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Productivity and environmental regulation: the effect of the nitrates directive in the French pig sector

Isabelle Piot-Lepetit · Monique Le Moing

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Abstract This paper measures the ensuing changes in productivity in the French pig sector following the introduction of the European regulation addressing water pollution by nitrates from agriculture. Productivity is measured using the Malmquist–Luenberger index. The sources of changes in productivity observed are examined by breaking down this index into its technical progress and efficiency components. The results show that in the early stages, increases in productivity were stimulated by increased efficiency, before being driven by technical progress. The estimations regarding the sources of efficiency gains for the farms in the sample (technical efficiency, efficiency of scale and environmental efficiency) are then used to estimate the indirect costs and benefits (or negative costs) linked to the introduction of the environmental regulation controlling the disposal of organic manure and the management of nitrogen surplus from pig farms. The existence of a "win-win" effect as regards the Porter hypothesis relation between efficiency and environmental regulation is highlighted for the French pig sector.

Keywords Environmental costs · Porter Hypothesis · Environmental efficiency · Productive efficiency · Directional distance function · Malmquist–Luenberger index

JEL classification C60 · D21 · D24 · D62 · Q20

1 Introduction

The development of pig production in France is one of the country's most obvious agricultural successes. In the sixties, this sector was based on archaic and atomised structures. When the common agricultural policy was introduced, it went through a major crisis with a great many farms going out of business, and in the early seventies, a

I. Piot-Lepetit (✉) · M. Le Moing
INRA-UR122, 4 allée Adolphe Bobierre, CS 61103, Rennes cedex 35011, France
e-mail: Isabelle.Piot@rennes.inra.fr

substantial commercial deficit appeared. A plan was then introduced to boost French production by means of technical progress. As a result of developments in production techniques and husbandry management, economies of scale and considerable increases in productivity were achieved. This change could be seen in the greater concentration of production, but little thought had been given to the effect the new production model might have on the environment. Following the introduction in 1991 of the European Directive addressing water pollution by nitrates from agriculture, public decision-makers sought to restrict the productive choices made by producers, with a view to reconciling pig production with environmental protection by imposing, among other things, a standard on manure spreading and the mandatory application of a code of good agricultural practice.

There are a number of technological options that can help to reduce pollution in the pig sector. From the direct point of view, the adoption of new, less-polluting production technologies has an impact on environmental pollution by farms. These technologies mainly concern buildings, capacities and storage structures for manure, and manure treatment facilities. A large proportion of the environmental costs borne by farms following the adoption of these technologies are capital investment costs. As a general rule, there is no immediate return on investment, unless public decision-makers provide financial support payments aimed at encouraging producers to adopt these new technologies, as is the case in France. From the indirect point of view, improving productivity in the pig production sector implies greater efficiency in the way inputs are used and production processes are implemented. An improvement in the productive efficiency of farms can lead to a decrease in feed consumption or water requirements, in turn leading to a reduction in production costs and pressure on the environment, especially on water quality, per output unit. These changes are often referred to as being "win-win", in the sense that they both reduce the environmental risks for producers and at the same time cover all or part of the costs incurred by these improvements in practices. This effect is known as the "Porter Hypothesis" (Porter 1991). Porter and van der Linde (1995) argue that introducing an environmental regulation gives producers an opportunity to improve their productivity by providing them with a strong incentive to change their practices or to adopt a new production technology. Palmer et al. (1995) contest this assumption. However, they do not reject the idea of a link between the efficiency of firms and the introduction of an environmental regulation. They suggest that studies be carried out to establish the extent of this effect.

The aim of this contribution is to examine changes in the productivity of farms operating in the pig sector in France following the effective introduction of an environmental regulation, and to determine whether this regulation was the source of any "win-win" outcomes. An understanding of the link between productivity, efficiency and environmental performance in the pig sector may indeed have major implications both for the farms themselves and for public decision-makers, especially as far as assessing the costs and impacts of an environmental regulation is concerned.

Recently, a certain number of studies have set out to measure the relation between the environmental performance of firms and their productivity using distance functions (Färe et al. 1989, 1993, Chung et al. 1997, Boyd and McClelland 1999, Boyd et al. 2002, Murty and Kumar 2003, Ball et al. 2005). The work presented here is a continuation of the work of Boyd et al. (2002). First, the paper looks at pollution through the emission of a polluting output. This output is taken directly into account in the measurement of productivity and its components as a by-product of the activity to produce marketable goods. Then, the productivity index is calculated using the Malmquist–Luenberger (ML) productivity index (Chung et al. 1997). This index is based on the definition of several output directional distance functions. It enables the existence of an undesirable—because it is a source of diffuse pollution (surplus nitrogen)—by-product related to the production activity to be taken into account. This index can then be broken down into two components—technical progress and efficiency—so as to assess the weight of these different explanatory factors in the changes in productivity.

This paper is unique in two ways. Firstly, in order to characterise the "win-win" outcomes induced by the environmental regulation aimed at reducing water pollution by nitrates from agriculture, we study the efficiency component of the Malmquist-Luenberger productivity index more specifically.[1] We seek to characterise the sources of inefficiency: inefficiency in the production techniques, inefficiency related to the scale of the production activity, and inefficiency resulting from restrictions on the disposal of polluting outputs imposed by the environmental regulation. Secondly, this paper proposes an assessment not only of the indirect costs linked to the environmental regulation, but also of the benefits that may potentially be achieved as a result of the reduction in productive inefficiencies. The empirical illustration is based on a sample of 320 farms located in France during the period 1996–2001, mainly producing pigs and which all had a nitrogen surplus; they all had polluting emissions to dispose of.

The paper is set out as follows. Section 2 deals with methodological issues. Section 3 describes the data. The main results are reported in Section 4 and the conclusion is given in Section 5.

2 Methodology

2.1 Model the production technology in presence of production externalities

Consider a firm employing a vector of inputs $x \in R_+^N$ to produce a vector of desirable outputs $y \in R_+^M$ and of undesirable outputs $b \in R_+^S$. Let $P(x)$ be the feasible output set for the given input vector x. This technology set that includes all technically feasible output vectors is defined as:

$$P(x) = \{(y, b) : (y, b) \text{ can be produced by } x\}$$

This output set is assumed to satisfy the usual axioms of possibility of inaction, no free lunch and to be convex and compact. Inputs and good outputs are assumed to be freely disposable while undesirable outputs are only weakly disposable. Furthermore, good and bad outputs are assumed to be null-joint (Färe and Grosskopf 2004).

We assume that there are K observations on inputs and outputs and that each observation is indexed by $k(k = 1, \ldots, K)$. The production technology can be modelled as:

[1] Unlike Managi et al. (2005), who study the impact of technological innovations on the productivity index, the work carried out here is interested in the efficiency component of the productivity index, in other words in the changes in this index resulting from the introduction of more environmentally-friendly practices.

$$P(x) = \left\{ \sum_{k=1}^{K} z_k y_{km} \geqslant y_m,\ m = 1, \ldots, M;\ \sum_{k=1}^{K} z_k b_{ks} = b_s,\ s = 1, \ldots, S; \right.$$
$$\left. \sum_{k=1}^{K} z_k x_{kn} \leqslant x_n,\ n = 1, \ldots, N;\ z_k \geqslant\ 0,\ k = 1, \ldots, K \right\} \tag{1}$$

where z_k is the intensity vector of each observation $k(k = 1, \ldots, K)$. Since the desirable outputs y and the inputs x are freely disposable, the constraint is represented by an inequality. For the undesirable outputs, we have introduced an equality corresponding to an assumption of weak disposability.

Alternatively, the production technology can be described by means of a directional distance function (Chambers et al. 1996). This approach enables us to represent a production technology in the presence of environmental externalities. Formally, the output directional distance function is defined as:

$$\vec{D}_o(x, y, b; g) = \sup \{\beta : ((y, b) + \beta g) \in P(x)\} \tag{2}$$

and inherits its properties from $P(x)$. The directional distance function takes (y, b) in the g direction and places it on the boundary of the production set $P(x)$. Here, we assume that $g = (y, -b)$, in other words, that farms can only increase their production if they can reduce the nitrogen surplus by the same proportionβ. The directional output distance function takes the value of zero when the output vectors are on the boundary of $P(x)$, whereas positive values apply to output vectors below the boundary.

The directional distance function can be used to provide a measure of the productive efficiency of the observations by defining:

$$\text{Eff} = \vec{D}_o(x, y, b; g) \tag{3}$$

The measure of productive efficiency defined by Eq. 3 is zero when the observation is efficient. When an observation is inefficient, it is greater than zero. The nearer its value is to zero, the more the observation will be considered as efficient, and the more minor will be the adjustments needed to move it onto the production possibility frontier.

2.2 Malmquist–Luenberger (ML) productivity indices

The productivity measure is calculated on the basis of several directional distance functions defined in such a way as to capture the movements of the production frontier and modifications in the efficiency of farms between two consecutive dates.

Chung et al. (1997) define the output-oriented Malmquist-Luenberger productivity index between periods t and $t+1$ as:

$$ML_o^{t,t+1} = \left(\frac{1 + \vec{D}_0^t(x^t, y^t, b^t; y^t, -b^t)}{1 + \vec{D}_0^t(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \frac{1 + \vec{D}_0^{t+1}(x^t, y^t, b^t; y^t, -b^t)}{1 + \vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \right)^{1/2} \tag{4}$$

It measures the productivity change between two time periods by calculating the ratio of two associated output-oriented directional distance functions.

To explain the origin of the changes in productivity, the index defined in Eq. 4 is then broken down into a measure of the change in the index resulting from technical progress, and a measure of the change in this index as a result of a change in the productive efficiency of the observations between the two time periods. This decomposition can be formulated as:

$$ML_o^{t,t+1} = \underbrace{\left(\frac{1+\vec{D}_0^t(x^t,y^t,b^t;y^t,-b^t)}{1+\vec{D}_0^{t+1}(x^{t+1},y^{t+1},b^{t+1};y^{t+1},-b^{t+1})}\right)}_{\text{Efficiency change}} \cdot \underbrace{\left(\frac{1+\vec{D}_0^{t+1}(x^{t+1},y^{t+1},b^{t+1};y^{t+1},-b^{t+1})}{1+\vec{D}_0^{t}(x^{t+1},y^{t+1},b^{t+1};y^{t+1},-b^{t+1})}\frac{1+\vec{D}_0^{t+1}(x^t,y^t,b^t;y^t,-b^t)}{1+\vec{D}_0^t(x^t,y^t,b^t;y^t,-b^t)}\right)^{1/2}}_{\text{Technical change}} \tag{5}$$

The technical progress component corresponds to movements in the production frontier over time. Changes in the latter are interpreted as technical production possibilities that appear or disappear. The efficiency component corresponds to movements towards the production frontier. By definition, efficiency describes the distance separating each observation in the sample from the production frontier. Thus, any producer whose activity is not on the production frontier can improve his earnings by increasing his production jointly with a decrease in the pollution generated by his productive activity, without changing either his production technology or the level of his inputs, simply by modifying his routine farm management system over time.

To determine the origin of the Malmquist–Luenberger index changes in efficiency, and according to Färe et al. (1985, 1994), we break down this measure as follows:

$$\text{EffCh} = \text{TechEffCh} \cdot \text{ScEffCh} \cdot \text{EnvEffCh} \tag{6}$$

where EffCh is the change in efficiency defined in Eq. 5, whose components are TechEffCh for the change in technical efficiency, ScEffCh for the change in efficiency of scale and EnvEffCh for the change in environmental efficiency.

Changes in technical efficiency are assessed using a production frontier with the assumption of variable returns to scale, i.e. in relation to a set of production possibilities where the following constraint has been introduced:

$$\sum_{k=1}^{K} z_k = 1 \tag{7}$$

Changes in efficiency of scale are determined by comparing efficiency in relation to two production frontiers, one under constant returns to scale, defined by Eq. 1 and the other under variable returns to scale, defined by Eqs. 1 and 7.

Lastly, changes in environmental efficiency are calculated by comparing efficiency in relation to a frontier with variable returns to scale and the weak disposal of undesirable outputs, as defined by Eqs. 1 and 7, and a frontier where the assumption of free disposal is re-established, i.e.; where the constraint on the polluting output is replaced by:

$$\sum_{k=1}^{K} z_k b_{ks} \geqslant b_s, \quad s = 1, \ldots, S \tag{8}$$

2.3 Costs of environmental regulation and efficiency measurement

The aforementioned measures enable us to study the changes in productivity within a sector of activity, and to characterise the sources of these changes. We shall now seek to measure the costs of the environmental regulation. We shall be more particularly concerned with two types of costs: indirect costs and negative costs (Pizer et al. 2005).

The indirect costs, or revealed costs, of the environmental regulation are costs that are not directly entered in the books as expenditure on bringing production facilities up to standard, but that result from the restrictions imposed on producers with regard to the disposal of their polluting output—in this case, nitrogen surplus. Following the introduction of the regulation aimed at limiting nitrate emissions, producers must comply with a standard defining the maximum level of manure that can be spread. They now also have to comply with the Code of Good Agricultural Practice, which specifies effluent storage times and spreading conditions. The costs incurred as a result of these statutory measures are difficult for producers to measure; they are revealed by measuring environmental efficiency. This measure is determined by comparing the efficiency of each observation in relation to two production frontiers. The first of these assumes that there is no constraint on the polluting output, which is freely disposable, whereas the second is built on the assumption that the polluting output, produced jointly by the production activity, is weakly disposable as a result of the regulation restricting producers' possibilities for disposing of this undesirable product. Thus, the measure of environmental efficiency provides information about the loss of outputs resulting from policy measures restricting producers' practices so that they abide by the Code of Good Agricultural Practice and comply with the spreading standard set by the Nitrates Directive. If the value of the measure is equal to zero, this means that the weakening of the free disposal assumption has no effect, and the firm is not constrained by these regulatory measures. Where the value is greater than zero, it provides us with information about how far the firm's productive capacity is restricted, in other words about the level of outputs not produced because of constraints that these policy measures impose on the firm. A measure of the loss of outputs due to the polluting output management constraint is given by:

$$\text{Output loss} = \text{EnvEff} * y$$

where EnvEff is the measure of the firm's environmental efficiency and y is the level of production of desired outputs. Symmetrically, the decrease in pollution resulting from measures restricting the polluting output is obtained by:

$$\text{Pollution reduction} = \text{EnvEff} * b$$

where b is the level of production of the undesired output, in other words, the firm's nitrogen surplus.

According to the definition given by Pizer et al. (2005) to the costs of environmental regulations, there are also negative costs, or indirect benefits for the firm. When a firm is not operating as efficiently as it might do, the environmental regulation could provide an effective stimulus and encourage the firm to pinpoint and rectify its inefficiencies. This absorption of inefficiencies is thus a "negative" compliance cost, which helps to at least partially reduce not only the direct costs related to the firm's investments in new production or pollution treatment processes, but also the indirect costs linked to the limitations on the disposal of the polluting output imposed by the environmental regulation. Within the framework of this study, we are able to identify two types of negative costs. The first is connected with the notion of technical efficiency, while the second is based on that of efficiency of scale. Increasing a firm's technical efficiency optimises the production process and improves the firm's results through either a reduction in production costs or an increase in production. Technical efficiency corresponds to an evaluation of the distance from each observation to a production frontier with the assumptions of variable returns to scale and weak disposability of undesirable outputs. It does not therefore capture the effects on efficiency related to the scale of production or to the environmental regulation. Absorbing inefficiencies of scale results in an increase in production without any changes in the production process, simply by modifying the size of the productive activity. It is obtained by comparing the efficiency measure of each observation in relation to two production frontiers with the assumption of weak undesirable output disposability, and in relation to two assumptions about returns to scale: variable or constant. The benefit that firms can gain from absorbing these two types of inefficiency can be measured by:

$$\text{Output benefit} = \text{Eff} * y$$
$$\text{Pollution decrease} = \text{Eff} * b$$

where Eff = TechEff, ScEff is the measure of the technical efficiency and efficiency of scale of the firm.

As a result of the direction used, $g = (y, -b)$, the absorption of these inefficiencies leads the firm to produce more and pollute less without investing in new production processes and without taking into account the restriction on the disposal of the polluting output. In this sense, these measures effectively capture the benefit that firms can gain from improving their productive efficiency (without this being related to pollution control measures) after the introduction of the environmental regulation, which drives them to look again at the whole of their production process.

3 Data

The empirical part of the work was carried out using a sample of 320 individual pig-producing farms in France. The data used comes from the Farm Accountancy Data Network (FADN). The farms in the sample are all listed as mainly producing pigs, which accounts for 2/3 of their gross margin. They use a production process that generates a nitrogen surplus, i.e. an undesirable output that has a detrimental impact on the environment. Thus, these farms are all affected by the regulations relating to the reduction in water pollution by nitrates of agricultural origin—the Nitrates Directive and the PMPOA (*Programme de Maîtrise de la Pollution d'Origine Agricole*, a programme to control pollution of agricultural origin).

The Nitrates Directive has resulted in around 50% of the utilized agricultural area in France being classified as Nitrogen Vulnerable Zones since 1994. These zones include not only regions of intensive livestock farming like Brittany, but also areas of intensive arable farming in the Paris basin and the South West of France, where problems related to water pollution by nitrates of agricultural origin have been identified. The farms in the sample are located in five French regions; Nord-Pas de Calais, Pays de la Loire, Brittany, Midi-Pyrenees, and Auvergne. The sample therefore depicts the activity of the French pig sector and groups together a set of farms with different degrees of specialisation and production intensity. Consequently, the results presented are not specific to one production system; on the contrary, they take account of the pig sector's many possible adaptations in the wide-ranging types of farms operating therein.

The Nitrates Directive has also led to the drafting of a Code of Good Agricultural Practice, which lists the technical rules to be followed so that water pollution by nitrates is reduced, and to the implementation of action programmes. The selected period of study runs from 1996 to 2001. This tallies with the introduction of France's first action programme, known as the PMPOA. The requirements set out in action programmes mainly refer to the agricultural practices that are to be implemented to achieve well-balanced nitrogen fertilisation. The amounts of organic nitrogen from livestock effluent that are spread must not exceed 170 kg/ha. To help farmers adjust their storage capacities and times in line with these new constraints, the PMPOA provides for the allocation of government aid, so that investments can be made and spreading practices changed to improve the protection of water. Should the optimisation of spreading practices prove to be insufficient, other courses of action may also be taken. In order of priority, these are: a reduction in nitrogen at its source through an improvement in livestock feeding, exports of manure towards areas that do not have a nitrogen surplus, the treatment of effluent, or as a last resort, a cut in production. Sanctions cannot be imposed on farmers who sign up to the PMPOA until the investments to be made have been completed. To begin with, the PMPOA programme targeted the largest farms who were borrowing available land for spreading purposes as a means of complying with the spreading constraint set out in the Nitrates Directive. The rollout of the programme fell several years behind schedule because far more farms signed up for it than had been expected. Over the period 1994–2001, some 14,911 applications were filed for the Brittany region alone, 60% of which were registered during the period under study, but by 2001, only 26% of the work had actually been carried out. Given the low level of investment actually made over the period under study, our attention will focus on increases in efficiency resulting from the introduction of the Code of Good Agricultural Practice and on the limitations on manure spreading, in other words, on environmental costs that are hard to quantify in impact studies.

Special attention needs to be paid to 2 years in the selected period. Firstly, 1999, when the 1998 Voynet-Le Pensec directive, which specifies spreading requirements in the most water pollution-sensitive areas, was implemented. Secondly, the year 2001, which was a year of waiting for negotiations with the European Commission on the possible continuation of the PMPOA. No applications could be filed that year.

To determine the productivity and efficiency indices, we have defined an empirical model based on economic variables. It includes a desired output (y), which is the farm's constant price gross output 1996, equivalent to the agricultural goods produced by the farms and intended for sale on the commodity market. The undesirable output (b) is the nitrogen surplus. It is estimated on the basis of the livestock population present and the use of land, using CORPEN[2] standards. The nitrogen surplus represents the proportion of manure that cannot be spread in good agricultural and environmentally-friendly conditions, given the availability of land, the kind of crops grown and the amount of chemical fertilisers purchased by the farm.

We also assume that these outputs are obtained from four inputs: land (x_1) measured in hectares, the livestock population (x_2) measured in livestock units, work (x_3)

[2] The CORPEN is an organisation responsible for defining the Codes of Good Agricultural Practice relating to the management of nitrogen and phosphorus. It also provides information on the average level of nitrogen produced by different types of animal and taken up by crops.

Table 1 Sample description (Sample means with standard errors in parenthesis)

Variable	1996	1997	1998	1999	2000	2001
y—Gross output (1996 euros)	247,858 (160,517)	253,326 (156,117)	229,819 (147,158)	232,788 (134,106)	263,457 (162,387)	302,842 (206,333)
b—Nitrogen surplus (kilograms)	6,643 (4,827)	6,661 (5,002)	6,633 (5,726)	6,109 (5,180)	5,646 (4,605)	6,666 (5,622)
x_1—Land (hectares)	53 (31)	56 (34)	58 (37)	60 (35)	61 (37)	63 (36)
x_2—Livestock population (livestock units)	216 (175)	221 (160)	242 (187)	241 (172)	257 (187)	257 (207)
x_3—Work (annual worker units)	1.9 (0.8)	1.9 (0.8)	2 (0.8)	1.9 (0.8)	1.9 (0.7)	2 (0.8)
x_4—Variable expenses (1996 euros)	151,122 (150,108)	157,689 (106,995)	162,066 (121,798)	156,437 (107,886)	163,386 (112,618)	183,405 (136,668)

measured in terms of the number of workers, and variable expenses[3] (x_4) in euros 1996. Table 1 shows a number of descriptive statistics relating to these data.

4 Results

The productivity indices and their components are calculated for each farm in relation to the production frontiers including all of the farms in the sample. They describe the change observed between two consecutive years. A value greater than 1 indicates a positive change in the index (growth in productivity, technical progress or improvement in efficiency). A value of less than 1 is a sign of a deterioration in the index (decrease in productivity, technical regression or loss of efficiency). A value equal to 1 indicates that there has been no effect.

Figure 1 shows the development of productivity and its components—change in technical progress and efficiency—from 1996 to 2001. After a drop early on in the period, we then see an increase in productivity. Two factors may explain the fall in productivity in 1997. On the one hand, the environmental regulation and especially the restrictions on spreading, came into effect, curbing all production possibilities for certain farmers. On the other hand, the economic climate in which producers make their decisions was in 1996–1998 characterised by a fall in prices to below the cost of production. In the wake of this production crisis, we can observe a revival in the growth of productivity. Over the period 1998–2000, the increase in productivity is spurred on by the index's efficiency component. The increase in efficiency resulting from improved on-farm practices gives new impetus to the revival in productivity well before the effect of technical progress is felt. Technical progress influences productivity in the same direction until 2000 but to a slightly lower degree. In 2001, the growth in productivity (index greater than 1) is slightly weaker than that observed in 2000. Unlike in other years, it is solely the result of technical progress, and therefore of investments made by the farms over the period. As noted previously, 2001 was a year

[3] The variable expenses group together all expenses directly linked to the production process, such as animal feed, water, electricity, minor equipment, vets' fees and transport costs, as well as expenses linked to building and equipment maintenance, and the amortization of investments made.

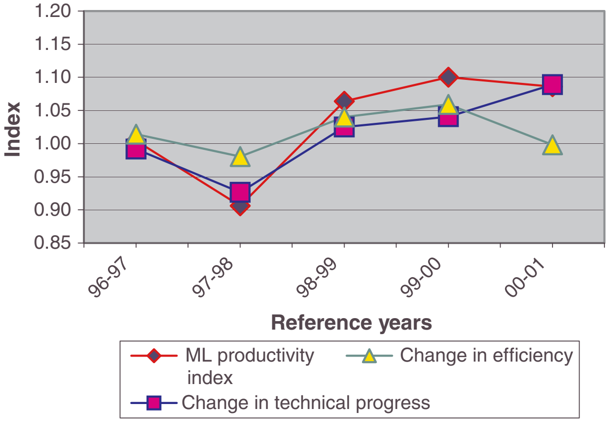

Fig. 1 Malmquist–Luenberger (ML) index and changes in its components (Technical progress and efficiency)

of waiting to find out whether the investment aid programme would be continued, which meant that there was less incentive for farmers to improve their productive efficiency. However we can see that at the end of the first action programme introducing the European regulation addressing water pollution by nitrates in France (2001), efficiency is no longer a productivity-boosting component. Technical progress alone stimulates increases in farm productivity.

In the absence of any data on the investments made in new, less-polluting technologies over the period, we limit our interest to the factors that explain the improvements in producer's efficiency, in other words to the indirect cost borne by producers when they comply with the measures specified in the Code of Good Agricultural Practice and with the spreading constraint of the Nitrates Directive, aside from any investment in new equipment. Figure 2 presents the decomposition of the efficiency component of the productivity index into three components: change in technical efficiency, change in efficiency of scale and change in environmental efficiency. Changes in technical efficiency describe the improvements resulting from the more efficient use of the production technology, brought about by an improvement in the technical management of the farm. Changes in efficiency of scale describe the gains resulting from a change in the size of the production activity. Changes in environmental efficiency are the changes that occur when practices on the farm are modified following the introduction of regulatory constraints on the disposal of the polluting output or on the management of nitrogen surplus.

Early in the period, we can see a fall in the efficiency component, due to a reduction in the farms' efficiency of scale. Over this period, during which the pig sector was shaken up by the environmental regulation and the production crisis, the size of the production activity acts negatively on the measure of the efficiency component of productivity. From 1998 to 1999, the improvement in farm efficiency can mainly be explained by the technical component, whereas from 1999 to 2000, the scale component plays the positive role. From 2000, increases in efficiency are once more generated by performance-related improvements, linked to the effectiveness with which the production technology is implemented; the positive effect of technical efficiency. Thus, the improvement in technical efficiency and efficiency of scale has

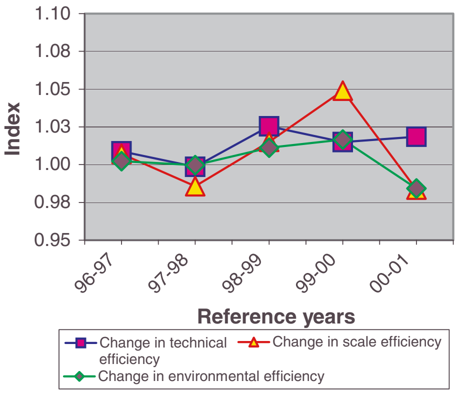

Fig. 2 Change in the components of the efficiency index (technical efficiency, efficiency of scale and environmental efficiency)

Table 2 Indirect cost of the environmental regulation

Variable	1996	1997	1998	1999	2000	2001	Mean
EnvEff (%)	4.9	5.1	5.9	5.2	3.8	6.1	5.2
Output loss (€)	8, 766	11, 186	10, 533	10, 581	7, 026	14, 230	10, 387
Unit cost (€/kg)	5	20	8	11	13	22	13.17
Pollution reduction							
(kg)	154	165	188	152	74	167	150
(kg/ha)	3.71	4.06	5.13	3.50	1.99	3.04	3.6

generated productivity gains by modifying on-farm practices, and by modifying the size of the production activity so as to absorb the wasting of productive resources and reduce the negative impact of production activities on the environment, aside from any investment in new, less-polluting technologies.

Changes in environmental efficiency provide us with information about the impact of the environmental regulation aimed at limiting the possible disposal of the polluting output and controlling the management of surplus nitrogen. From 1996 to 2000, changes in environmental efficiency are greater than 1. They therefore make a positive contribution to changes in the efficiency component of the productivity index. Then, the value of these changes falls to less than 1 in 2001. This decrease coincides with the end of the first action programme and the introduction of a second programme for the period 2001–2004, which again modified the productive context within which farmers operate. Overall, the introduction of statutory provisions restricting the disposal of organic nitrogen into the environment and the management of nitrogen surplus has led to improvements in practices that have had a positive effect on the efficiency component of the measure of farm productivity.

The results relating to the indirect costs of the regulation borne by producers are shown in Table 2. These costs stem from the set of measures brought in to limit the disposal of organic manure into the environment and control the management of surplus nitrogen. They are assessed in terms of the output not produced as a result of the constraints controlling the polluting output. They are derived from the measure of environmental efficiency. Depending on the year, the loss of output is between 3.8% and 6.1%, and corresponds to an average loss of income of somewhere in the region of €10,387 per year, with values stretching from €7,026 to €14,230. The indirect costs of

Table 3 Negative costs or output benefits of the environmental regulation

Variable	1996	1997	1998	1999	2000	2001	Mean
TechEff (%)	13.3	13.8	16.0	14.8	15.2	14.9	14.7
Output benefit (€)	25,802	27,642	29,724	28,495	31,393	33,265	29,387
Pollution decrease							
(kg)	833	907	1,006	830	774	960	885
(kg/ha)	19.2	19.1	23.1	16.8	16.5	17.8	18.8
ScEff (%)	4.1	3.9	6.1	6.9	3.9	4.4	4.9
Output benefit (€)	8,649	9,320	11,354	13,149	11,124	12,516	11,019
Pollution decrease							
(kg)	304	272	305	380	279	278	303
(kg/ha)	5.1	4.8	7.6	7.5	4.9	5.6	5.9

the environmental regulation are estimated at an average €13 per kg per year across the sample. These values do however vary considerably depending on the year, from €5/kg in 1996 to €22/kg in 2001. The main factor explaining these annual differences is the unfavourable economic climate over the years 1996–1998. At the start of the period under study, the regulatory measures mainly affected larger farms, as they were potentially the most polluting ones; this is expressed by a higher indirect cost in 1997. Then, difficulties on the pig market took prices to below production costs, throwing the sector into a crisis, the upshot of which was that existing productive structures were modified. 2001 was a special year in that it marked the end of the first action programme, and the introduction of the second one. We must exercise caution when interpreting the higher unit cost because we lack information about adjustments made at this time. Overall, the average reduction in the nitrogen surplus is 150 kg per year, with a minimum of 74 kg in 2000 and a maximum of 188 kg in 1998. So, the introduction of restrictive measures governing the disposal of pollution leads to an average reduction in the nitrogen surplus of 3.6 kg/ha per year. The constraints of the environmental regulation on organic manure disposal and nitrogen surplus management result in indirect costs for farms, equivalent to a 4.1% annual decrease in total production over the period and to an average annual decrease of 2.3% in the total volume of surplus nitrogen produced over the whole of the sample and the selected period.

Table 3 shows the negative costs linked to the introduction of the environmental regulation, or to be more precise, the benefits that farms can achieve as a result of the incentive to reduce productive inefficiencies not directly related to the measures imposed by the regulation restricting the disposal of organic manure and the management of nitrogen surplus. Regarding the technical component of efficiency, 13–16% gains are achievable, depending on the year. This is equivalent to an increase in production jointly with a reduction in the polluting output of an average 14.7% a year. The negative costs or associated benefits are estimated at an average €29,387 per year, which more than covers the indirect costs linked to pollution control, as shown in Table 2. The decrease in the nitrogen surplus associated with these productive benefits is an average 885 kg per year, or 18.8 kg/ha. These figures correspond to an average annual increase of 11.5% in total production over the period, and to an average annual decrease of 13.8% in the volume of nitrogen surplus produced, achieved by simply reducing the technical inefficiency of farms. The gains that can be achieved by reducing farms' inefficiency of scale are lower, but help to increase the amount of potentially achievable negative costs. So, the efficiency of scale stands at an average of 4.9% per year, the equivalent of an €11,019 increase in total production, and a decrease in the total nitrogen surplus of 303 kg, or 5.9 kg/ha. For the sample as a whole over the period, these figures correspond to an average annual increase of 4.3% in total production, and to an average annual decrease of 4.7% in the total volume of nitrogen surplus, achieved by simply reducing farms' inefficiency of scale.

By comparing the results of Tables 2 and 3, we can observe that the indirect costs linked to the regulatory restrictions on the disposal of organic manure and the management of nitrogen surplus are more than covered by the benefits or negative costs expected from the absorption of technical and scale inefficiencies brought about by changes in the set-up of production processes, quite aside from any change in technology. The balance of the potentially achievable benefits may cover part of the direct costs linked to investments imposed by the environmental regulation. Thus, the work carried out highlights a "win-win" effect with respect to the efficiency component of the productivity index; in other words, there is a positive relation between efficiency and environmental regulation in the French pig sector. Further work would involve investigating whether this effect also exists, at least partially, with respect to the relation between technical progress and environmental regulation.

5 Conclusion

The aim of this paper is to identify and measure the changes brought about by the introduction of an environmental regulation in the pig sector in France. The paper is particularly concerned with the impact of regulatory measures on farm productivity and on the efficiency component of the productivity index. Assessing the indirect costs and benefits ensuing from the relation between the efficiency of firms and the environmental regulation enable us to assess the magnitude of the Porter hypothesis "win-win" effect in this activity sector.

Productivity is measured using the non-parametric Malmquist–Luenberger index. This provides an analysis framework that takes into account the existence of an environmentally undesirable by-product jointly with the marketable production activity. The productivity index used can be decomposed in order to identify the sources of the change in productivity over time—change in technical progress and efficiency. The empirical illustration uses a sample of pig farms in France that had a nitrogen surplus over the period 1996–2001, when the first action programme was set up to bring the environmental regulation into effect. The results show the existence of increases in productivity. These increases were initially stimulated by gains in efficiency, before being generated by technical progress. Measures relating to the efficiency of farms enable us to then estimate the indirect costs linked to constraints on the disposal of nitrogen surplus. The estimated magnitude of these costs shows that they are offset by the benefits (or negative costs) brought about through the absorption of the technical and scale inefficiencies of the farms in the sample.

So, by concentrating on the relation that exists between efficiency and environmental regulation, we have been able to estimate a "win-win" effect in the French pig sector over the period 1996–2001. The lack of information about investments made after the environmental regulation was introduced, and therefore about the direct costs borne by farms, meant that we were unable to extend the study to the relation between technical progress and environmental regulation as suggested by the Porter hypothesis. However, the results of this research show that over the period under study, possibilities existed for farms to recover the indirect costs of the environmental regulation addressing water pollution by nitrates from agriculture, by reducing productive inefficiencies existing in the French pig sector.

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