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Augmenting the production function with knowledge capital to test the Porter hypothesis: the case of French food industries*

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Abstract: We investigate the impact of pollution abatement effort on the economic performances by exploiting a rich panel data set composed of French food industry firms, observed over the 1993-2007 period. We test the Porter hypothesis, assuming that pollution abatement effort has a positive effect on the firm performance by triggering innovation. This is done by estimating a production function augmented with knowledge capital, such a capital being produced by both pollution abatement and R&D investments. Using different estimation methods, including structural semi-parametric ones, we first show than the so-called Porter assumption cannot be rejected when focusing on the full population of French food industry firms since the estimations indicate a positive and significant (though rather small) contribution of the pollution abatement capital to the firm productivity. Then, we consider a more restrictive sample of (potentially) innovative firms, actually engaging both RD and pollution abatement investments. Henceforth, the contribution of pollution abatement capital becomes not significant in regard to the R&D's one. These results do not support the sometimes invoked hypothesis according to which the positive effect of pollution abatements efforts on firms' performances is linked to the induced increased innovation. At the same time, the standard hypothesis, assuming that pollution abatement effort significantly decreases the firm performance is always rejected.

Keywords: *productivity, environmental investment, R&D, knowledge capital, food industries.*

JEL-Codes: *C23, D24, L25, Q55*

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1. Introduction

« Physically, pollution occurs because it is virtually impossible to have a productive process that involves no waste; economically, pollution occurs, because polluting is less expensive than operating cleanly » (Helfand et al., 2005, p. 249).

According to the conventional wisdom, firms produce pollution as a fatal by-product and moreover they would not voluntarily expense some money in order to produce cleanly. Consequently, environmental regulation may be a necessary instrument to force firms to reduce their pollution. Following a standard view, pollution abatement effort due to environmental regulation may be benefic for environmental performance but would negatively affect the firms' competitiveness. At the contrary, the so called Porter hypothesis (Porter, 1991) assumes that environmental regulation could have a positive effect on the firm competitiveness. One reason would be that such regulation would stimulate firms and produce "innovation offsets" (Porter and Van der Linde, 1995). A large number of empirical studies have investigated the Porter hypothesis, obtaining rather mixed results even if there is increasing evidence supporting such a hypothesis (Ambec et al., 2011).

This study contributes to this empirical literature in four ways. First, as many other studies, we include the pollution abatement (PA hereafter) effort within a production function but we also include the Research and Development (RD hereafter) effort in the same function. This is done because it assumed along the paper that knowledge is obtained not only from the R&D activity but also from the firms' efforts to reduce pollution. Second, we use a panel dataset which provides a consistent measurement of both RD and PA investments at the firm level, while many previous studies adopted rougher proxies for PA efforts. Third, we focus on the French Food Industry which is a field of particular interest for this question. Finally, we propose a distinction between two kinds of populations, which are called as the "reference" and the "innovative" populations of firms and we show that the results differ significantly depending on population which is analysed.

A lot of studies test the Porter hypothesis by using a production function augmented with a measurement of antipollution effort (Shabedgian and Gray, 2005). We extend such an approach by incorporating it into the quite standard framework used to explore the relationship between innovation and firm efficiency, namely the production function augmented with "knowledge capital" (Griliches, 1979). We shall assume that knowledge capital is the fruit of several inputs. First, RD activity is considered as the main observable innovation input and has been traditionally incorporated into standard production functions as an additional separable factor of production (Hall et al. 2010, for a survey). When extending such an approach in order to test the Porter hypothesis, we also introduce the pollution abatement effort and we thus consider a production function augmented with both RD and PA as inputs.

Second, we propose a consistent measurement of these two inputs at the firm level. To do this, we use a unique large data base concerning a thousand of firms and covering the period 1993-2007. This dataset provide a measurement of both RD and PA annual investment, from which we can build the corresponding stock of RD and PA capital stocks. These inputs are then included in the production function together with the traditional inputs, namely labour and capital stock.

Third, our population is composed of firms from the French Food Industries, a field which is particularly relevant for such a kind of analysis. The Food industry is not only relevant in terms of size, representing in France à large part of manufacturing, (about 550,000 employees in 2011, i.e. 18% of manufacturing employment), but is also relevant because it is both very polluting and more and more innovative. With respect to pollution, it has been documented that the food sector is one of the most polluting sector with respect to several indicators in many European economies, especially when looking the effects of total final consumption of the produced goods. This has been shown by several studies. Marin et al. (2012) using the NAMEA 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 sector to the total green house gas emission range from 15 to 31%. In terms of innovation, many authors have stressed that despite that food industries have been for long time considered as low-tech, they are becoming more and more technology intensive as a result of an increasing demand for research (Trail and Meulenberg, 2002). As an example, when looking at the French fourth wave of the Community Innovation Survey, it can be noticed that in the food sector, the share of firms introducing product or process innovation (37% and 35% , respectively) is higher than when looking at the total French economy (26% for both product and process innovation). These figures are confirmed when looking at the expenditures for R&D and for other kinds of knowledge. The relevance of such a sector is also attested by the number of studies, based on this empirical field, testing the Porter hypothesis such as Galdeano-Gomez et al. (2008) or Alpay et al. (2002). Finally, when considering the survey statistics, PA and RD efforts offer very different patterns. PA investment concerns a large (more than 50%) and growing overtime share of firms, but with a low average investment amount (representing only 2% of the physical capital stock). At the opposite, RD investment only concerns less than 20% of firms, such a share being almost stable during the observed period. But firms engaging RD activities provide a relevant effort in doing so since the RD capital stock represents, in average, more than 13% of the stock of physical capital. This may suggest that the AP effort is conducted by some constraints, particularly regulatory constraints, while RD effort is the result of an active firm's strategy in terms of innovation. To make such a distinction clearer, we build two different samples. The first one, called the "Reference population" concerns a large part of the firms of French industry, i.e. 999 firms. The second one, called the "Innovative population", is composed of the 197 firms, extracted from the first population, which are actually engaged in both RD and PA and thus are supposed to be (potentially) innovative. Our assumption is that the second population is the right one to consider when speaking of innovation, while the first one is generally considered in the literature.

As surveyed by Ackerberg et al. (2007) endogeneity problems arise when estimating a production function because of both simultaneity and unobserved heterogeneity. Because of this, we use the structural semi-parametric estimator proposed by Levinsohn and Petrin (2003). Our results are as follows.

In the case of the Reference population including most French food firms, the PA capital exhibits a significantly positive estimate which is even higher than the RD coefficient. However, the results change when considering the innovative population: the estimated RD coefficient becomes significant with a magnitude in line with the related literature (Hall et al., 2010), while the PA capital' estimate is no more significant. Indeed, when compared with the returns to RD capital, and when considering the adequate population, it clearly appears that PA capital has no effect on productivity. On the other hand, the standard hypothesis, assuming that PA effort significantly lower the firm performance is always rejected.

The remainder of the paper is as follows. Section 2 describes the model. Data and our sample are presented in Section 3. In Section 4 we provide the estimation results. Section 5 concludes.

2. The model

2.1. Pollution in the economic process: Standard versus Porter hypothesis

Pollution clearly appears as an undesirable output of production (Ball *et al.*, 2001). Because producing cleanly is more expensive than polluting, environmental regulation may be necessary to reduce pollution and pursue a sustainable process of economic growth. But, the standard view among economists is that environmental regulation aiming at reducing pollution is a detriment factor for firms' competitiveness and productivity. Indeed, according to this view, environmental regulation forces firms to allocate the usual production inputs labor and capital to pollution reduction, which push 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, pollution regulation may hamper economic growth: Jorgenson and Wilcoxen, (1990) suggest that environmental regulation (combined with the increase of world petroleum prices) may explain the sharp decline in the rate of economic growth during the 1970's and 1980's.

From the early nineties, however, this traditional view has been challenged by what has become known as the "Porter hypothesis" (Porter, 1991). Porter and Van der Linde (1995, p. 98) assume that: *"Strict environmental regulation can trigger innovation (broadly defined) that may partially or more than fully offset the traditional costs of regulation"*. This citation first suggests a result: not only firm's environmental performance, but also firm's economic performances, may be positively affected by environmental regulation. It also suggests that innovation can be the channel to explain this result.

On the applied perspective, some authors have proposed a distinction. The statement that a well-designed antipollution regulation may trigger innovation has been labeled the "weak" version of the Porter hypothesis whereas the idea that this induced innovation may more than offset regulatory costs enhancing productivity has been called the "strong" version of the Porter assumption. To date, there is a certain evidence supporting the existence of a positive link between environmental regulation and innovation (Jaffe and Palmer, 1997; Arimura et al. 2007; Brunnermeier and Cohen, 2003) whereas much more mixed results have been achieved by looking at the link between regulation and productivity (Jaffe et al., 1997; Berman and Bui, 2001, Alpay et al. 2002; Shadbegian and Gray, 2005; Lanoie et al., 2008, 2012; Gray, 1987). A large review of the literature can be found in Ambec et al. (2011).

2.2. Augmenting the production function with knowledge capital to test the Porter hypothesis

The production function framework provides a tractable way to test the strong version of the Porter hypothesis and consequently some studies have focused on the estimation of a function which can be expressed as:

$$Q_{it} = f(L_{it}, C_{it}, PAE_{it}, U_{it}) \qquad (1)$$

Where Q_{it} is a measure of production, L_{it} and C_{it} are the standard labor and physical capital inputs, PAE_{it} measures the Pollution Abatement efforts of the firm and U_{it} stands for all other unobserved determinants of output. Different solutions may be used to measure the variable PAE_{it} in the production function. Some works introduce dummies for the existence of constraining environmental regulations: Alpay et al. (2002) use "*The frequency of reported inspections (concerning environmental laws) as a proxy for abatement expenditures*" (*p. 892*), or environmental devices (as "*environmental management systems*" used by Albornoz, 2009). Finally some studies use a direct measurement of the expenses and/or investments engaged by the firms. Studies using the US PACE (Pollution Abatement Costs and Expenditures) are an example (Keller et al., 2002, Shadbegian et al., 2005). Such approach deserves some few comments. The first one concerns the conceptual argument underlying the use of the production function. The Porter main arguments explaining a rather counterintuitive positive impact of PA effort on firms' performances are twice: the "green products" and the triggering of innovation. If the success of green products may be indeed a way to improve the commercial performances of a firm, it is not straightforward to understand how it should affect the productive efficiency. Analyzing the relation between environmental regulation and firms' financial performances (Yang and Yao, 2011; Konar and Cohen, 2001) is a consistent way to test whether the (profitable) demand for "green" products is a possible explanation for the Porter hypothesis. However, using the analytical framework of a production function may be appropriate if the triggering of innovation is the main argument to support the Porter hypothesis. Indeed, augmenting the production function with "*knowledge capital*" is the usual approach to test the impact of innovation on firm productivity (see Griliches, 1979, or Hall, 2011, for a recent survey). A general specification can be written as:

$$Q_{it} = f(L_{it}, C_{it}, K_{it}, U_{it}) \quad (2)$$

Where K_{it} is the knowledge (intangible) capital. As this knowledge capital is not directly observed, most studies use some proxies, especially the Research and Development (R&D) expenditures. Obviously, R&D contributes to innovation and, by this, may increase the productivity level of the firm. Other relevant determinants of knowledge and innovation are more difficult to observe such as experience, conducting to learning by doing, while other factors may contribute to the firms' stock of knowledge by improving their "absorption capacity" (Cohen and Levinthal, 1989). Finally, and as specific focus of this paper, following the Porter hypothesis, PAE can enter such a specification because it will stimulate the innovation process. According to this, R&D and PA efforts can be viewed as two observable measures for the knowledge capital, both representing an input of innovation.

But several points should be addressed. The definition of the variable PAE_{it}, namely the PA effort, in the production function is a first important one. We argue that the measurement of PAE_{it} should be consistent with the definition of a production input, thus favoring the studies which use a direct measurement of the expenses and/or investments engaged by the firms, as the one using the US PACE (Keller et al., 2002, Shadbegian et al., 2005). Consequently, we will measure both R&D and PA efforts as stocks of capital, which are calculated by using a perpetual inventory approach, as a sum of the current investment and the past stock of capital which depreciates with a specific rate, as we do for the physical capital *C*:

$$C_t = (1-\delta_k)C_{t-1} + I_t \quad (3)$$

$$KRD_t = (1-\delta_{rd})KRD_{t-1} + RD_t \quad (4)$$

$$KPA_t = (1-\delta_e)KPA_{t-1} + PA_t \quad (5)$$

It is important to use the stock of the different capitals instead of the annual flows of investments because the innovation process is impacted by the contemporaneous but also by the lagged level (at period *t-1, t-2…*) of investments. Indeed, both RD (Griliches, 1979) and PA (Lanoie et al., 2008; Ambec et al. 2011) may take time to become productive. Moreover, past RD and PA investments depreciate and become obsolete. Using such formula allows handling both issues.

3. Data and summary statistics

3.1. The field: food industry

To our knowledge, this study is the first one to use simultaneously a direct measurement of RD and PA investments at the firm level. To do this, we employ the French survey on the PA investments (named the "*Antipol*" survey) and the French survey on the RD (named the "*Moyens de la recherche*" survey). As in many empirical French studies, the Annual Business Survey ("*Enquête Annuelle d'Entreprise*") is used as a complement to provide data on firm performances.

These surveys cover the same field: food industry, defined as the transformation of agricultural materials and products, into food products[1]. Such a field is an interesting one for several reasons. First it represents a significant part of French Manufacturing firms (about 550,000 employees in 2011, i.e. 18% of manufacturing employment). Second, it is composed of many industries, namely 10 at the NACE2-3 digit level, and 41 at the 4-digit level, with various characteristics. Thus, a significant heterogeneity can be preserved within such a sample, in terms of performance, PA regulation, RD effort... Third, pollution regulation matters in such industries. On one hand food industries use large amounts of materials, as water, on the other hand provide consumers goods for which sanity/safety characteristics are crucial. As an illustration, food industry was in 2007 the third French industry in terms of PA investment, with a total amount of 167 million €, only preceded by the Energy (437 million €) and Chemicals, Rubbers and plastics (204 million €). Undoubtedly, PA is a relevant issue for food industry. This is attested by the number of studies, based on this empirical field for testing the Porter hypothesis. For instance, Galdeano-Gomez et al. (2008) study the case of Agri-food business in Southeast Spain and find evidence of the links between environmental practices (firm internal practices but also spillover effect) and economic performance. Alpay et al. (2002) study the relationship between the local environmental regulation and the firm performances, comparing the Mexican and U.S. food manufacturing contexts. Finally, it also worth to note that the food industry, despite that it has been for long time considered as low-tech, it is becoming more and more technology intensive as a result of an increasing demand for research (Trail and Meulenberg, 2002) and thus studying the relation between productivity and knowledge capital in such an industry is more and more relevant.

3.2. The Antipol survey

The *Antipol* survey is a plant-level annual survey devoted to French Food Industries, conducted by the Ministry of Agriculture. Since 2006 it concerns productive units which employ at least 20 persons. From 1993 to 2005, only plants with at least 100 employees were concerned. Three kinds of indicators are used to describe pollution abatement investments[2]:

- investments specifically devoted to pollution abatement;
- general process investment inducing some effects in terms of pollution abatement;
- Studies devoted to pollution abatement.

[1] Such a definition excludes non transformed products (agriculture) or transformed products with non-alimentary use (bio-fuel).

[2] This survey provides a precise distinction between *investments* and *current expenses* (as taxes, for instance, or the cost of maintaining or using currently anti-pollution equipment). Current expenses are not surveyed annually.

Investments specifically devoted to pollution abatement concern different fields: water, wastes, air, noises, floor/ground, and landscape. In 2007, water still represents the main domain with 56.4 % of specific investments, but this part decreases: it was 61.1 % in 2004 and 76.4 % in 2001. The general process investments inducing some effects in terms of pollution abatement are measured along two ways: the total amount of investment and the part which is devoted to pollution abatement. This part is self-evaluated by the firm. One has to keep in mind that the specific investments still represent the main part of PA investments: 80.5 % in 2007, 79.6 % in 2004, and 80.8 % in 2001.

Several steps are necessary to provide a measurement of PA investment consistent with our approach. First, we build a global indicator, named *INVANTIPOL* which equals the sum of the specific investment plus the part of global investment devoted to pollution abatement plus the amount of investment devoted to studies. Second, we only keep the plant which employ 100 employees and more, in order to have a sufficiently long period (namely from 1993 to 2007). Third this plant-level observed indicator is aggregated at the firm-level, by summing the investments amounts of the different plants which compose the firm. Then, we build a corresponding PA capital stock using the perpetual inventory approach with a commonly used depreciation rate of 15%, and name this variable *KPA15*. We finally obtain an unbalanced panel dataset of 8260 observations, concerning 999 firms and covering the 1993-2007 years.

3.3. The RD survey

The "*Moyens de la recherché"* survey is a firm-level annual survey conducted by the Research Ministry and concerns all the French firms which actually perform RD activity. It provides a measurement for both the RD performed by the firm itself (defined as internal expenses) and the RD subtracted by the firm to other firms, or private/public research units (defined as external expenses). We first extract the population concerning food industry and build an unbalanced panel data covering the years 1993-2007, as for the previous Antipol survey. We build an aggregated indicator *DRD*, summing internal and external RD expenditures engaged by the firm. As for physical and PA investment, we build a stock of RD capital using the perpetual inventory approach with a depreciation rate of 15%, and then we obtain the variable *KRD15*. An important point is that RD survey has a particular selection rule: it only concerns firms which actually perform RD. It is worth to know that this represents only a small part of the entire population (namely 1/200 for the French economy, according to the survey presentation). This leads to a small panel data which is composed of 2608 observations concerning 755 firms during the 1993-2007 periods with no "0" value for the variable of interest *KRD15*.

3.4. Our sample design: two populations

In order to estimate the production function defined in section 2, we have to merge three files: the two previous surveys (Antipol and RD) and the Annual Business Survey ("*Enquête Annuelle d'Entreprise*"). This last one is the French survey which provides relevant information about the economic performances and structure of the firm: namely in our case, value-added, number of employees, physical investment and the stock of capital, plus a certain number of control variable as the industry location. It is an exhaustive survey at least for the category of firms considered by other surveys (firms with plants of up than 100 employees and firms which actually perform RD). Because of this, one can suppose that there is no attrition due to a merge with EAE Survey. As mentioned before, the Antipol survey is a sample composed of 999 firms and 8260 observations. It is supposed to be exhaustive when considering plants of 100 employees and more. The RD survey is also supposed to be exhaustive for this population but with a very hard selection rule: it only includes firms which actually perform R&D. Then, we are faced to three sub-populations:

1. The firms both surveyed in Antipol and RD, with full information on both RD and PA investment;
2. The firms surveyed in Antipol but not in RD: because of the selection rule of RD survey, we can affect the value '0' to the RD investment of such firms;
3. The firms surveyed in RD but not in Antipol. In this case we are not allowed to say anything about the PA investments of such firms: it may equals to 0 as well as being positive. Those firms cannot be used for the estimations.

According to this, when merging the surveys we obtain the populations presented in Table 1.

(Table 1)

One can observe that almost all firms with a strictly positive RD capital stock also exhibit a strictly positive PA capital stock (197 firms on 203). The opposite is not true: 889 firms have a positive PA capital stock but 692 firms have both positive PA capital stock and zero RD capital stock. This is a first important result: RD investment is much more concentrated than PA investment: 20% of the observed firms against around 80%[3]. According to this, we consider two samples of interest for our estimation. The first one is composed of all the 999 food industry firms which are surveyed in PA survey and completed by the information from RD survey, which we could call the "*Reference population*". This first population can be considered as a representative sample of the greatest firms from French food industries (i.e. including at least a plant with 100 employees or more), whatever such firms are concerned or not by innovation. Thus, within this population we extract a second interesting sample, composed of the 197

[3] Such values differ of those from section 3.2 and 3.3 because we are considering here the stock and not the investment: a firm which invests one year has a positive stock during the period even if it does not invest after.

firms which both invest in PA and RD. These firms are engaged both in RD and PA efforts and try to innovate by using the innovation inputs. They compose what we may call the (potentially[4]) "*Innovative population"*.

(Table 2)

Table 2 presents summary statistics for all the variables used in the analysis recalling their definitions. The "*Reference population*" is composed only of firms with plants of 100 employees and more, which is the threshold used in the Antipol survey. Therefore, a large part of food industry firms, especially small firms are not taken into account in this study. But the gap is still larger between this *Reference Population* and the firms actually (or potentially) engaged in an innovation process, present in the *Innovative Population*. The second ones are larger (almost twice), their value-added as well as capital being more than twice as large. Such results are consistent with the literature, suggesting a positive relationship between the size and the innovation propensity of the firm (see Mansfield, 1963).

A special attention should be paid to our two variables of interest, namely PA and RD investments and capital stocks. It is worth to recall that the investment average amount has two components: the number of firms which actually invest and the average amount engaged by these investing units. The respective cases of PA and RD investment appear to be very different, as shown by Graph 1 which represents the part of firms which actually invest in RD and PA.

(Graph1)

First, the average level is significantly higher in the case of PA investment: the rate of firms which actually invest is almost up than 50%, while it never attains 20% in the case of RD. RD concerns a minority of firms while the majority of firms invest to abate pollution. The respective trends also differ. In the case of RD, the rate of investing firms first declines (16.76% in 1994) until 2000 (9.86%), then grows until the end of observed period (16.55%). The rate of PA investing firms globally rises during the observed period, from 44.97% in 1994 to 65.70% in 2007. When considering the period, it appears that the average amount by plant increase because of this growing share of plants which actually invest whereas the average amount by investing plant does not significantly augment. This average amount represents only 3% of the total investment. AP investment concern now a majority of food industry firms (at least those with plants of 100 employees and more), but each firm contribution still remains low.

An important point is the relationship between the environmental regulation and the actual AP investment. It is extremely difficult to define regulation and moreover to provide a synthetic indicator of

[4] By using the term "potentially", we just mean that all firms using these inputs do not necessarily innovate, whereas, at the opposite, some firms may innovate without using its.

regulation stringency, because regulation has different forms and applies differently according to the industry, the size, the location…But, it is sometimes possible to identify a temporal shock, as the one which happened in 2000, when the European Union promulgated a directive devoted to the use of water by firms. Because water is an important dimension of pollution, especially in the case of food industry, because such a directive has important implications and assuming that the year 2000 was not affected by any other substantial exogenous shock, it is thus possible to assume that the significant leap, from 53.46% in 2000 to 69.04% in 2001 reveals the impact of environmental regulation on PA investment.

Once the share of firm population which actually invests has been studied, we consider the corresponding average investment amounts. The average amount of PA investments is low for populations, conducting to a PA capital stock which represents less than 2% of the stock of physical capital. The case of RD investment is different. Because it concerns few firms, the average amount is apparently low in the reference population, with a RD capital stock around 5% of the stock of physical capital, which is however higher than PA capital stock. But, when considering the firms actually engaged in RD investment, the amount of such an investment attains 13.84% of the amount of physical investment and represents more than seven times the amount of PA capital stock.

Such differences are significant: PA and RD efforts are different. The first one concerns a lot of firms with a low average intensity while the second one greatly matters but for a reduced part of firms. One should need additional information in order to explain this difference, but it could be suggested that PA effort is merely conducted by some constraints, particularly regulatory constraints, while RD effort is the fruit of an active strategy. The first one concerns automatically all firms of a given category (of a plant size category, for instance) while the second is issued from firms for which innovation is a necessary but also an attainable goal.

4. Results

4.1. Econometric model and estimation methods

In order to estimate an empirical specification we make some assumptions:

1. As in Griliches (1979), the production is a function of standard inputs labor and physical capital, knowledge capital and others unobservable variables:

$$Q_{it} = f(L_{it}, C_{it}, K_{it}, U_{it}) \tag{6}$$

2. The knowledge capital is a function of both R&D and PA capital stocks.
3. The unobservable term U_{it} can be decomposed in two distinct terms:

$$U_{it} = \exp(\omega_{it} + \varepsilon_{it}) \tag{7}$$

   where ω_{it} represents productivity shocks potentially linked to firms' input decisions while ε_{it} indicates shocks that are not related to input choices and refers to the standard econometric error term.

4. The technology of the firms can be represented using the Cobb-Douglas formulation where both observable and unobservable determinants enter multiplicatively. This gives:

$$q_{it} = \beta_l l_{it} + \beta_c c_{it} + \beta_{krd} krd_{it} + \beta_{kpa} kpa_{it} + \omega_{it} + \varepsilon_{it} \quad (8)$$

Minuscule letters indicate the log transformation of the variables. The estimation of such a production function leads to some well-known problems, namely endogeneity due to simultaneity and unobserved heterogeneity. Simultaneity occurs because in the profit maximization program of the firm, the levels of inputs are jointly determined and depend on the level of output. Unobserved heterogeneity occurs because some variables, as manager ability, environmental conditions…may affect the resulting level of output, for a given level of inputs. In order to solve such problems, some methods are proposed, which take advantage of the use of panel data. The standard panel data methods provide alternative way to introduce the key term ω_{it} which is supposed to affect the input choices and is known by the producers but is not known by the econometrician. In the standard panel data approaches, it is assumed that the term ω_{it} can be written as a sum of a firm specific firm effect and a common time effect, i.e. $\omega_{it} = \alpha_i + \lambda_t$. By taking natural logarithms we obtain the standard specification:

$$q_{it} = \beta_l l_{it} + \beta_c c_{it} + \beta_{krd} krd_{it} + \beta_{kpa} kpa_{it} + \alpha_i + \lambda_t + \varepsilon_{it} \quad (9)$$

Such a model can be estimated assuming either that the individual and time effects are fixed or that they are random variables. Both specifications are imperfect. The random model supposes that the individual effects are drawn from a normal distribution and uncorrelated with the explanatory variables (Hsiao, 2003). Such an exogeneity assumption, stating that there is no correlation between the effects the explanatory variables, seems to be unrealistic in the framework of a firm level production function. The individual effect reflects the unobserved heterogeneity which may be linked to some variables, as manager ability, environmental conditions: such variables may be correlated to the explanatory variables introduced in the production function, as labour, capital or the two RD and PA capital stock that we define. As an example a more "efficient" manager may have a higher propensity to invest in RD and in PA.

The assumption of no correlation between the individual effects and the explanatory variables is no more necessary when applying the Within estimator to the Fixed-Effect model. But it still imposes an additive structure to the unobservable:

$$\omega_{it} = \alpha_i + \lambda_t \quad (10)$$

Such a structure is very restrictive because it does not allow considering unobserved time varying firm individual effects. Consequently, some authors, following Olley and Pakes (1996) have proposed some methods, which improve the previous ones, to several extents. Such methods are directly derived from a theoretical model of industry dynamics (Ericson and Pakes, 1995) and are based on several assumptions. First, the inputs levels are fixed at different periods: labour, considered as a totally flexible factor, is fixed at the considered period, while capital is fixed at the previous period, avoiding simultaneity problems. Second, the unobserved heterogeneity is taken into account under a single variable ω_{it}. This variable is unobserved by the econometrician, but known by the firm and may be estimated with the help of proxies, namely investment (Olley and Pakes, 1996) or materials (Levinsohn and Petrin, 2003). When using the Levinsohn and Petrin approach, m being the materials, this leads to the following model:

$$q_{it} = \beta_l l_{it} + \beta_c c_{it} + \beta_{krd} krd_{it} + \beta_{kpa} kpa_{it} + \omega_{it} + \varepsilon_{it} \tag{11}$$

$$\omega_{it} = \ell(m_{it}, c_{it}, krd_{it}, kpa_{it}) \tag{12}$$

A detailed technical discussion of such an approach can be found in Ackerberg et al. (2007) and an empirical use applied to environmental economics in Coles (2007).

4.2. Estimation results

As discussed in the previous section we estimate the production function of equation (11) by using the Levinsohn-Petrin estimator. Table 3 presents the results of the estimations successively on the *Reference* population and on the *Innovative* population.

(Table 3)

It may be first noted that, whatever the population considered, the physical capital and labor estimates exhibit standard values, which are a little bit higher (resp. lower) in the case of capital (resp. labour) than those generally obtained when using the standard panel estimators (Within or FGLS).

If we first consider the *Reference* population, we obtain a significant and positive estimate for β_{kap}, which equals 0.0124. The Porter hypothesis is thus not rejected when considering the full population of French Food firms. Such a result is consistent with some previous studies (Berman and Bui, 2001, Alpay et al. 2002; Shadbegian and Gray, 2005; Lanoie et al., 2008). When considering β_{krd} a significant and positive estimate of 0.0070 is obtained. The value is lower than those found in the literature, whose magnitude is often between 0.10 and 0.20 (see the survey by Hall et al., 2010). Most of these studies, however, do not analyze the entire population of firms, but only focus on the firms engaged into RD activities, or in some cases use the predicted RD obtained from a selection equation instead of the observed RD (Griffith et al., 2006). This should explain why higher estimates are obtained for the RD coefficient.

The results obtained in the case of the *Innovative* population are significantly different from the previous ones. In this case, the RD's coefficient is positive, significant and much higher than in the previous case. The value equals 0.200 being in line with previous studies. Also the results concerning physical capital and labor are changed presenting a lower value for the labor's coefficient estimate and a higher value for the physical capital estimate. This is consistent with the respective composition of the two populations: innovative firms are significantly more capital-intensive than the others. But the most relevant result concerns the PA capital's coefficient which is no more significant in the case of such innovative population. Thus, while the Porter hypothesis is not rejected in the case of the population of all food firms, this is no more the case when considering specifically the population of innovative firms.

Our results suggest that when considering the complete population of firms in the French food industry, the Porter hypothesis cannot be rejected since whatever the estimator used, we obtain a small, but always significant and positive estimate for the coefficient associated to PA capital. But, when focusing on the innovative population, the results dramatically change. To our point of view, it does not reject the possibility of a "Porter effect", but it does not favor the assumption that such an effect could be explained by innovation. Indeed when considering the consistent population, in terms of innovation, and when compared to the "natural" input of innovation, namely RD capital, the PA capital does not appear to have any significant influence (positive or negative) on the firm performance. One should also note that in both cases (reference and innovative populations) the standard hypothesis of a negative and significant effect of PA on firm performances is decisively rejected.

5. Conclusions

This paper provides an econometric investigation of the relation between pollution abatement efforts and firms' performance for the French food industry by exploiting a rich panel data set covering the period 1993-2007.

We analyse a production function augmented with knowledge capital and combine the literature of the Economics of innovation and technological change with the framework used in the empirical tests of the Porter hypothesis. We indeed assume that both the PA and RD capital stocks are inputs of knowledge capital and consequently estimate a production function augmented with both RD and PA capital stocks. Different estimations methods are used, including the standard panel data methods and the Levinsohn and Petrin's estimator. A first look to summary statistics reveals that PA and RD investments are different. PA concerns a majority of firms with a low amount of investment. RD is concentrated on a more reduced population, but represents a much greater effort in the case of the firms which are actually concerned. Our estimation results suggest that for the French food sector the Porter hypothesis cannot be rejected since whatever the estimator used, we obtain a small, but always significant and positive estimate for the coefficient associate to PA capital. However, the often invoked argumentation, based on the fact that PA efforts will affect productivity via the induced innovation does not seem validated. Indeed, when the analysis is constrained to a consistent population, those of firms which are actually concerned by innovation, the comparison of the returns to PA with the returns to RD, clearly shows that

PA capital has not effects on firms' performances while RD' estimated elasticity is positive and significant.

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Table 1: The sample design

	Firms with PAK = 0	Firms with PAK > 0	Total
Firms with RDK = 0	104	692	796
Firms with RDK > 0	6	197 *(Innovative Sample)*	203
Total	110	889	999 *(Total sample)*

Table 2
Descriptive statistics: mean (S. D.), by firm

Variable	*Reference Population*	*Innovative Population*	*Definition*
VA	24,827 (48,793)	56,385 (87,861)	Output: Value-Added *(K Euros)*
L	379 (480)	691 (783)	Labour: Number of Workers
I	5,333 (13,750)	9,998 (18,039)	Investment *(K Euros)*
K	41,415 (88,151)	92,140 (157,343)	Capital stock *(K Euros)*
API	155 (391)	322 (639)	Anti Pollution investment *(K Euros)*
APK	863 (2,246)	1,939 (3,637)	Anti Pollution Capital stock *(K Euros)*
RD	336 (1,467)	1,681 (2,953)	R&D Expenses *(K Euros)*
RDK	1,707 (7,903)	12,675 (19,267)	R&D capital stock *(K Euros)*
N (firms)	999	197	Number of firms
NT (observations)	8260	1073	Number of observations, between 1993 and 2007

Graph 1: % of firms actually engaged in AP and RD investment

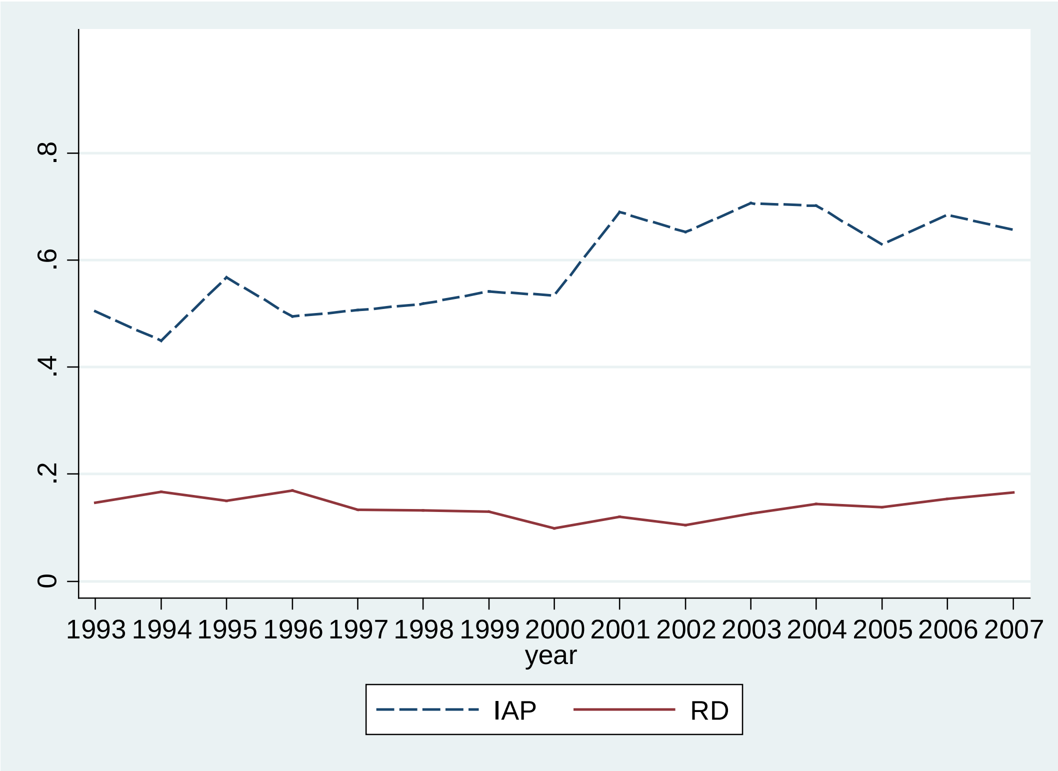

Table 3: Estimates of the production function, food Industry: 1993-2007
Levinsohn-Petrin estimator

Variables	*Reference population*	*Innovative population*
L	0.601***	0.643***
	(0.000)	*(0.000)*
K	0.274***	0.352***
	(0.000)	*(0.000)*
KRD15	0.0070***	0.2005***
	(0.001)	*(0.008)*
KAP15	0.0124***	-0.0149 ns
	(0.004)	*(0.541)*
N	8260	1073
Adj R-squared *(Step 2)*	0.7087	0.7568

P values are in parentheses: * *p* < 0.10, ** *p* < 0.05, *** *p* < 0.01
Time and industry (Nace3 level) dummies are included in regressions whose coefficients are not reported.

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