Analysis, 11, 251-273.

[13] Daraio, C. and L. Simar (2005), Introducing environmental variables in non-parametric frontier models: a probabilistic approach, Journal of Productivity Analysis, vol 24, 1, 93–121.

[14] Ericson R. and Pakes A., 1995. Markov-Perfect Industry Dynamics: A Framework for Empirical Work. Review of Economic Studies 62, 53-82.

[15] Fried, H. O., C. A. K. Lovell, S. S. Schmidt and S. Yaisawarng. (2002). "Accounting for environmental effects and statistical noise in Data Envelopment Analysis." Journal of Productivity Analysis, 17, 157–174.

[16] Fuss, M., D. McFadden and Y. Mundlak (1978), 'A survey of functional forms in the economic analyses of production', in M.Fuss and D.McFadden (eds), Production Economics: A Dual Approach to Theory and Applications, North-Holland, Amsterdam

[17] Galdeano-Gomez, E. and J. Cespedes-Lorente, (2008), "Environmental spillover effects on firm productivity and efficiency: An analysis of agri-food business in Southeast Spain", *Ecological Economics* 67: 131-139.

[18] Gallaher, M. P., Morgan, C. L. and R. J. Shabedgian, (2005), "Redesign of the 2005 Pollution Abatement Costs and Expenditure Survey", *Journal of Economic and Social Measurement* 33: 309-360.

[19] Gray, W.B., (1987), "The Cost of Regulation: OSHA, EPA and the Productivity Slowdown", The American Economic Review 77(5), 998-1006.

[20] Greenstone, M., (2002). The impacts of environmental regulations on industrial activity: evidence from the 1970 and 1977 clean air act amendments and the census of manufactures. Journal of Political Economy 110, 1175-1219.

[21] Hall, B., Mairesse, J. and Mohnen, P. (2010), Measuring the returns to R&D, in B. Hall & N. Rosenberg, eds, 'Handbook of the Economics of Innovation', North-Holland, Amsterdam.

[22] Henry, M., Kneller, R. and Milner, C. (2009) Trade, technology transfer and national efficiency in developing countries. European Economic Review 53(2): 237–254.

[23] Jondrow, J., Lovell, C.A.K., Materov, I. and Schmidt, P. (1982), "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model," Journal of Econometrics 19, 233-238.

[24] Jorgenson, D. W. and P. J. Wilcoxen, (1990), "Environmental Regulation and U.S. Economic Growth", The RAND Journal of Economics, 21(2), 314-340.

[25] Kallis, G., Butler, D., (2001). The EU water framework directive: measures and implications. Water Policy 3, 125–142.

[26] Keller, W. (2002) and A. Levinson, "Pollution Abatement costs and Foreign Direct Investment Flows in the USA", *The Review of Economics and Statistics* 84(4): 691-703.

[27] Kempkes G, Pohl C. (2010). The efficiency of German universities: Some evidence from nonparametric and parametric methods. Applied Economics. 2010;42:2063–2079.

[28] Klassen, R.D., McLaughlin, C.P. (1996). The impact of environmental management on firm performance. Management Science, 42(8): 1199-1213.

[29] Lanoie, P., Patry, M., Lajeunesse, R. (2008), "Environmental Regulation and Productivity: New Findings on the Porter Hypothesis", Journal of Productivity Analysis 30, 121-128.

[30] Lanoie, P., J. Laurent-Lucchetti, N. Johnstone, S. Ambec (2011). "Environmental Policy, Innovation and Performance: New Insights on the Porter Hypothesis," Journal of Economics & Management Strategy, Wiley Blackwell, vol. 20(3), pages 803-842, 09.

[31] Mastromarco C., A. Zago (2012), "On modeling the determinants of TFP growth", Structural Change and Economic Dynamics, Volume 23, Issue 4, December 2012, Pages 373–382.

[32] Marin, G., Mazzanti, M., Montini, A., (2012), "Linking NAMEA and Input output for 'consumption vs. production perspective' analyses. Evidence on emission efficiency and aggregation biases using the Italian and Spanish accounts." *Ecological Economics* 74: 71-84.

[33] Oliver C. (1991), Strategic Responses to Institutional Processes, Academy of Management Review, 1991, 16:145-179.

[34] Porter, M. S. (1991), "America's green strategy", Scientific American, 264, 168.

[35] Porter, M. S. and C. Van der Linde, (1995), "Toward a New Conception of the Environment-Competitiveness Relationship", Journal of Economic Perspectives, 9(4), 97-118.

[36] Roome N. (1992), Modeling Business Environmental Strategy, Business Strategy and the Environment, 1(1): 11-12.

[37] Roudaut, N. (2006) 'Influences of the business environment on manufacturing firms technical efficiencies: The côte d'ivoire case.' Journal of Productivity Analysis 25(1-2), 93–109.

[38] Shadbedgian, R. J. and Gray, W. B., (2005). Pollution abatement expenditures and plant-level productivity: a production function approach. *Ecological Economics* 54: 196-208.

[39] Sharma S. (2000), Managerial Interpretations and Organizational Context as Predictors of Corporate Choice of Environmental Strategy, Academy of Management Journal, 43(4): 681-697.

[40] Van Leeuwen, G., Mohnen, P. (2013). "Revisiting the Porter Hypothesis: An Empirical Analysis of Green Innovation for the Netherlands," CIRANO Working Papers 2013s-02, CIRANO.

[41] Vieux, F., Darmon, N., Touazi, D. and Soler, L. G., (2012). "Greenhouse gas emissions of self-selected individual diets in France: Changing the diet structure or consuming less?". *Ecological Economics* 75: 91-101.

[42] Viscusi, W.K., (1983). "Frameworks for analyzing the effects of risk and environmental regulation on productivity". American Economic Review 73, 793–801.

[43] Viscusi W.K. and Magat W.A., Huber J. (1991), Pricing Environmental Health Risks: Survey Assessments of Risk-Risk and Risk-Dollar Trade-Offs for Chronic Bronchitis, Journal of Environmental Economics and Management, 1991, 21: 32-51.

[44] Yang X and Yao Y. (2012). Environmental Compliance and Firm Performance: Evidence from China. Oxford Bulletin of Economics and Statistics, 74(3), 397-424.