Exploring cost dominance between high and low pesticide use in French crop farming systems by varying scale and output mix

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Abstract:

Policy makers as well as land users in developed countries are willing to promote new agricultural practices that are more environmentally friendly. This can be possible notably among several others by reducing chemical utilization. For instance in France, the agreement of the "Grenelle de l'environnement" encourages farmers to decrease pesticide use per ha about 50% over a period of ten years. This paper deals with a framework which aims at assessing the cost dominance between technologies that favor less or more pesticide levels per ha. Cost functions are estimated thanks to a non-parametric activity analysis model and a robust approach frontier is introduced in order to lessen the sensitivity of the cost frontier to the influence of potential outliers. With respect to this, two cost functions characterized by a relatively lower or higher pesticide level per ha are compared. Based on a sample of 707 French crop farms observed in year 2008, our simulations clearly show that agricultural practices using less pesticide per ha are more cost competitive than practices using more pesticide without inducing other input substitution costs. In addition, results are differentiated by farm size and types of crop to identify possible scale and output mix effects. They reveal that this cost dominance is a robust phenomenon across size and scope dimensions and economically support more green practices in terms of crop activities.

Keywords*:* Pesticide Use (PU), Cash crops farming systems, Activity Analysis Model (AAM), Non Parametric Robust Cost Function (NPRCF), Hamming Distance (HD).
JEL Classification: C61, D22, D24, Q12.

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1. Introduction

French agriculture ranks third in the world for pesticide consumption and is the leading user in Europe. With a total volume of 76,100 tons of active substances sold in 2004. Fungicides account for 50% of this volume, herbicides for 34%, insecticides for 3% and other products for 14%. Nevertheless, in the last fifty years there has been two periods characterized by different growth rates of pesticide consumption by French farmers. The first one (1959-1989) corresponds to the French agriculture expansion with a 7% annual growth rate of pesticide consumption while there is a deceleration of output growth implying a stabilization of pesticide use during the last period (1990-2011). This reveals that in recent time there has been a close attention paid to promote new agricultural practices that tries to stabilize or diminish chemical input utilizations thus becoming more eco-friendly.

It is therefore imperative to note that farmers can view the relationship between agriculture and environment as conflicting (win-lose) or as synergistic (win-win). A win-lose situation is occurring when productivity gains coming from pesticide use are leading to environmental degradation or when environmental protection induces additional production costs. A synergistic approach, on the other hand, assumes that sustainable environmental management and productivity gains or cost reductions can be achieved simultaneously. Thus, when sustainability for development is an ultimate goal, it requires the balancing of environmental, social and economic systems. With this, the long-term sustainability of agricultural production will not be threatened, thus implying an official recognition of the necessary tradeoffs between short-term productivity and long-term sustainability. Therefore, increasing attention should be paid to alternative production systems that strive for both high production and environmental quality. From an ecological economic perspective, environmental and economic developments are complementary rather than conflicting goals. Ecological agriculture seeks to balance the long-term costs of farm production against the short-term profits of goods sold at market. In view of this reality, a consensus or commitment that ultimately leads to environmentally sound and economically acceptable agricultural practices should be forged (Robertson and Swinton 2005).

In this respect, agricultural sustainability entails making the best use of nature's goods and services with the consideration of not damaging these indispensable assets (McNeely and Scherr 2001; Uphoff 2002). The aims are to: (i) integrate natural processes such as nutrient cycling, nitrogen fixation, soil regeneration and natural enemies of pests into food production processes; (ii) minimize the use of non-renewable inputs that damage the environment or harm the health of farmers and consumers; (iii) make productive use of the knowledge and skills of farmers, so improving their self-reliance and substituting human capital for costly inputs; (iv) make productive use of people's capacities to work together to solve common agricultural and natural resource problems, such as pest, watershed, irrigation, forest and credit management. Agricultural systems emphasizing these principles are also multi-functional within landscapes and economies. They jointly produce food and other goods for farm families and markets, but also contribute to a range of valued public goods, such as clean water, wildlife, carbon sequestration in soils, flood protection, groundwater recharge, and landscape amenity value. In addition, they are most likely to emerge from new configurations of social capital, comprising relations of trust embodied in new social organizations, and new horizontal and vertical partnerships between institutions, and human capital comprising leadership, ingenuity, management skills, and capacity to innovate. Agricultural systems with high levels of social and human assets are more able to innovate in the face of uncertainty (Pretty and Ward 2001). As a more sustainable agriculture seeks to make the best use of nature's goods and services, so technologies and practices must be locally adapted. In addition, if it can be proved that these more sustainable agricultural practices are in convergence with higher productivity levels and cost competitiveness, farmers will naturally adopt them by achieving a win–win strategy with the societal preferences.

Irrespective of the fact that many elements (site conditions, regional pedo-climatic factors, etc.) affect the eco-efficiency of farm activities, the farmers' technical choices (farming system, crop rotation, tillage intensity, chemical application, etc.) significantly impact the efficient use of limited resources and, accordingly, on the potential of environmental endangerments. In this regard, previous studies have already shown a positive relationship between managerial and environmental efficiencies (De Koeijer et al. 2002) thus highlighting substantial potentialities to improve the sustainability of arable farming with a lower production cost. Of course it is not easy to generalize these results in conformity with all local and regional agriculture, more applied researches therefore need to be conducted in order to see if green practices are in line with the producers' economical benefit.

In view of this, this paper attempts to find out if low pesticide use farming is (not) more cost competitive than systems with higher pesticide consumption in French agriculture. Using data from 707 farms located in the Eure & Loir Département[1] in year 2008, cost estimations are done empirically to assess the comparisons between two technologies characterized by different levels of pesticide per ha. Allowing for eventual presence of technical and allocative inefficiencies in the data, a cost frontier framework is therefore preferred to a traditional cost function approach. Following Boussemart, Leleu and Ojo (2011) and in order to avoid any bias linked to the choice of the frontier specification, we start with an Activity Analysis Model (AAM) (Koopmans1951; Baumol 1958) and estimate cost frontiers for the High Pesticide Use and Low Pesticide Use technologies (respectively *HPU* and *LPU*). In comparison to Boussemart, Leleu and Ojo (2011), the originality of this paper dwells on four specificities. First, instead of focusing on common mixed farming systems (crops and livestock) with relatively small crop surfaces, we made use of farms with big surfaces specialized in cash crops located in the geographical area which appears to be the main region in France for planting cereals and other cash crops. Second instead of evaluating observed farms, competitiveness of technologies in terms of cost is established for different crop-mixes and several levels of size. This allows us to explore the whole cost functions in their respective scale and scope dimensions. Third, as the crop mixes influence significantly the level of pesticide use, it is crucial to take into account the surface partition among the crops in order to compare similar farming systems. In our case study, surface partition gathers 25 different crops. With respect to this, we explicitly introduce the concept of Hamming Distance which serves to control the similarity of crop mixes when including farms in the AAM. Technically, we ensure that the optimal solution in the AAM initiates a similar crop surface partition than the evaluated production plan. Fourth, while non-parametric cost function is estimated thanks to an AAM which imposes very few assumptions on the production set, its main drawback lies in the sensitivity of the measure to potential presence of outliers. We therefore adapt our cost model to a robust frontier approach.

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[1] Eure & Loir Département is an administrative area geographically located in the center of France.

This paper is therefore divided into four sections. The subsequent sections are detailed thus: first we unveil the methodology used in assessing the cost dominance effect between the two specified technologies respectively *HPU* and *LPU*. Then we address the common concerns of pesticide use among crop producers in Eure & Loir our empirical analysis, results and discussion. A final note concludes the paper.

2. Methodology detailing high or low pesticide practices and their cost effects

Cost frontiers can be modeled, thanks to an AAM originally developed by (Koopmans 1951; Baumol 1958). AAM is a linear programming based technique for modeling a production technology with the presence of multiple inputs and multiple outputs. Subsequently, this literature has exponentially grown under the Data Envelopment Analysis (DEA) label for measuring technical efficiency. It is a relevant alternative to econometrical models based on a more engineered approach rather than a pure statistical approach. At this junction, it is expedient to state that the main advantage of AAM is to allow cost function estimations without specifying any functional form between inputs and outputs. However, it is important also to note that the disadvantage of the AAM is that it does not allow for deviations from the efficient frontier to be a function of random error. As such, AAM can produce results that are susceptible to the influence of outliers which can easily bias the cost function estimation. This however sounds a note of caution and to this regard, our paper attacks this problem with the use of a robust frontier approach to overcome the uncertainty on the data thus silencing the possible effect of outliers in our results. The implementations of the robust approach proposed by Simar and Wilson (2008) for FDH and DEA methods are new programming problems which could be solved easily.

2.1. The production technology

Starting from the damage control model initially proposed by Lichtenberg and Zilberman (1986) and recently developed in a more general non parametric context by Kuosmanen, Pemsl and Wesseler (2006), we define the production technology by differentiating direct inputs (land, fertilizer, seeds, etc.) and damage abatement inputs (pesticides). In such an approach, pesticide uses differ fundamentally from direct inputs as they do not directly increase output yields. Their role is essentially to control potential losses caused by damage agents such as insects, weeds or bacteria. Thus, the production technology links the maximal potential outputs obtainable from direct inputs, taking into account potential losses which depend on pesticide use.

Let us consider that K farms or more generically K Decision Making Units (DMUs) are observed and we denote the associated index set by $\mathfrak{K}=\{1,\ldots,K\}$. These DMUs face a production process with M outputs, N direct inputs and one damage control input (pesticide). The respective index sets of outputs and direct inputs are defined as $\mathfrak{M}=\{1,\ldots,M\}$ and $\aleph=\{1,\ldots,N\}$. We denote by $\mathbf{y}=\left(y_1,\ldots,y_M\right)\in\Re_+^M$ the vector of observed output quantities, $\mathbf{x^D}=\left(x_1^D,\ldots,x_N^D\right)\in\Re_+^N$ the vector of direct input quantities and $x^P\in R_+$ the damage control input (pesticide). Finally $\mathbf{w^D}=\left(w_1^D,\ldots,w_N^D\right)\in\Re_+^N$ and $w^P\in\Re_+$ are respectively direct input and pesticide prices.

Using the general framework as developed by Shephard (1953), the production possibility set (denoted as *T)* of all feasible input and output vectors is defined as follows:

$$T=\left\{(\mathbf{x^D},x^P,\mathbf{y})\in\Re_+^{N+1+M}:(\mathbf{x^D},x^P)\text{ can produce }\mathbf{y}\right\}\quad(1)$$

T also referred to as production technology is supposed to obey the following axioms:

A1: $(\mathbf{0},0,\mathbf{0})\in T$, that is inactivity is feasible and $(\mathbf{0},x^P,\mathbf{y})\in T\Rightarrow\mathbf{y}=0$ that is, no free lunch;

A2: the set $A(\mathbf{x^D},x^P)=\left\{(\mathbf{u},x^P,\mathbf{y})\in T:\mathbf{u}\le\mathbf{x^D}\right\}$ of dominating observations is bounded $\forall\mathbf{x^D}\in R_+^N$, that is infinite outputs cannot be obtained from a finite direct input vector;

A3: *T* is closed;

A4: for all $(\mathbf{x^D},x^P,\mathbf{y})\in T$, and all $(\mathbf{u^D},x^P,\mathbf{v})\in\Re_+^{N+1+M}$, we have $(\mathbf{x^D},x^P,-\mathbf{y})\le(\mathbf{u^D},x^P,-\mathbf{v})\Rightarrow(\mathbf{u^D},x^P,\mathbf{v})\in T$ (free disposability of direct inputs and outputs);

A5: *T* is convex.

2.2. Definition of technologies for low pesticide use (LPU) and high pesticide use (HPU)

To compare the cost functions according to the level of pesticide per ha thanks to this previous AAM, we redefine the production possibility set as:

$$T(PU) = \left\{ (\mathbf{x}^{\mathbf{D}}, x^P, \mathbf{y}) \in \Re_+^{N+1+M} : (\mathbf{x}^{\mathbf{D}}, x^P) \text{ can produce } \mathbf{y} \text{ given } PU \right\} \quad (2)$$

where *PU* denotes a given ratio of pesticide use per ha.

Thus we define two different technologies based on a level of pesticide use, *PU*. By denoting $T^{HPU}(PU)$ as the technology using more or equal pesticide than *PU* per ha and $T^{LPU}(PU)$ as the technology utilizing less or equal pesticide per ha. For estimation purpose $T^{LPU}(PU)$ will include the observed DMUs in the data set using less pesticide per ha than a given level of *PU* while $T^{HPU}(PU)$ comprises only the observed DMUs that has an equal or higher ratio of pesticides per ha than *PU*. From an observed sample of K farms and the axioms A1-A5 applied on $T(PU)$ defined in (2), they are respectively defined by:

$$T^{LPU}(PU) = \left\{ (\mathbf{x}^{\mathbf{D}}, x^P, \mathbf{y}) : \sum_{k \in \mathfrak{K}} \lambda^k y_m^k \geq y_m, \forall m \in \mathfrak{M}, \sum_{k \in \mathfrak{K}} \lambda^k x_n^{D,k} \leq x_n^D, \forall n \in \aleph, \sum_{k \in \mathfrak{K}} \lambda^k = 1, \lambda^k \geq 0 \ \forall k \in \mathfrak{K}, \text{ and } PU^k \leq PU \right\} (3)$$

$$T^{HPU}(PU) = \left\{ (\mathbf{x}^{\mathbf{D}}, x^P, \mathbf{y}) : \sum_{k \in \mathfrak{K}} \lambda^k y_m^k \geq y_m, \forall m \in \mathfrak{M}, \sum_{k \in \mathfrak{K}} \lambda^k x_n^{D,k} \leq x_n^D, \forall n \in \aleph, \sum_{k \in \mathfrak{K}} \lambda^k = 1, \lambda^k \geq 0 \ \forall k \in \mathfrak{K}, \text{ and } PU^k \geq PU \right\} (4)$$

2.3. *The basic cost model*

Formally, the production cost is equal to $C = \mathbf{w}^{\mathbf{D}} (\mathbf{x}^{\mathbf{D}})^t + w^P x^P$ where the superscript *t* denotes a transposed vector. Assuming identical prices for all farmers, observed costs can be directly considered instead of the product of input price and quantity vectors[2]. Thanks to the previous definitions (3) and (4), we are now able to define the two cost functions including the direct input and pesticide costs, respectively C_{LPU} and C_{HPU}. They are respectively defined by:

$$C_{LPU}(\mathbf{x}^{\mathbf{D}}, x^P, \mathbf{y}) = \min \left\{ \mathbf{w}^{\mathbf{D}} (\mathbf{x}^{\mathbf{D}})^t + w^P x^P : (\mathbf{x}^{\mathbf{D}}, x^P, \mathbf{y}) \in T^{LPU}(PU) \right\} \qquad (5)$$

$$C_{HPU}(\mathbf{x}^{\mathbf{D}}, x^P, \mathbf{y}) = \min \left\{ \mathbf{w}^{\mathbf{D}} (\mathbf{x}^{\mathbf{D}})^t + w^P x^P : (\mathbf{x}^{\mathbf{D}}, x^P, \mathbf{y}) \in T^{HPU}(PU) \right\} \qquad (6)$$

Then for the above two technologies, the estimation of a cost function entails solving the following basic linear programs to retrieve the estimated minimal costs $\tilde{C}_{LPU}$ and $\tilde{C}_{HPU}$ for every production plan with a production level $(\mathbf{y}^{\mathbf{0}})$.

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[2] That farmers are assumed to have the same market power which seems rather acceptable based on their similar specificities in terms of size and output mixes within the same local area (Eure & Loir Département).

$$\begin{aligned}
&\min_{\lambda}\ \tilde{C}_{LPU} = \sum_{k\in\mathfrak{K}} \lambda^k C^k \\
&\sum_{k\in\mathfrak{K}} \lambda^k y_m^k \geq y_m^o, \forall m \in \mathfrak{M} \\
&\sum_{k\in\mathfrak{K}} \lambda^k = 0 \text{ if } \exists PU^k > PU^o \\
&\sum_{k\in\mathfrak{K}} \lambda^k = 1 \\
&\lambda^k \geq 0, \forall k \in \mathfrak{K}
\end{aligned} \tag{7}$$

$$\begin{aligned}
&\min_{\lambda}\ \tilde{C}_{HPU} = \sum_{k\in\mathfrak{K}} \lambda^k C^k \\
&\sum_{k\in\mathfrak{K}} \lambda^k y_m^k \geq y_m^o, \forall m \in \mathfrak{M} \\
&\sum_{k\in\mathfrak{K}} \lambda^k = 0 \text{ if } \exists PU^k < PU^o \\
&\sum_{k\in\mathfrak{K}} \lambda^k = 1 \\
&\lambda^k \geq 0, \forall k \in \mathfrak{K}
\end{aligned} \tag{8}$$

The solutions to these models result in estimated minimum costs $\tilde{C}_{LPU}$ and $\tilde{C}_{HPU}$ for every production plan *o*. For each $\lambda^k \neq 0$, DMU k forms a part of the optimal linear combination which minimizes cost of plan *o* and can be considered as a benchmark referent defining the cost function. By varying size and scope of $(\mathbf{y^o})$, the linear programs are therefore solved and allow us to explore the entire cost function over its whole domain. By making the comparison between $\tilde{C}_{LPU}$ and $\tilde{C}_{HPU}$ we measure the gap between the two minimal costs, thus the cost dominance in relation to pesticide use for farming systems can be assessed. At this stage, it is essential to highlight that potential situation of inefficiencies, depending on many different factors and more specifically climatic effects, do not affect the gap between the two technologies since we focus on the comparison of two optimal cost functions within the same region with homogenous pedo-climatic characteristics.

2.4. Cost functions with heterogeneous production

In farming systems, it is well known that output mixes influence significantly the production cost and the pesticide use level. Consequently, it is crucial to take into account the production heterogeneity among DMUs to be sure of comparing similar farming systems. In models (7) and (8), the first set of constraints relative to the M outputs ensure theoretically that the minimal cost is effectively computed for a given crop partition. But usually, empirical researches based on farm account data cannot deal with output quantity information about each detailed crop and satisfy themselves with one global aggregated output value (at worst) or with some different output values for a few types of main crops (for the best). On the other hand, it is usually easier to get statistical material from Farm Accounting Data Network concerning utilized surfaces for each detailed crop. These are indeed highly correlated to the output mixes and directly linked to the pesticide treatments. Thus it is possible to correctly characterize farm output-mixes thanks to their respective crop surface partition even without complete figures about output levels.

To manage this problem, we introduce a relevant way of taking care of the detailed crop mixes. We borrow from fuzzy set theory the concept of Hamming distance (Kaufmann 1975) to evaluate the proximity between two production plans *a* and *b* belonging to $T^{LPU}(PU)$ or $T^{HPU}(PU)$ according to their respective structure of crop surfaces. More precisely, the Hamming distance HD is measured by the sum of absolute deviations between two vectors defined on crop surface partition. Formally, for DMUs *a* and *b* we have:

$$HD(a,b) = \sum_{m \in \mathfrak{M}} \left| s_a^m - s_b^m \right|$$

Where s^m is the share of crop surface m in total used land.

The maximum value of Hamming distance is 2 when *a* and *b* are characterized by entirely different crop surface profiles and the minimum value is 0 when all crop surface shares are equal. $\frac{HD(a,b)}{2}$ has a straightforward economic interpretation: for instance, a HD value of 0.2 means that in comparing *b* to *a*, 10% of its surfaces occur in different crops.

Introducing the total crop revenue as: $R = \sum_{m \in \mathfrak{M}} p_m Y_m$ instead of the M output constraints and adapting cost models (7) and (8), we therefore have the following linear models (9) and (10):

$$
\begin{aligned}
&\min_{\lambda,S^{+},S^{-}} \tilde{C}_{LPU} = \sum_{k\in\mathfrak{K}} \lambda^{k} C^{k}\\
&\sum_{k\in\mathfrak{K}} \lambda^{k} R^{k} \geq R^{o}\\
&\sum_{m\in\mathfrak{M}} \sum_{k\in\mathfrak{K}} \lambda^{k} L_{m}^{k} = \sum_{m\in\mathfrak{M}} L_{m}^{o}\\
&\sum_{k\in\mathfrak{K}} \lambda^{k} L_{m}^{k} = L_{m}^{o} + S_{m}^{+} - S_{m}^{-}, \forall m \in \mathfrak{M}\\
&\sum_{m\in\mathfrak{M}} (S_{m}^{+} + S_{m}^{-}) \leq HD \sum_{m\in\mathfrak{M}} L_{m}^{o}\\
&\sum_{k\in\mathfrak{K}} \lambda^{k} = 0 \text{ if } \exists PU^{k} > PU^{o}\\
&\sum_{k\in\mathfrak{K}} \lambda^{k} = 1\\
&\lambda^{k} \geq 0, \forall k \in \mathfrak{K}
\end{aligned}
\tag{9}
$$

$$
\begin{aligned}
&\min_{\lambda,S^{+},S^{-}} \tilde{C}_{HPU} = \sum_{k\in\mathfrak{K}} \lambda^{k} C^{k}\\
&\sum_{k\in\mathfrak{K}} \lambda^{k} R^{k} \geq R^{o}\\
&\sum_{m\in\mathfrak{M}} \sum_{k\in\mathfrak{K}} \lambda^{k} L_{m}^{k} = \sum_{m\in\mathfrak{M}} L_{m}^{o}\\
&\sum_{k\in\mathfrak{K}} \lambda^{k} L_{m}^{k} = L_{m}^{o} + S_{m}^{+} - S_{m}^{-}, \forall m \in \mathfrak{M}\\
&\sum_{m\in\mathfrak{M}} (S_{m}^{+} + S_{m}^{-}) \leq HD \sum_{m\in\mathfrak{M}} L_{m}^{o}\\
&\sum_{k\in\mathfrak{K}} \lambda^{k} = 0 \text{ if } \exists PU^{k} < PU^{o}\\
&\sum_{k\in\mathfrak{K}} \lambda^{k} = 1\\
&\lambda^{k} \geq 0, \forall k \in \mathfrak{K}
\end{aligned}
\tag{10}
$$

Programs (9) and (10) are not the most intuitive and simplest way to introduce Hamming distance constraints in (7) and (8). However they result from algebraic manipulations in order to keep the linearity of programs. As a result (9) and (10) can be solved with standard LP solvers. This approach avails the privilege to add a constraint on the maximum tolerated Hamming Distance to the standard cost frontier models as seen in programs (7) and (8) above in a bid to limit the degree of heterogeneity between observations in terms of crop surface profile. Moreover in our application, the models considered only one single aggregated output but include 25 specific crop surface constraints plus one global land surface constraint. They are solved using linear programs (9) and (10). $S^{+}{}_{m}$ and $S^{-}{}_{m}$ are respectively positive and negative slack variables associated with the *m* constraints on the land categories. The exogenous Hamming Distance parameter HD indicates the closest degree of proximity possible in the sample. If HD=0, then the cost function is defined only by a DMU which has exactly the same land partition than the evaluated production plan. If a tolerance of HD=α is accepted, the cost function relies on referent DMUs which have a maximum of $\frac{\alpha}{2}\%$ difference in crop surface shares. The higher α is, the less DMUs defining the technology are comparable in terms of crop surface mixes. Finally, let us underline HD=2, all observed DMUs will be included in the technologies $T^{LPU}(PU)$ and $T^{HPU}(PU)$ irrespective of their crop surface mixes compared to the evaluated production plan. In that case (9) and (10) return to (7) and (8) respectively.

2.5. The Robust Cost function

Compared to econometric techniques, the non-parametric nature of the AAM approach avoids the possibility of confounding the misspecification effects due to an arbitrary choice of functional forms of the technology and the inefficiency components. It is therefore a strong advantage. Nevertheless, as mathematical programming techniques are inherently enveloping techniques, the main practical inconveniency of the previous cost models is the difficulty to include a statistical error component as usual into the econometrical approach. For instance, the input–output vectors are assumed to be measured with full accuracy while, practically, almost always there are some perturbations in the input/output data. In a survey study on some benchmark problems, Ben-Tal and Nemirovski (2000) showed that a small change in the sample could lead to big variations in solutions for some benchmark optimization problems. Therefore the results are considered to be very sensitive to some extreme observations of the reference production set which can be considered as potential outliers.

To avoid this main drawback, Cazals, Florens and Simar (2002); Daraio and Simar (2007) have recently developed robust alternatives to the traditional non parametric approach. These alternatives lie on the concept of partial frontier in contrast to the usual full frontier. In that line, this subsection is devoted to the estimation of the robust cost frontier from a sample of observed DMUs. Notice that throughout the presentation of the theoretical model we have always assumed a well-defined technology frontier. However in the empirical work, in order to take into account heterogeneity and exogenous factors in firms' production, we allow for the presence of outliers (located below the cost frontier). We therefore need to compute the expected minimal cost in a robust way.

In view of this, a selection of a large number of sub-samples from the reference sets $T^{LPU}(PU)$ and $T^{HPU}(PU)$ which allows the resampling and computation of the minimal cost has to be done. Finally the minimal cost is estimated as the average of the successive minimal costs computed over all the previous sub-samples. With such an approach, the sub-reference sets change over the different samples and the evaluated production plan is not constantly benchmarked against potential outliers which may sometimes be present (or not) in the sub-reference set. The final average cost can be interpreted as the expected minimal level of cost.

The computational algorithm is now described as inspired by Dervaux et al (2009). First in the case of the technology $T^{LPU}(PU)$, for a given evaluated production plan o characterized by its total output value R^o and its crop surface partition $\mathrm{s}^o = (s_1^o, s_2^o, ..., s_M^o)$, a sample b of size G with replacement is drawn from the reference set and is defined by:

$$\Lambda_{b,G}^{LPU}(PU) = \left\{ (C^k, R^k, s^k, PU^k) : PU^k \le PU, k \in \mathfrak{K} \right\} \quad (11)$$

Afterwards, the minimal cost is now defined on the sub-sample $\Lambda_{b,G}^{LPU}(PU)$ and then computed thanks to program (9). Lastly, where B is the number of Monte-Carlo replications, we repeat this for b = 1…B, therefore our final minimal cost is computed as:

$$\tilde{C}^{LPU} = \frac{1}{B} \sum_{b=1}^{B} \tilde{C}_{b,G}^{LPU} \qquad (12)$$

The same procedure is duplicated for the alternative technology $T^{HPU}(PU)$ in order to compare the two minimal expected costs $\tilde{C}^{LPU}$ and $\tilde{C}^{HPU}$.

Under such a robust cost frontier approach, two parameters ‘B’ (number of replications) and ‘G’ (size of the sub-samples) are introduced to measure the minimal costs. As it is shown by Dervaux et al (2009), the parameter ‘B’ does not seem to play a crucial role and its value has to be chosen according to an acceptable time of computation. The second parameter ‘G’ plays a more decisive function. One can note that if ‘G’ is tending to infinity, usual non-robust minimal costs are recovered since all DMUs have a very high probability to be included in each sub-sample and consequently cost functions are evaluated on all production plans of the initial reference sets. For any applied analysis, a value of ‘G’ has to be chosen. In fact, in most applications the sub-sample size of potential referents varies a lot depending on the current evaluated production plan. With respect to our application, we follow the approach inspired by Dervaux et al (2009) opting for a relative value as a percentage of the sub-sample size instead of a specified absolute value of the parameter ‘G’. It guarantees the same proportion of observations in each sub-sample used in the 'B' replications independently of the size of the sub-sample.

3. Comparing cost functions between lower and higher levels of pesticide uses

In developed countries, policy makers and land users alike are enthusiastic about promoting new agricultural practices that are more environmentally friendly. Among several others, this enthusiasm can be actualized by reducing chemical use. For instance in France, the agreement of the "Grenelle de l'environnement" encourages farmers to decrease pesticide use per ha about 50% over a period of ten years. Based on the fact that pesticide application is a means of pest control, it becomes crucial to suggest the best technology for the farmers in terms of cost competitiveness thus allowing for both better management and good ecological improvement. In the following, the common concern as regards pesticide use in Eure & Loir Département in France is addressed through our empirical application, results and comments.

3.1. Brief discussion about the data used

With respect to the sample of 707 crop farms in Eure & Loir observed in year 2008, the technology of farms are specified using one global revenue aggregating twenty-five output values and four inputs. The outputs for which cultivated surfaces are available include: crops cultivated on fallow land, forage crops, dehydrated alfalfa, corn, irrigated corn, oat, other cereals, flaxseed, sunflower, other industrial crops, flax, spring barley, winter barley, sugar beet, wheat, durum, hard wheat, proteaginous peas, beans, green peas, other vegetables, winter rapeseed, horticulture, potato consumption, and fruits. The total cost evaluated in euros comprises operational costs which are linked to the physical process of crop growth such as fertilizer or seeds plus other intermediate inputs like fuel, electricity, water, land and quasi fixed primary input costs (labor and capital) and finally pesticides as the damage control input. The unit price of land is estimated by the hired cost that the farmer paid to the owner when the land was leased. As regards to the owned land, a fictitious price equal to the hired cost of his leased land is used. A similar rule is applied for the family labor. The wage including social taxes per full time equivalent salary is multiplied by the family labor units and then aggregated to the hired labor cost. Finally the capital expenditures are evaluated by the amortization related to equipment and building.

The descriptive statistics showing the total output value and different cost components are presented in table 1. Data reveals a rather low spread for these variable inputs since their respective coefficients of variation are less than one. It can be noticed that even for the ratios of total cost and pesticide per ha, the sampling distributions are well focused around the mean.

Table 1: Brief Descriptive Statistics of Cost Components and Output Value

	Mean in €	Input Shares in %	Coefficient of Variation in %
Total Output Value	178 670		46.2
Total Cost	163 621	100.0	38.2
Seed + Fertilizer	35 088	21.4	44.7
Other Intermediate Inputs	25 165	15.4	55.7
Land Cost	23 912	14.6	39.4
Labor cost	28 052	17.1	49.1
Amortization	26 982	16.5	62.2
Pesticide	24 422	14.9	44.9
Total Cost per Ha	1 333		21.2
Pesticide per Ha	196		24.8

Table 2 presents the crop surfaces and their partition. Only 7 crops out of 25 aggregate 91% of total land. Nevertheless, although most farms are specialized in these main cash crops, one can underline that some of them develop specific activities such as horticulture, fruit or vegetables which may differ significantly in terms of pesticide uses.

Table 2: Crop Surface Partition

Crops	Mean in ha	Coefficient of Variation in %	Minimum in Ha	Maximum in Ha	Surface Share in%
Wheat	48.0	59.6	0.0	187.1	38.2
Winter rapeseed	19.7	82.3	0.0	86.5	15.6
Winter barley	15.6	95.7	0.0	84.9	12.4
Set aside lands	11.3	70.4	0.0	99.2	9.0
Durum	6.8	163.7	0.0	63.8	5.4
Spring barley	6.7	177.4	0.0	73.4	5.3
Irrigated corn	5.9	192.5	0.0	125.2	4.7
Proteaginous peas	1.9	243.9	0.0	37.4	1.5
Sugar beet	1.7	330.7	0.0	48.5	1.4
Hard wheat	1.5	383.2	0.0	63.8	1.2
Corn	1.3	340.7	0.0	36.7	1.0
Potato consumption	1.2	288.2	0.0	26.0	1.0
Other cereals	1.0	428.2	0.0	55.9	0.8
Other legumes	0.6	471.4	0.0	31.7	0.5
Total forage crops	0.5	455.9	0.0	25.9	0.4
Sunflower	0.4	583.4	0.0	25.2	0.3
Other industrial crops	0.4	490.7	0.0	19.0	0.3
Beans	0.4	519.7	0.0	20.0	0.3
Green peas	0.4	555.2	0.0	23.0	0.3
Oat	0.3	838.1	0.0	46.4	0.2
Flax	0.3	617.6	0.0	23.6	0.3
Flax seed	0.0	2657.1	0.0	3.3	0.0
Dehydrated alfalfa	0.0	2657.1	0.0	17.8	0.0
Fruits	0.0	1547.5	0.0	10.2	0.0
Horticulture	0.0	1065.2	0.0	3.1	0.0
Total surface	125.8	39.4	27.1	297.5	100.0

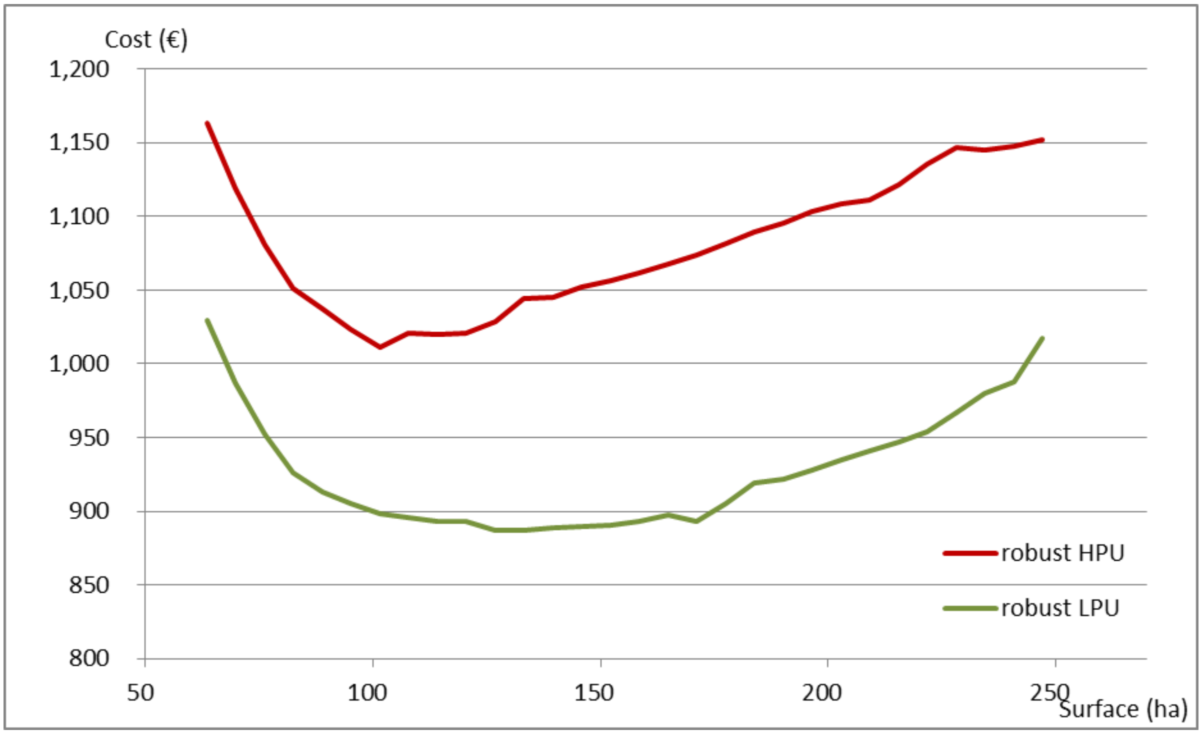
3.2. Simulation procedure

In our empirical work *LPU* and *HPU* cost functions are estimated by varying the size dimension in an interval between 60ha and 250ha comprising more than 92% of observed farms and excluding extreme points. Focusing only on the scale effect at this step of analysis the output mix is constant and defined at the sample mean. The two robust cost functions are therefore estimated for B=100 replications of each simulated production plan with a ‘G’ parameter equal to 75% of the initial sample size. As explained in the previous section a HD value of 0.2 is chosen. With this tolerance, the cost functions rely on DMUs which have a maximum of $\frac{HD}{2} = 10\%$ difference in crop surface shares. Finally, the two average cost per ha curves are compared in order to assess which technology economically dominates the other.

3.3. Results

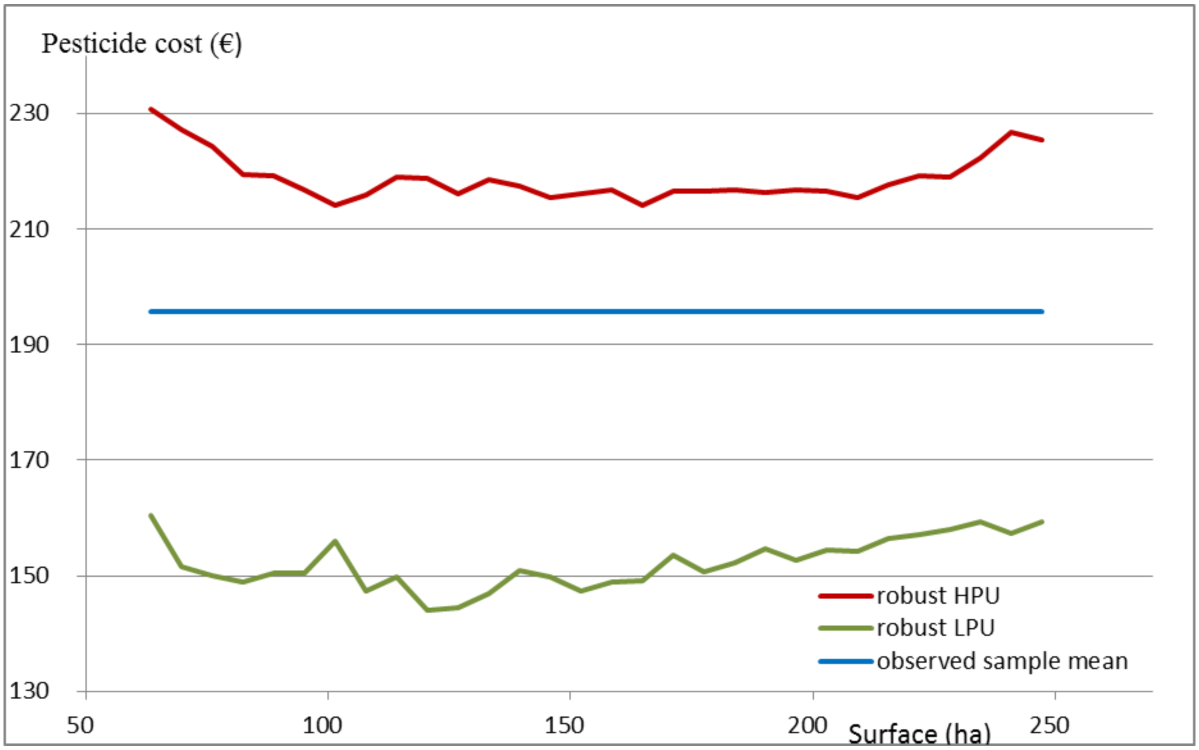
Figure 1 clearly reveals that LPU is a more cost competitive technology than HPU for each simulated point between 60ha and 250ha of size. From the robust approach taking into account the presence of outliers, the gap between the two cost curves is conspicuous and surpasses 14% on average and can reach 16% for the rather big surface levels while it is reduced around 11% for the small farm sizes. In conformity with the usual U shaped average cost curve, the HPU technology presents an optimal size around 100 ha for which the average cost is the lowest (1012€) while the optimal size for LPU technology is varying between 127ha and 159ha at a minimum average cost of 887€. At this stage it is essential to recall that for each point of the two cost functions, the level of output is the same for both LPU and HPU, therefore cost differences infer higher margins per ha for LPU.

Figure 1: Average Cost per Ha for Low Pesticide Uses (LPU) and High Pesticide Uses (HPU) Technologies



The total cost of production used in the above simulations as initially mentioned encapsulates the operational costs which are linked to the physical process of crop growth such as fertilizer, seeds, plus other intermediate inputs like fuel, electricity, water, land, quasi fixed primary input costs (labor and capital) and lastly pesticides. Nonetheless, since pesticide input is known to be a great environmental burden and which is a significant constituent of the total cost, similar comparisons on these specific input expenditures are done between the two technologies. The pesticide cost per hectare as shown in figure 2 presents a quasi-flat line. It is clear that this type of operational cost is more or less proportional to the land surface. The gap between the two technologies on the pesticide cost is more significant than for the total cost and exceeds 30%. If we consider the observed pesticide cost of 196€ per ha, the LPU technology would be able to reduce this specific expense about 22% on average by adopting the best practices.

Figure 2: Average Pesticide Cost per Ha for Low Pesticide Uses (LPU) and High Pesticide Uses (HPU) Technologies



Considering the other specific inputs, one can notice that cost difference between LPU and HPU also takes its origin from savings around 22% on other operational inputs (fertilizer and seeds) and 33% on capital amortization which appear to be complementary with pesticide. It indicates that less seed and fertilizer induces lower pesticide treatments and thus reduces machinery utilization. Otherwise the LPU technology seems to use a bit more labor and other intermediate consumptions than HPU as reflected in table 3.

Table 3: Cost per Hectare by Specific Inputs (€)

	Pesticide	Fertilizer +Seeds	Land	Intermediate Consumptions	Labor	Capital Amortization	Total
LPU	152	180	190	156	147	105	930
HPU	220	230	190	147	144	158	1 089
differences (%)	30.7	21.8	0	-6.0	-2.1	33.3	14.6

Therefore as displayed in table 4, the cost structures of the two technologies differ but not very significantly meaning that the adoption of LPU do not need to realize substantial substitution effects or shift among input intensity. This result allows us to assess that the adoption of LPU appears a relative achievable practice by all the farmers. It essentially depends on how the inputs are effectively managed without significant reallocation among inputs.

Table 4: Cost Shares by Specific Inputs (in % of total cost)

	Pesticide	Fertilizer + Seeds	Land	Intermediate Consumptions	Labor	Capital Amortization	Total
LPU	16.39	19.26	20.48	16.73	15.82	11.32	100.00
HPU	20.22	21.12	17.50	13.52	13.20	14.44	100.00
differences	-3.83	-1.86	2.98	3.21	2.62	-3.12	

In order to extend the previous conclusion established in the scale dimension but with respect to the scope dimension, it is necessary to run new simulations within different crop mixes and related input practices.

These are defined on our observed sample by a cluster analysis based on the individual crop surface partitions. We finally concluded with five groups clearly differentiated in their output mixes. Mix 1 is characterized by legumes, durum and irrigated corn which occupy 14%, 13% and 10% of total surface respectively. Mix 2 is composed by farms which mainly cultivate wheat, winter barley and rapeseed (43%, 18% and 22%). Mix 3 is made up of wheat, rapeseed and proteaginous peas (respectively 48%, 13% and 7%). Mix 4 comprises sugar beet, spring barley and hard wheat (14%, 11% and 19%). Finally, mix 5 is characterized by durum, irrigated corn and potatoes (18%, 15% and 5%).

As it is observed in table 5, the crop mixes have no significant differences in terms of total land size but three of them are characterized by a high margin level per ha thanks to some specific remunerative crops as legumes, sugar beet, hard wheat or potatoes (mixes “legumes-durum-corn”, “sugar beet-spring barley-hard wheat” and “durum-corn-potatoes”). The two last mixes “wheat-winter barley-rapeseed” and “wheat-rapeseed-proteaginous peas” have an outcome of a very low margin per ha with only common cash crops. For these orientations, one can notice that the share of pesticide use in total cost is the highest in comparison to the others.

Table 5: Characterization of Crop Mixes

	Legumes-Durum-Corn	Wheat-Winter Barley-Rapeseed	Wheat-Rapeseed-Proteaginous Peas	Sugar beet-Spring Barley-Hard Wheat	Durum-Corn-Potatoes
Number of farms	40	309	192	48	118
Total surface (ha)	128	130	127	121	115
Revenue/ha	1 957	1 290	1 274	1 760	1 742
Total cost per ha (€)	1 664	1 255	1 250	1 457	1 508
Margin per ha (€)	293	35	24	303	234
Pesticide cost per ha (€)	231	200	185	189	192
Pesticide cost share (%)	13.9	16.0	14.8	13.0	12.8

This follows that for each crop mix, the initial procedure is duplicated by varying the size dimension in a same scale interval between 60ha and 250 ha. Table 6 and figure 3 show that LPU technology dominates HPU technology for all output mixes. The gap between the two technologies appears to be highest for mix “legumes-durum-corn” and lowest for mix “wheat-rapeseed-proteaginous peas” respectively 18% and 11% on average. In addition, one can notice that for all mixes, the LPU technology presents a quite large interval of optimal size (approximately between 100ha and 190ha) characterized by constant returns to scale which does not seem so clear for their respective HPU technologies. In terms of pesticide use per ha, the LPU cost dominance permits to save between 25% and 33% of pesticide inputs according to the different crop mixes. All these figures reveal to a greater extent that cost dominance in favor of LPU technology is a strong conclusion since its average cost curve per ha is lower than the other for each size of the scale interval.

Table 6: Cost Dominance Characteristics by Crop Mix

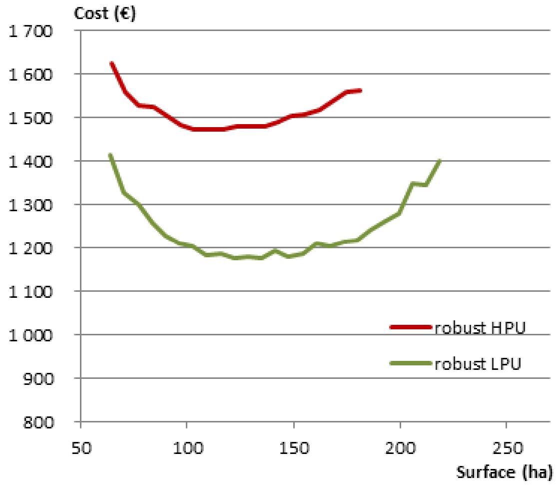
	Legumes-Durum-Corn	Wheat-Winter Barley-Rapeseed	Wheat-Rapeseed-Proteaginous Peas	Sugar beet-Spring Barley-Hard Wheat	Durum-Corn-Potatoes
LPU cost per ha (€)	1 229	902	933	1 157	1 127
HPU cost per ha (€)	1 504	1 101	1047	1 286	1 295
Cost difference (%)	18.3	18.1	10.9	11.1	13.0
LPU pesticide per ha (€)	181	152	143	164	158
HPU pesticide per ha (€)	257	226	206	219	217
Pesticide difference (%)	29.6	32.7	30.6	25.1	27.2
LPU optimal size (ha)	109-167	143-175	127-165	97-193	92-178
HPU optimal size (ha)	96-113	97-110	102-146	126-133	98-121

3.4. Discussion

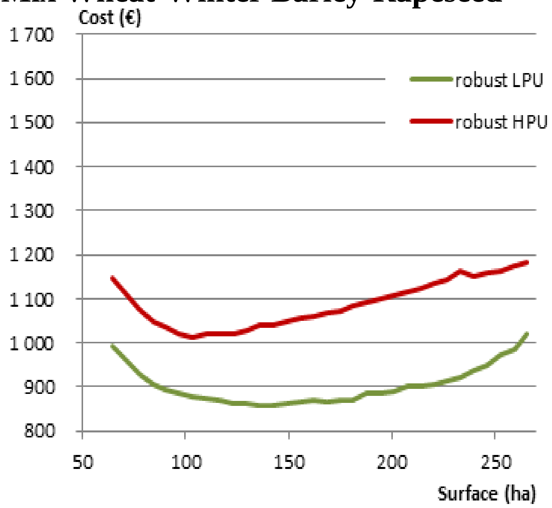
Our results in the specific context of the Eure & Loir Département in 2008 therefore signifies a total cost difference of 15% and a gap of 31% of pesticide use per ha between the two technologies in favor of LPU. But from the average observed use in pesticide, this leads to 22% reduction based on the condition that the farmers adopt this cost competitive and ecological practice. These findings are consistent with the conclusions drawn by Saint-Ges and Bergouignan (2009); Boussemart, Leleu and Ojo (2011). Despite the differences between these approaches as regards the regions, periods under consideration, types of farming systems and the cost definitions, they arrived at a conclusion that states that in order to improve the cost of production, it is possible to reduce the amount of pesticide use per hectare without incurring any other significant additional costs. Consequently, a win-win strategy can be achieved which leads to environmental friendliness at a more competitive cost. Although it is not easy to generalize this current results in conformity with all European agriculture, all these outcomes established in French agriculture are also in line with the case of Swiss Arable crop farming (Nemecek et al. 2011) where a reduction in chemical inputs showed higher impacts in environmental efficiencies and thus emphasizing that a considerable environmental potential exists in Swiss farming systems to improve the sustainability of their arable farming through better management.

Figure 3: Average Cost per Ha for LPU and HPU among different output mixes

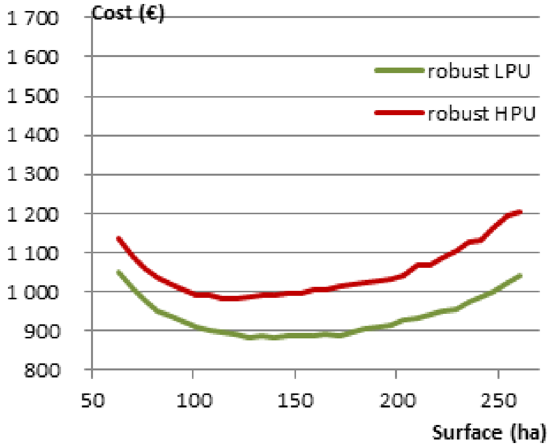
Mix Legumes-Durum-Corn



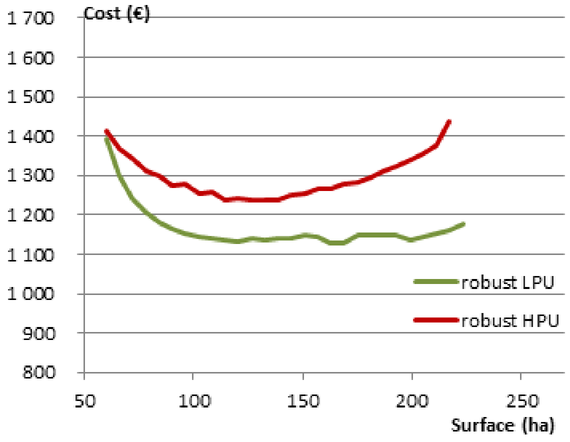
Mix Wheat-Winter Barley-Rapeseed



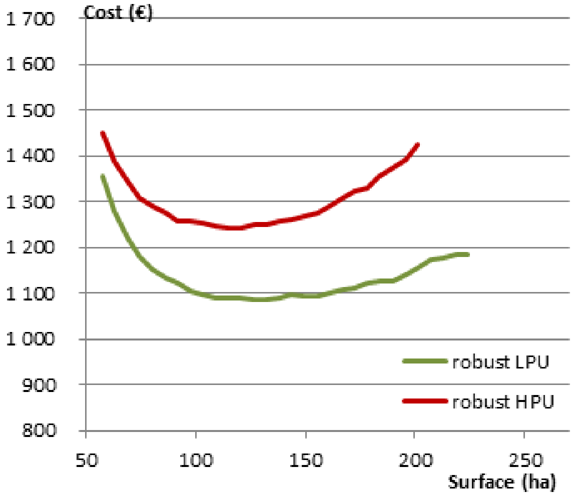
Mix Wheat-Rapeseed-Proteaginous Peas



Mix Sugar beet-Spring Barley-Hard Wheat



Mix Durum-Corn-Potatoes



A common, though erroneous, assumption about agricultural sustainability is that it implies a net reduction in input use correlated to a yield reduction, thus making such systems essentially extensive (they require more land to produce the same amount of food) which are generally considered as less profitable by farmers. This study shows that alternative more efficient (and thus more cost competitive) practices can lead to the same level of output per ha of surface. By diminishing their pesticide use and also other expenses as fertilizer or capital consumption without significant higher level of labor utilization, farmers are able to adopt more sustainable practices characterized by a higher profitability. To this regard, recent empirical evidence shows that successful agricultural sustainability initiatives and projects arise from shifts in the factors of agricultural production (e.g. from use of fertilizers to nitrogen-fixing legumes; from pesticides to emphasis on natural enemies; from ploughing to zero-tillage). A better concept than extensive is one that centres on intensification of resources, making better use of existing resources (e.g. land, water, biodiversity) and technologies (Buttel 2003; Tegtmeier and Duffy 2004). Thus intensification using natural, social and human capital assets, combined with the use of best available technologies and inputs that minimize or eliminate harm to the environment remains a better option. Pretty, Morison and Hine (2003) examined the extent to which farmers have improved food production with low cost, locally available and environmentally sensitive practices and technologies and they found improvements in food production occurring through several key practices and technologies, one of which is pest control using biodiversity services with minimal or zero-pesticide use. Their research reveals promising advances in the adoption of practices and technologies that are likely to be more sustainable with substantial benefits thereby encouraging farmers to settle for practices that minimize the use of chemical inputs that can cause harm to the environment or to the health of the farmers and consumers alike.

However, the substantial cost difference between HPU and LPU lead us to wonder why relative high pesticide using practices are still chosen by some farmers. Risk aversion is frequently mentioned as a justification but few researches were able to surely gauge this effect and no clear conclusions have been established (Carpentier et al. 2005). A relevant literature debating on the right specification of technologies incorporating pesticide as a damage-control input in a parametric or non-parametric context (see Lichtenberg and Zilberman 1986 and Kuosmanen, Pemsl and Wesseler 2006 among others) highlights that the usual specification of pesticide as a direct input leads to overestimate its productivity and underestimate the productivity of other inputs. Therefore agricultural policies based on these available econometric results would promote intensive use of pesticides. Following Chambers and Lichtenberg (1994) and the initial contribution of Lichtenberg-Zilberman, Chambers, Giannis and Vangelis (2010) conclude that the traditional damage measure belittles the profit losses caused by pest infestations. They highlight that when farmers are faced with pest attacks, they will take a supply-response adjustment which boosts their income losses. This last effect is usually ignored by the traditional pest-damage measure. Therefore pesticides seem to be less economically effective as opposed to what other studies established.

Unfortunately, factors such as strong influence of pesticide distributors and quick results obtained in the short term after pesticide applications could also presumably encourage farmers to rely more on pesticide use. This high dependence on pesticides could be an indication that farmers are less concerned about agricultural practices that are effective, inexpensive and yet more favorable to the environment. This has been a very serious hindrance to the adoption of low pesticide input techniques in the case of French field crop farms (Barbier et al. 2010). However, in the case of Belgian cereal crop farmers, Vanloqueren and Baret (2008) also noted that despite the existence of alternative technologies, the use of pesticide is still on the increase and thus chemical inputs gradually became the main pest control strategy. They added that modern wheat cropping practices are ‘locked-in’ to a fungicide-dependency situation which requires new conditions (such as tougher pesticide regulations, changes in cereal prices, changing consumer preferences, programs of pesticide reduction to evolve round greater managerial efforts and innovative skills, etc.) to pull apart the lock-in. To this effect, they suggested that specific actions must be undertaken to get out of this static situation.

This research therefore encourages agricultural practices that focus on the necessity to develop technologies and practices that are environmental friendly, are accessible to and cost effective for farmers, and lead to improvements in food productivity.

4. Conclusion

A competitiveness of technologies in terms of cost is established for different surface sizes, crop-mixes and pesticide uses by exploring the cost function over its whole domain of definition. Thus, it deals with a framework which aims at assessing the cost dominance between technologies that favor high or low pesticide levels per ha. The authenticity of our result indicate that low pesticide use per ha which creates environmental friendliness is more competitive in terms of total cost in comparison to a high pesticide use which stimulates environmental burden. While the results gotten here depend on the Eure & Loir sample and thus are not easy to generalize in conformity with all European's agriculture, they are totally in convergence with previous researches using different methodological tools and other data in various European regions.

From a methodological point of view, the originality of this study resides on several elements. First instead of developing the usual econometric approach, cost frontier estimations are done empirically thanks to an AAM which imposes few assumptions on the production set and does not require any a priori specific functional form for the cost benchmark. This AAM allows the assessment of the competiveness between two technologies characterized by different levels of pesticide per ha. These comparisons of technologies in terms of cost are established for different crop-mixes at several levels of size. Second the concept of Hamming Distance is endogenously introduced in the linear programs which estimate the HPU and LPU minimal costs. This guarantees that the optimal solution have a similar profile than the current evaluated farming system in terms of crop surface structure. Third, in order to get round the possibility of comparing the sensitivity of our result to the potential presence of outliers, we assume a well-defined technology frontier by computing the expected minimal cost in a robust way, thereby reducing the sensitivity of the cost frontier to the influence of potential outliers.

Since our results strongly show that Low Pesticide Use (LPU) dominates High Pesticide Use (HPU) in terms of total cost, they can provide a direction for policy-makers or farmers as regards the reduction of pesticide use in French Agriculture thus motivating environmental friendliness. It is somehow very striking to note that practices that creates less burden to the environment and which are simultaneously the most efficient in terms of costs are not embraced by farmers who prefers the more intensive pesticide use technique to the less intensive one despite the significant expense-gap between these two technologies, HPU and LPU respectively.

Indeed, health and environmental problems cannot be isolated from economic concerns due to the fact that inappropriate pesticide use results not merely in yield loss but also in health problems and possible air, soil and water pollution. The problem of farmers' health should be an important concern for policymakers when looking at the economic and efficiency of pesticides in agricultural production. The conclusion from this study will inform ongoing efforts to promote upstream policy interventions to reduce hazardous pesticide exposures for vulnerable farmers. It is important to state that the results gotten in this paper are derived from the current technology of farms which ensures its possibility by adopting the observed practices with low pesticide uses. Thus, in ten years time, the aim of 50% rate of reduction may be achievable only with some improvements in technology which will enable the farmers and the Society to opt for a win-win strategy.

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