5èmes Journées de recherches en sciences sociales

INRA-SFER-CIRAD

AgroSup Dijon, les 8 et 9 décembre 2011

The spread of pesticide practices among cost efficient farmers

Jean-Philippe Boussemart[a]

Hervé Leleu[b]

Oluwaseun Ojo[c*]

This research has been supported by the "Agence Nationale de la Recherche" on the project "Popsy: Arable Crop Production, Environment and Regulation", decision n°ANR-08-STRA-12-05. We use a database of Centre d'Economie Rurale de La Meuse financed as part of an agreement with INRA.

---

a. LEM-IESEG School of Management and University of Lille, 3 rue de la Digue 59000 Lille, France, jp.boussemart@ieseg.fr
b. CNRS/LEM and IESEG School of Management, 3 rue de la Digue 59000 Lille, France, h.leleu@ieseg.fr
c. CNRS/LEM and IESEG School of Management, 3 rue de la Digue 59000 Lille, France, o.ojo@ieseg.fr
* corresponding author : Tel: 33 (0)3 20 54 58 92, Fax: 33 (0)3 20 57 48 55

Abstract

The purpose of this paper is to analyze the spread of pesticide practices with respect to crop production (wheat, barley and rapeseed) in French agriculture. This is made possible by conducting a double step analysis based on non-parametric reference technologies. First, from a panel data of 600 farms over a 12 year period located in the French department of Meuse, we select the cost efficient farms thanks to a Free Disposal Hull (FDH) technology. A second FDH frontier analysis was run only on the selected cost efficient farms thus enabling us to reveal the units which minimize the pesticide use per ha while maintaining constant yields. Therefore, all the different total cost efficient practices among farmers were evaluated in terms of pesticide per ha and the minimum uses were selected. Our main conclusion is that the pesticide reductions per hectare for the cost efficient farms could reach 20%. However, we also show that these potential reductions decrease with yield augmentation overtime. Therefore, farmers have less flexibility in their pesticide usage as their yield level increases.

Keywords: pesticide, cost, efficiency, agriculture, environmental performance, Free Disposal Hull.

JEL Classification: C61, D24, Q12, Q52

1. Introduction:

Agriculture is intrinsically of multifunctional character, which encompasses the entire range of related environmental, economic, food security, social and cultural functions. In addition to producing food, fiber and fuel for human needs as its essential role, agriculture has unintended external effects on the functions mentioned above that impacts on people other than farmers. Most of these functions are externalities, that is, they are not accounted for in markets and their economic values are unknown (FAO, 2001). Farmers do not bear any costs associated with negative environmental externalities and do not reap any direct benefit from positive ones (Cooper, 2001).

As a major provider of environmental services, agriculture plays important roles in carbon sequestration, flood control, groundwater recharge, soil conservation, biodiversity preservation, open space, scenic vistas, isolation from congestion, and purifying water, soil and air. These cover almost all ecological services provided by natural ecosystems, including provisioning services, regulating services, supporting services and cultural services (Millennium Ecosystem Assessment, 2003). Unfortunately, most are not recognized and are unremunerated. On the other hand, unlike natural ecosystems that produce positive ecological services only, agroecosystems also contribute to negative environmental externalities: greenhouse gas (GHG) emissions, nutrient and pesticide runoff, soil erosion, reduction in biodiversity, wildlife habitat destruction and less attractive rural landscapes from specialized crop cultivation (World Bank, 2008; FAO, 2001).

There is therefore an increasing recognition of agriculture's environmental externalities. Ever since the environmental hazard from indiscriminate use of pesticides was identified by Rachel Carson in 1962 (Carson, 1962), more flaws of conventional agriculture have been exposed (Conway and Pretty, 1991).

From the economic point of view, the use of pesticides is based on three-legged supports of efficiency in production: the increase in production of crops, the increase in quality of production and the reduction in agricultural labour and energy expenses (Newman, 1978). This belief is still widely shared by farmers, although society, environmentalists, consumers and public health professionals increasingly debate the serious social, environmental and health impacts (Cole et al., 2000). This is simply due to the fact that pesticides use forms a typical case of negative externality, where one or more producers are the sources, and one or more individuals are the receivers of the externalities (Jeong and Forster, 2003; Travisi and Nijkamp, 2008). In taking a decision as to the quantity of a product to apply, normally a farmer makes the evaluation in relation to the marginal productivity and the private marginal cost of using it.

However, this may not be the best result from the perspective of social and even individual well-being in the long term, as the individual marginal cost or marginal benefit may ignore effects to human health and that of the ecosystems, as well as the impacts of these on the health system and on society as a whole. Thus, if on the one side the marginal cost of the use of pesticides by the farmer includes items such as the price of the raw material, the cost of the work of the person applying the pesticide and the material used in the application, on the other side, frequently it does not include the damage to fauna and flora, to the quality of the water and the soil and to human health (Tietemberg, 2000).

Thus, in order to satisfy continued growth in food demand without further degrading the soil fertility, it is advisable for farmers to pursue a reduction in the use of pesticide inputs. The latter requires an adequate use of capital to maintain soil fertility and conserve the land while meeting productivity goals. This directly agrees with the context of the agreement of about 50% reduction in pesticide uses according to the accords du "Grenelle de l'environnement" in France. Thus, confirming the fact that people need low cost and readily available technologies and practices to increase food production. A further challenge is that this needs to happen without further damage to an environment increasingly harmed by existing agricultural practices (McNeely and Scherr, 2001)

Much research has therefore been done on the environmental external costs of pesticide use in Germany, the Netherlands, the Philippines, Italy, France, Denmark, the UK, the US and China (Pretty, 2002). As there are no standard frameworks and methods for assessment, the results cannot easily be compared. To analyze technologies and cost efficiencies, a variety of alternative methods have also been developed in the literature. In addition to deterministic and stochastic parametric frontiers, several non-parametric reference technologies have been suggested, including Data Envelopment Analysis (DEA) (see, for example, Charnes et al., 1978) and the non-convex Free Disposal Hull (FDH) reference technology introduced by Deprins et al. (1984).

Not surprisingly, several recent studies have used these methodologies to analyze the efficiencies of different organizations. However, most of this research has been based on either stochastic frontier approaches or non-parametric methods such as DEA or FDH. Based on the importance of the underlying reference technology, the purpose of this paper is to add to the evolving literature on pesticide practices evaluation by studying the cost efficiency of French farmers that produce wheat, barley and rapeseed on 600 farms. This entails the use of panel data from la Meuse (a French department) over a 12 year period (1992-2003). Both temporal and spatial dimensions of the sample allow us to test the robustness of the empirical results.

More precisely, the objective of this research is to evaluate the differences in pesticide practices among farmers in order to select the best practice of pesticide use with the application of FDH technology. This brings to mind that it is very possible for farmers to be total cost efficient with either more or less pesticide use, this depends on the substitution possibilities between land and chemical inputs (pesticides, fertilizers). It is worthy of note to mention here that the less intensive way in the use of pesticides is often a rational strategy when sufficient land is available but in contrast, its more intensive use is likely when productive land is absolutely or relatively scarce (Bassett, 2001)

In view of this, we conduct a double step analysis based on non-parametric reference technologies. First, the cost efficient farms were selected using a FDH technology. A second FDH frontier analysis was run only on the cost efficient farms that were selected from the first step thus revealing the units that minimizes the pesticide use per hectare while maintaining constant yields. Therefore, in terms of pesticide use per ha, all the different total cost efficient practices among farmers were evaluated with the best ones selected and lastly, a regression analysis was used as a sub-staged step to explain the potential pesticide reductions by a common set of explanatory variables.

The remaining part of this paper is therefore organized as follows. In the next section, we give the methodology for FDH and stating its relevance to this paper while Section 3 details the computation of cost efficiency measures for our empirical applications. Lastly, section 4 summarizes our conclusions.

2. The FDH model

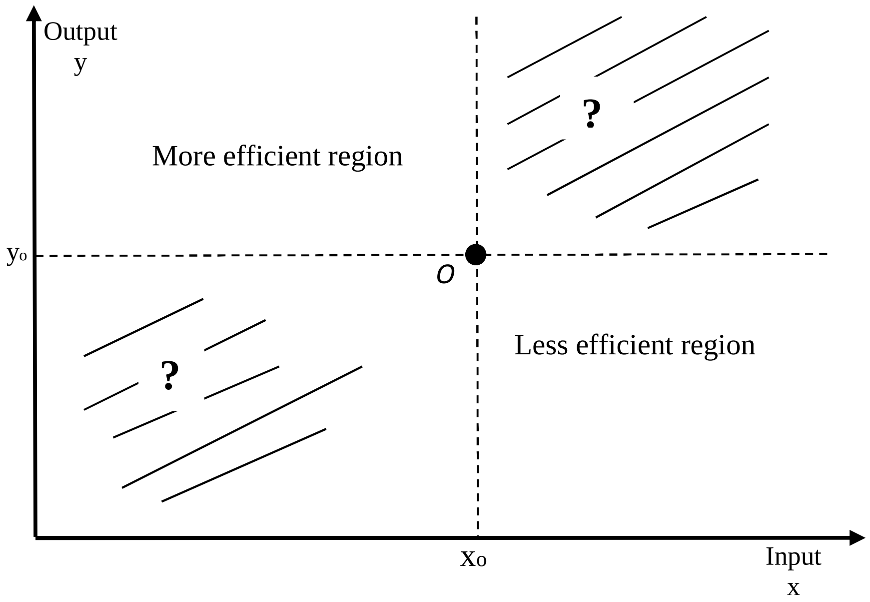
2.1 A brief FDH review

Free Disposable Hull (FDH) is a well-known empirical approximation of the production possibility set, which is based on minimal assumptions concerning the properties of the true but unobservable production set. In contrast to the popular DEA model, FDH is not restricted to convex technologies but only compares evaluated DMUs to others by rejecting both additivity and divisibility assumptions of the production possibility set. This is particularly convenient since it is frequently difficult to find a good theoretical or empirical justification for convexity[1] (see e.g. Cherchye et al. 2000).

Since production technologies are not always known, inefficiencies must be measured relative to some cost or production ‘frontier’ which is estimated from the data. Thus, measurements of inefficiency are really measures of the deviations of costs or input usage away from some minimal levels found in the data rather than from any true technologically-based minima. The differences among techniques found in the efficiency literature largely reflect differing maintained assumptions used in estimating the frontiers.

The major assumptions of FDH technology can be represented as follows. First: for each observed DMU *O*, the output-input space can be partitioned into four quadrants as it is drawn in figure 1. The more efficient region pools all the possible situations which produce more than DMU *O* with less inputs together. Alternatively, the less efficient region groups together all the circumstances where the outputs are lower with higher inputs. The two last indeterminate zones contain all the states where no dominated relationship can be concluded for DMU *O*.

Figure (1): Dominance regions for an evaluated DMU

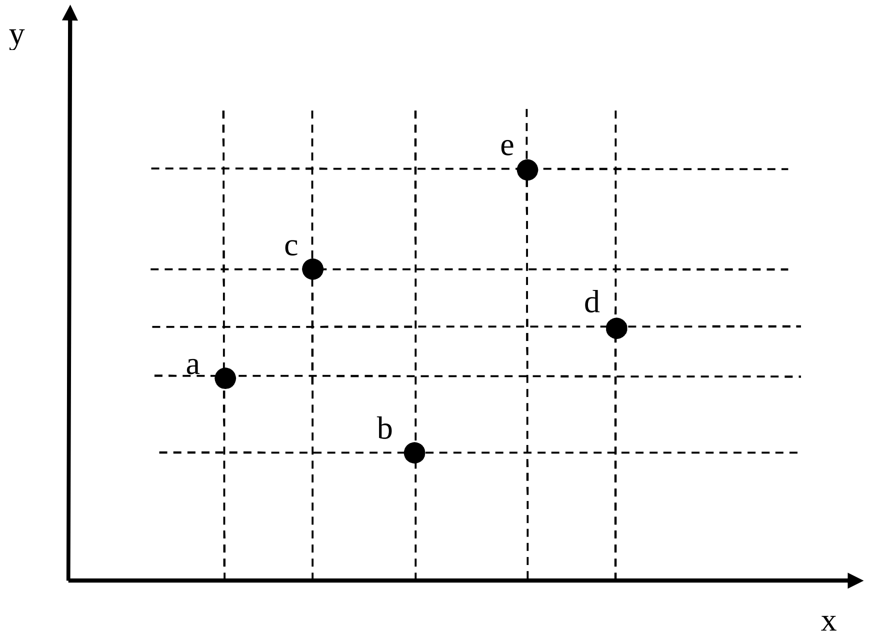


---

[1] The convexity assumption has often been questioned because the divisibility of inputs and outputs are not always possible especially in agriculture.

Second: all the observed firms are considered to be feasible and assumed to belong to the production possibility set. Therefore some DMUs can be in the more or less efficient regions of other DMUs (see figure 2). Here, we see that ‘a’, ‘c’, and ‘e’ represents the efficient DMUs in the sense that no other DMU dominates them while ‘b’ and ‘d’ represent the inefficient ones as they are dominated by some of the efficient ones. For example, a and c belong to the more efficient region of b.

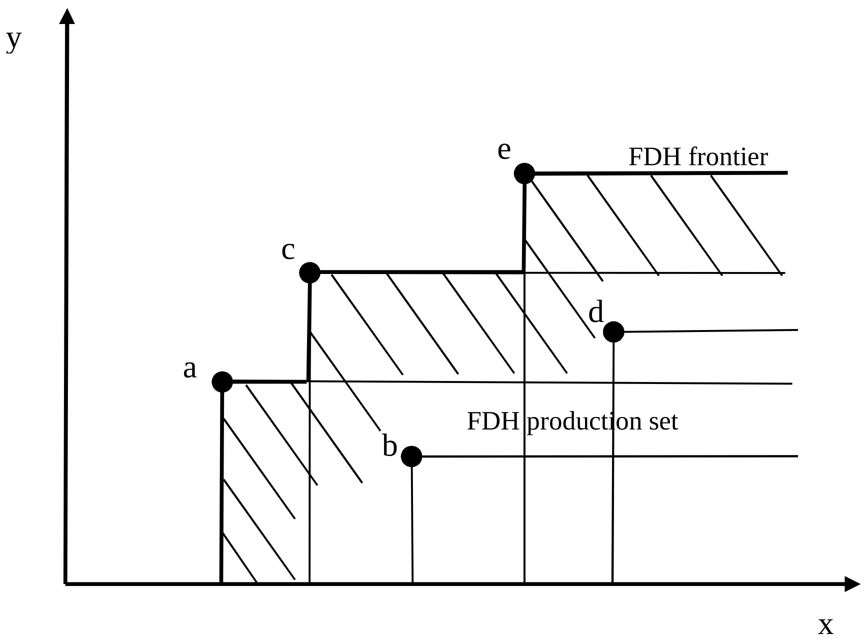
Figure (2): Efficiency comparisons among observed DMUs



Third: for the illustrative case of one output and one input (see figure 3), FDH production set adds to (figure 2) the free disposability assumption of outputs and inputs which states that an increase in inputs never result in a decrease in outputs (input wastes are feasible), and that any reduction in outputs remains producible with the same amount of inputs (anyone with the possibility of producing more will have the capability of producing less). The FDH production set is then defined as the union of the less efficient region of each observed DMU while the FDH frontier is the boundary of this set. Observations a, c, and e are efficient because they belong to the FDH frontier while observations b and d are inefficient and belong to the interior of the production set. A typical FDH frontier is given by the staircase-shaped line “ace”.

Therefore, the efficient frontier represents the most innovative firms (role models) which produce a given level of output with a minimum amount of inputs (alternatively we can see DMUs onto the frontier as producing a maximum level of output given an input basket). Thus affirming that the best observed practices makes the FDH technology. Any firm below the frontier is allocated to inefficiency (the resources here are wasted because the firm is inefficient) and it has to reach the frontier in order to be found efficient hence it belongs to a zone called the feasible region.

Figure (3): The production frontier of a strongly disposable FDH model



Having this in mind, we conducted a two step application with the use of this FDH approach in order to characterize the firms with the best practice. Firstly, FDH was run on all the data to select the cost efficient farms in order to evaluate the spread of cost competitive pesticide practices. As it was said before, it is possible to be cost efficient with either more or less pesticide use, depending on the flexibilities between land and chemical inputs. In a second step, this framework was run again on only these cost efficient farms. The gaps to the technical frontier, which links best practices in pesticide use per hectare to the observed yields of output per ha, were then evaluated for each of the farms. These gaps consequently availed us the opportunity to evaluate the potential reduction of individual pesticide uses per ha in percentages and Euros. As a sub-staged step, we examine the degree to which the potential pesticide reduction can be explained overtime by a common set of explanatory variables as productivity levels or farm sizes.

2.2 The cost FDH frontier: aims at selecting the cost efficient farms

It is important to note at this junction that the cost of production is the summation of the cost of the inputs used such as land, fertilizer, seeds and pesticide. Hence, while we consider one global input orientation as the production cost throughout this paper, the focus of the discussion is to minimize the aggregated input expenses. Therefore, for consistency sake we substitute 'X' as the traditional designation for inputs with 'C' which represents the global aggregated input cost.

Let us consider that K DMUs are observed and we denote the associated index set by $\mathfrak{K} = \{1,\dots,K\}$. We also assume that DMUs face a production process with M outputs and N inputs and we define the respective index sets of outputs and inputs as $\mathfrak{M} = \{1,\dots,M\}$ and $\aleph = \{1,\dots,N\}$ where $y = (y_1,\dots,y_M) \in R_+^M$ $x = (x_1,\dots,x_N) \in R_+^N$ and $w = (w_1,\dots,w_N) \in R_+^N$ are respectively the vector of output quantities, input quantities and input prices. The production cost is equal to $C = wx^T$ where the superscript T denotes a transposed vector.

We begin by introducing the assumptions on the production possibility set (*PPS*) of all feasible output vectors with a cost C and which is defined as follows:

$$PPS = \left\{ (C, y) \in R_+^{1+M} : y \text{ can be produced at cost } C \right\} \quad (1)$$

Now, we suppose that the technology obeys the following axioms:

A1: $(0,0) \in PPS, (0, y) \in PPS \Rightarrow y = 0$, that is, no free lunch;

A2: the set $A(C) = \left\{ (u, y) \in PPS : u \leq C \right\}$ of dominating observations is bounded $\forall C \in \mathbb{R}_+$, that is infinite outputs cannot be obtained from a finite cost level;

A3: *PPS* is closed;

A4: for all $(C, y) \in PPS$, and all $(u, v) \in R_+^{1+M}$, we have $(C, -y) \leq (u, -v) \Rightarrow (u, v) \in PPS$ (free disposability of input-cost and outputs);

We now introduce the distance function to compute the efficiency scores as the distance to the PPS of FDH frontier. We select an input-cost-oriented radial efficiency measure defined by:

$$\vec{D}_{FDH}(C, y) \ = \ Min\left\{ \delta \in R_+ : \left(\delta C, y \right) \in PPS \right\} \ (2)$$

The optimization program in (2) can be solved using alternative approaches. Traditionally, following Deprins et al (1984) a Mixed-Integer Program (MIP) is solved to compute FDH efficiency scores. However we prefer to follow Agrell and Tind (2001) and Leleu (2006) to derive Linear Programs to solve (2). Indeed LP is much more efficient than MIP to solve the optimization program in (2). While FDH models are generally considered as non-convex models they could however be solved with traditional LP solvers which also give a dual economic interpretation to the FDH technology in terms of shadow prices. Following Leleu (2006), the input cost inefficiency for a DMU j with a production plan (C^j, y^j) is computed via the following LP program:

$$\begin{aligned}
& \min_{h_k, z_k} \delta = \sum_{k \in \mathfrak{K}} h_k \\
s.t. \ & z_k \left(y_k^m - y_j^m \right) \geq 0 \qquad \forall m \in \mathfrak{M}, \ \forall k \in \mathfrak{K} \\
& z_k C_k \leq h_k C_j \qquad \forall k \in \mathfrak{K} \\
& \sum_{k \in \mathfrak{K}} z_k = 1 \\
& z_k \geq 0 \qquad \forall k \in \mathfrak{K} \\
& h_k \geq 0 \qquad \forall k \in \mathfrak{K}
\end{aligned} \qquad (3)$$

The optimal value δ^* is smaller than unity for inefficient observations and equals one for efficient ones. In the optimal activity vector z^* only one DMU has a value of one, indicating the cost efficient DMU or the best practice from which the evaluated farm is compared. Therefore, all evaluated DMUs with a δ^* score of one are qualified to be cost efficient and are selected for the second step used in evaluating the best practice of pesticide uses.

2.3 The technical FDH frontier: aims at selecting the best practice of pesticide uses among cost efficient farms

In the above first step we aim at selecting the efficient farms which minimize the cost of production for their activity levels. Now we turn to the efficiency in terms of pesticide utilization. Therefore we consider an alternative technology which links output yields per hectare to the intensity level of pesticide use per hectare.

In this second step, let us consider the *K'* cost efficient DMUs for which we obtained an efficiency score of one by solving program (3). We now denote by $\mathfrak{K}' = \{1, \ldots, K'\}$ the index set of cost efficient DMUs. In addition, we define the technology as a production process with *M* crop yields per ha as outputs and one input as the ratio of pesticide per ha. We take up $\mathfrak{M} = \{1, \ldots, M\}$ again as the index set of output yields. $\left(\frac{y}{l}\right) = \left(\left(\frac{y}{l}\right)_1, \ldots, \left(\frac{y}{l}\right)_M\right) \in R_+^M$ and $\left(\frac{p}{l}\right) \in R_+$ are respectively the vectors of output yields per ha and the ratio of pesticide cost per hectare. We adapt the above program (3) in order to select the best practice frontier in pesticide use for only the cost efficient farms, thus we have:

$$
\begin{aligned}
& \min_{h_k, z_k} \phi = \sum_{k \in \mathfrak{K}'} h_k \\
s.t.\ & z_k \left(\left(\frac{y}{l}\right)_k^m - \left(\frac{y}{l}\right)_j^m \right) \geq 0 \quad \forall m \in \mathfrak{M},\ \forall k \in \mathfrak{K}' \\
& z_k \left(\frac{p}{l}\right)_k \leq h_k \left(\frac{p}{l}\right)_j \quad \forall k \in \mathfrak{K}' \qquad\qquad (4) \\
& \sum_{k \in \mathfrak{K}'} z_k = 1 \\
& z_k \geq 0 \quad \forall k \in \mathfrak{K}' \\
& h_k \geq 0 \quad \forall k \in \mathfrak{K}'
\end{aligned}
$$

The LP program (4) aims at minimizing the pesticide use per hectare while maintaining or increasing yields of outputs per ha. Therefore the efficient use of pesticides per ha can be evaluated by comparing all the spread of pesticide practices of only the cost competitive farms. The optimal value ϕ^* is equal to one for pesticide minimizers and is smaller than unity for farms that could reduce their pesticide use intensity. Again in the optimal activity vector,

z^* only one DMU has a value of one, indicating the pesticide efficient DMU from which the evaluated cost efficient farm is compared.

3. Computing cost efficiency measures for the empirical applications

3.1. Brief discussion about the data used

An unbalanced panel was formed from an observation of 600 farms in the Meuse department from year 1992 to 2003. The technology of the farm was specified using three outputs and four inputs for a total of 7135 observations. The outputs which are measured in quintals include: Wheat, Barley and Rapeseed while the inputs which comprises Fertilizer, Seeds, and Pesticides are measured in constant Euros and Surface pond (land) which is the weighted surface by the land quality is measured in acres.

The descriptive statistics showing the different scenarios of inputs and output vectors used in the efficiency analysis are presented in table 1. The main crop is wheat, it is more than twice higher for barley output and more than three times for rapeseed production. Nevertheless these last two outputs increase faster. With respect to the cost, it can be noted that it grows at the same rate observed for land uses, therefore global expenses per ha do not increase significantly. On the other hand, the pesticide expenditure which represents 33% of the cost is increasing much faster than the surface area hence resulting to an intensification in pesticide uses per ha.

Table 1: Descriptive statistics of the data (period 1992-2003):

	Mean	CV	ROG (%)
Wheat (quintals)	2891	0.783	1.4
Barley (quintals)	1114	1.014	3.6
Rapeseed (quintals)	854	1.078	2.3
Surface for the three outputs (ha)	85.2	0.726	2.1
Cost (€)	34742	0.826	2.3
Pesticide (€)	11523	0.905	3.7
Pesticide per ha (€)	128	0.277	1.6

ROG = tendency rate of growth; CV = coefficient of Variation

3.2. Results and comments

3.2.1. First step analysis: FDH technology used in selecting the cost efficient farms

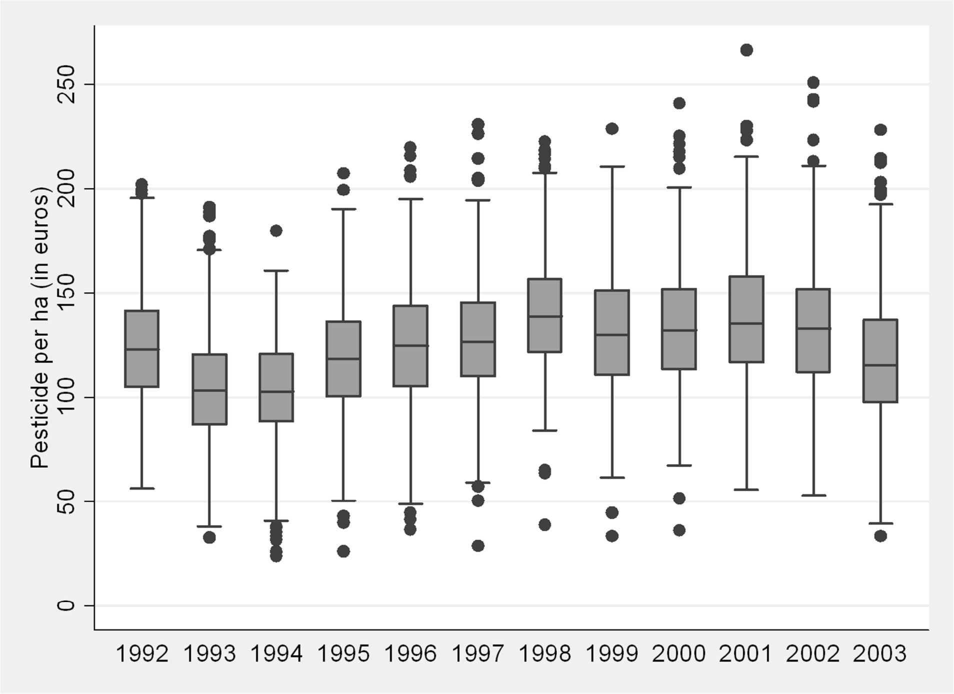
The first LP problem (program (3)) given in the methodology section is solved for each of the observations to select the cost efficient farms. The FDH cost frontier is defined by year in order to take eventual climatic or other contextual effects into account. The results of this first step analysis are presented in table 2. It shows a selection of 4032 cost efficient farms from 7135 total number of observations (approximately 57%). This percentage does not vary too much over all the period with a minimum of 51% observed in 2000 and a maximum of 60% in 1992.

Table 2: Selection of Cost efficient farms from the total observations

Year	Total no of observation	Number of cost eff farms	% of eff farms
1992	579	350	60.45
1993	604	346	57.28
1994	612	346	56.54
1995	620	368	59.35
1996	610	358	58.69
1997	619	354	57.19
1998	607	340	56.01
1999	608	326	53.99
2000	612	316	51.64
2001	570	300	52.63
2002	560	322	57.60
2003	534	308	57.68
Total	7135	4032	56.51

For these cost efficient farms, the spread of pesticide per hectare practices is illustrated by a yearly box plot in Figure 4. Over the period, the median fluctuates between 103 and 138 euros depending on yearly climatic conditions. The box stretch from the lower hinge (defined as the 25th percentile) to the upper hinge (the 75th percentile) is around 40 euros which is more than 30% of the mean of pesticide cost. The gap between the lower and upper adjacent values is quite large (around 150 euros each year). This shows how large the spread of cost efficient farmers are in pesticide practices thus revealing that there exist some pesticide use flexibilities in crop productions depending on the substitution possibilities between inputs, managerial skills of producers, crop rotations and heterogeneous approaches to pesticide applications in response to pest attacks.

Figure (4): Spread of farmers’ pesticide practices for the cost efficient farms



3.2.2. Second step analysis: Pesticide minimization for the cost efficient farms

The second LP problem (program (4)) is now solved for each of the previous selected cost efficient farms in order to reveal the best pesticide practices. The technical FDH frontier which links the yields and pesticide cost per hectare is also defined year by year. At the sample mean, if all the cost efficient farms align with the best practices to the frontier, one could reduce pesticide cost per hectare with 20%. This amount leads to an average cost reduction of more than 7000 € per farmer which represents approximately 7% of his production cost. According to the different years, this potential reduction of pesticide per hectare varies between 17% and 23% as reflected in Table 3.

Table 3: Cost reductions in pesticides

Year	Pesticide reduction/ha (€)	Pesticide reduction/ha (%)	cost reduction (€)	% pesticide reduction share in total cost
1992	27.22	20	6648	6.8
1993	23.23	21	4974	6.5
1994	24.15	23	5137	6.9
1995	28.00	22	7377	7.1
1996	29.54	22	7836	7.2
1997	29.86	22	8942	7.2
1998	25.52	17	7943	6.0
1999	26.10	18	7362	6.3
2000	23.54	17	6409	6.0
2001	26.20	18	7213	6.4
2002	28.47	19	7538	7.2
2003	28.75	22	7751	7.9
Total	26.74	20	7093	6.8

Table 4 gives us a more detailed analysis and shows that more than 19% of the total sample has good pesticide practices in the sense that they are not dominated by other DMUs, 42% of the total sample could reduce pesticides between the range of 0 and 25% while 39% have the possibility to reduce pesticide by more than 25%. The table below is a representative of the frequencies of the different pesticide practices per hectare reductions.

Table 4: Frequencies of different pesticide per hectare reductions

Year	=0%	(0% - 25%)	>25%	Total number of observations
1992	14.57	45.71	39.71	350
1993	21.68	38.15	40.17	346
1994	20.52	34.39	45.09	346
1995	17.66	38.86	43.48	368
1996	18.26	37.92	43.82	356
1997	15.54	38.98	45.48	354
1998	22.06	49.71	28.24	340
1999	21.17	42.94	35.89	326
2000	19.62	53.48	26.90	316
2001	19.67	47.67	32.67	300
2002	21.12	43.48	35.40	322
2003	18.83	36.04	45.13	308
Total	19.17	42.14	38.69	4032

These frequencies are directly linked to the characterization of the above pesticide reductions into classes as reflected in table 5, thus showing its eventual relationship with some structural variables such as age, land size, labour quantity per ha, degree of crop specialisation, ratio of subsidies on total turnover. Results displayed in this table do not show any clear statistical differences among the three classes of potential pesticide reductions and these variables. To go beyond these one way statistical tests, a between panel regression was run on pesticide reductions and the above exogenous variables. As for the previous statistical tests, no significant relationships were found. These results seem to mean that the pesticide reductions could concern quite different types of farms and are not focused on specific groups.

Table 5: Characterization of pesticide reduction and its link with some exogenous variables

Variables	Class 1 =0%	Class 2 [0% - 25%]	Class3 >25%	Total
Age	51.4	51.2	51.9	51.5
Total Land Surface (ha)	181.1	175.4	169.9	174.3
Total labour per ha[1]	0.014	0.014	0.014	0.014
Crop specialisation(%)[2]	45.8	45.8	45.6	45.8
Subsidies on total turnover (%)	21.4	20.9	21.1	21.1
Wheat share (%)	51.8	52.5	55.5	53.5
Barley share (%)	20.4	20.3	18.8	19.8
Rapeseedshare (%)	27.8	27.2	25.7	26.5

(1) In equivalent full time person per year and per ha
(2)Crops on total turnover

3.2.3. Relationship between pesticide reductions and output yields over time

We now focus on time variations of the three output yields and their respective effects on potential pesticide reductions over the period. Therefore we emphasize the results related to the following within procedure or Least Square with Dummy Variable Model (5). To control for size and climatic effects, we introduce the land surface *(SAU)* and annual dummy variables *(t)*, the usual fixed individual effect is denoted by (α_i) and allows the specificities of the farmer (such as, structure of production whether specialized or not, his financial situation, amongst others) to be put into consideration. The regression result is given in table (6) below.

$$\ln(pestred / ha)_{it} = \beta_w \ln(wYield)_{it} + \beta_b \ln(bYield)_{it} + B_r \ln(rYield)_{it} + \gamma \ln(SAU)_{it} + \alpha_i + \delta_t t + \mu_{it} \quad (5)$$

With respect to table 6, it is clearly obvious that yield increases for wheat, barley and rapeseed negatively affect potential pesticide reductions due to their respectively high level of significance. Moreover, the wheat yield elasticity seems to be twice higher than the ones for barley and rapeseed. These results therefore concludes that as the farmers try to improve their level of productivity or technical performance, pesticide practices approach the frontier of technical possibilities meaning that they have less flexibilities in their management of pesticide.

Table 6: The within model Regression Analysis Results

Variable	*Coefficient*	*Erreur Std*	*P-value*
wYield	-0.979	0.270	0.000***
bYield	-0.428	0.183	0.019**
rYield	-0.455	0.107	0.000***
SAU	-0.121	0.0471	0.010**
constant	11.516	1.389	0.000***
t_2	-0.218	0.090	0.016**
t_3	0.167	0.090	0.064*
t_4	0.594	0.101	0.000***
t_5	0.477	0.099	0.000***
t_6	0.388	0.100	0.000***
t_7	0.388	0.103	0.000***
t_8	0.256	0.100	0.010**
t_9	0.0659	0.096	0.492
t_10	0.378	0.099	0.000***
t_11	0.218	0.105	0.039**
R^2	0.464	*Adjusted* R^2	0.218
F(710,1546)	1886429	*P-value (F)*	0.000***
F test that all α_i*=0*	1827771	*P-value (F)*	0.000***

+ or - : sign of estimated coefficient; ***, **, *: statistically significant test at 99%, 95%, 90%

α_i= individual fixed effects

4. Conclusion

The purpose of this paper was to evaluate the differences in pesticide practices in order to assess the potential reduction of pesticide use by aligning the farmers with their respective best practices selected, thanks to a two step FDH frontier approach. The first step is a classical FDH analysis used as a filter to select all the cost efficient farms. Then a second step runs a FDH technology on this reference subset to measure the gap between the observed cost of pesticide per hectare and its optimal level while maintaining output yields. Finally a regression analysis was used as a sub-staged step to also link the pesticide reductions to the time variations of yields.

Our main results conclude that the pesticide reductions per hectare for the cost efficient farms could reach 20% on the average. This percentage leads to a cost reduction of nearly 7,000€ which represents 7% of the global cost and may concern various types of farmers. The within regression analysis clearly indicates that potential pesticide reductions decrease with improved level of yields thereby connoting that pesticide practices converge to the frontier. This gives a further reflection that farmers have less flexibility in their pesticide usage as their yields are augmented. This therefore shows that in French agriculture where pesticide expenses per ha is still on the increase, there are still lots of improvements to be achieved in terms of pesticide practices, but the ways to achieve them are in opposition with an increase of outputs per hectare which has been adopted as a common acceptance for farmers since the last forty years.

References

Agrell, P.J., Tind, J. (2001). A dual approach to nonconvex frontier models. Journal of Productivity Analysis 16(2): 129-147.

Bassett, T.J., 2001. The Peasant Cotton Revolution in West Africa: Cote D'Ivoire, 1880–1995. Cambridge University Press, New York.

Carson, R.L., 1962. Silent Spring. Houghton Mifflin Company, Boston.

Charnes, A., W. Cooper and E. Rhodes, 1978, Measuring the efficiency of decision making units, European Journal of Operational Research 2, 429-444.

Cherchye, L., T. Kuosmanen, and G. T. Post (2000): What is the Economic Meaning of FDH? A Reply to Thrall, Journal of Productivity Analysis, 13(3), 263-267.

Cole, D.C., Carpio, F., Leon, N., 2000. Economic burden of illness from pesticide poisonings in highland Ecuador. Pan. Am. J. Public Health. 8 (3), 196–201.

Conway, B.R., Pretty, J.N., 1991. Unwelcome Harvest: Agriculture and Pollution. Earthscan Publications Ltd., London.

Cooper, J.C., 2001. The environmental roles of agriculture: economic valuation of the environmental externalities of agriculture. Expert Meeting Proceedings: First Expert Meeting on the Documentation and Measurement of the Roles of Agriculture in Developing Countries, Rome, Italy March19 to 21, 2001: 31–88.

Deprins, D., L. Simar and H. Tulkens, 1984, Measuring labor-efficiency in post offices, in: M. Marchand, P. Pestieau and H. Tulkens, eds., The performance of public enterprises: Concepts and measurement (North-Holland, Amsterdam) 243-267.

FAO, 2001. The Environmental Roles of Agriculture, Summary Report for First Expert Meeting on the Documentation and Measurement of the Roles of Agriculture in Developing Countries, Rome, Italy March19 to 21, 2001

Jeong, H., Forster, L., 2003. Empirical investigation of agricultural externalities: effects of pesticide use and tillage system on surface water. Department of Agricultural, Environmental and Development Economics. In Ohio State University. Working Paper.

Leleu H. (2006). A linear programming framework for free disposal hull technologies and cost functions: primal and dual models. European Journal of Operational Research 168 (2): 340-344.

Millennium Ecosystem Assessment, 2003. Millennium Ecosystem Assessment, Eco systems and Human Well-Being: A Framework for Assessment. Island Press,Washington, DC.

Newman, J.F., 1978. Pesticides. In: Wright, S.J.L., Hill, I.R. (Eds.), Pesticide microbiology. InAcademic Press, New York, pp. 1–16.

Pretty, J.N., 2002. Agriculture: Reconnecting People, Land and Nature. Earthscan Publications Ltd., London.

Ramanathan, R., 2003. An Introduction to Data Envelopment Analysis: A Tool for Performance Measurement. Sage Publications, New Delhi.

Tietemberg, T., 2000. Environmental and Natural Resource Economics. Pearson Education Limited.

Travisi, M., Nijkamp, P., 2008. Valuing environmental and health risk in agriculture: a choice experiment approach to pesticides in Italy. Ecological Economics 67 (4), 598–607.

Tulkens, H., 1993, On FDH efficiency analysis: Some methodological issues and applications to retail banking, courts, and urban transit, Journal of Productivity Analysis 4, 183-210.

World Bank, 2008. Agriculture and the Environment, World Development Report. The World Bank, Washington, DC.