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Cost Efficiency Analysis of pesticide use reduction in crop activities on French Farms

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Analyse de l'efficacité coût et des réductions des pesticides pour les exploitations françaises de grande culture

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List of Publications

This thesis is based on the work contained in the following papers which are referred to by Roman numerals in the text:

(I) Boussemart, J.P., Leleu, H., Ojo, O., 2011. **Could Society's willingness to reduce pesticide use be aligned with Farmers' economic self-interest?** *Ecological Economics,* 70(10): 1797-1804.

-Could Society's willingness to reduce pesticide use be aligned with Farmers' economic self-interest? Communication aux 4èmes journées INRA-SFER-CIRAD de recherches en sciences sociales, Site AgroCampus Ouest, Rennes 9-10 décembre 2010

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-Could Society's willingness to reduce pesticide use be aligned with Farmers' economic self-interest? IESEG/LEM working paper n°2010-ECO-03

(II) **"The spread of pesticide practices among cost efficient farmers"-**

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(III) **"Exploring cost dominance in direct inputs between high and low pesticide use in French crop farming systems by varying scale and output mix"** -

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Analyse de l'efficacité coût et des réductions des pesticides pour les exploitations françaises de grande culture

Résumé général

Suite au Grenelle de l'environnement proposant une réduction de 50% des pesticides dans l'agriculture française, l'objet central de cette thèse est d'estimer les potentiels progrès de productivité et de diminution de ces inputs pour les grandes cultures. Dans cette perspective, le recours aux modèles d'analyse d'activités et les estimations de fonction de coût par des approches non paramétriques comme Data Envelopment Analysis (DEA) et/ou Free Disposal Hull (FDH) sont mobilisés afin d'évaluer les réductions potentielles de coût global et des dépenses en pesticide pour ce type de cultures. S'appuyant d'une part sur un panel reprenant environ 600 exploitations situées dans le département de la Meuse au cours de la période 1992-2003 et d'autre part sur un échantillon de 700 exploitations de l'Eure & Loir observées en 2008, notre recherche vise à établir une relation de dominance coût entre les technologies utilisant plus ou moins de pesticide à l'hectare. En conséquence deux fonctions de coût caractérisées par des niveaux de dépenses de pesticides à l'hectare différents (haut et faible) sont comparées. La fonction de coût non paramétrique est estimée de manière robuste pour réduire la sensibilité des résultats à l'éventuelle présence d'outliers. Les résultats indiquent que des réductions substantielles de coût sont envisageables si les agriculteurs géraient leurs inputs plus efficacement. De plus, les pratiques culturales utilisant moins de pesticide à l'hectare apparaissent plus compétitives en matière de coût. Cette conclusion indique que l'adoption de ces nouvelles pratiques économes en intrants et donc plus favorables à l'environnement serait bénéfique à la fois pour les agriculteurs et pour l'ensemble de la société.

Mots-clés : pesticide, efficacité coût, exploitations agricoles françaises, libre disposition des ressources, enveloppement des données, frontière robuste.

Cost efficiency Analysis of Pesticide use reduction in crop Activities on French Farms

General Abstract

In the context of the agreement of about 50% reduction in pesticide uses according to the accords du “Grenelle de l’environnement” (the Environment Round Table) in France, the central part of this study is to use some efficiency analysis to estimate the substantial productivity improvements and cost reductions on French farms. By employing Activity Analysis Models and estimating cost frontiers with non-parametric approaches such as Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH)], total cost and/or pesticide expense reductions are evaluated on crop farms. Based on this, a sample of 600 and 700 farms in the Meuse and Eure & Loir departments were respectively observed over a 12 year period (1992-2003) and in year 2008. A non parametric cost function is essentially employed to assess the cost efficiency dominance between technologies using either more or less pesticide and a robust approach frontier is introduced in order to reduce the sensitivity of the cost frontier to the influence of potential outliers, thus improving the accuracy of the result. With respect to this, two cost functions characterized by a relatively lower or higher pesticide level per ha are compared. The estimated efficiency scores indicated that substantial efficiency improvements are possible on French crop farms with a strong potential for cost decreases if farmers could manage inputs more efficiently. Therefore, agricultural practices using less pesticide per ha are more cost competitive which does not only benefit the farmers but also the society, thereby promoting new agricultural practices that are more environmentally friendly.

Keywords: Pesticide use, Cost efficiency, French farms, Free Disposal Hull, Data Envelopment Analysis, Robust frontier

Analyse de l'efficacité coût et des réductions des pesticides pour les exploitations françaises de grande culture

Résumé substantiel

Suite au Grenelle de l'environnement proposant une réduction de 50% des pesticides dans l'agriculture française, l'objet central de cette thèse est d'estimer les progrès de productivité et la diminution de ces inputs pour les grandes cultures. Dans cette perspective, le recours aux modèles d'analyse d'activités (AAM) et les estimations de fonction de coût par des approches non paramétriques comme Data Envelopment Analysis (DEA) et/ou Free Disposal Hull (FDH) sont mobilisés afin d'évaluer les réductions potentielles de coût global et des dépenses en pesticide pour ce type de cultures.

S'appuyant d'une part sur un panel reprenant environ 600 exploitations situées dans le département de la Meuse au cours de la période 1992-2003, un premier essai vise à établir une relation de « dominance coût » entre les technologies relativement plus ou moins intensives en termes de dépenses de pesticide à l'hectare aux différentes exploitations évaluées.

D'un point de vue méthodologique, l'originalité de cette approche réside dans les définitions respectives des technologies sous-jacentes aux fonctions de coût estimées. Celles-ci ne sont pas distinguées à partir d'un niveau arbitraire de dépenses de pesticide à l'hectare mais en utilisant un ratio spécifique à chaque exploitation étudiée. Plus précisément, reprenant l'approche initialement développée par Ruggiero (1998), les technologies plus ou moins intensives en pesticide sont définies en retenant ou excluant des deux sous-ensembles de références, les exploitations qui dépensent plus ou moins de pesticides à l'hectare que la firme évaluée.

Les résultats montrent que pour 80% des fermes étudiées, la technologie moins intensive en pesticide domine la plus intensive. En conséquence, par rapport à leurs situations observées, ces exploitations pourraient réduire de 25% leur coût global et diminuer de 29% leur niveau de pesticide à l'hectare. Ces résultats sont en total convergence avec ceux établis par Jacquet et al. (2011) pour les mêmes types de cultures mais avec une approche méthodologique très différente basée sur des modèles d'optimisation linéaires développés au niveau France entière. Finalement, quant à la question essentielle de savoir si le souhait de la Société d'une agriculture respectant mieux l'environnement grâce à la réduction des pesticides est en convergence avec l'intérêt économique individuel de l'agriculteur ? Cette conclusion est donc clairement oui.

Reprenant le même panel, le deuxième essai analyse l'éventail des dépenses de pesticides parmi les seuls agriculteurs « coûts-efficaces ». Cette étude développe une approche en deux étapes. En premier lieu, elle sélectionne les agriculteurs situés sur la frontière de coût total. En deuxième lieu, sur ces seules exploitations dites « coût-efficaces », elle mesure les possibilités de réduction des pesticides à niveau de rendements inchangés pour les trois cultures retenus (blé, orge et colza).

D'un point méthodologique, cet essai se distingue de l'analyse précédente d'une part en relâchant l'hypothèse de convexité de la technologie sous-jacente et d'autre part en développant une estimation robuste de la fonction de coût. En effet, l'hypothèse de convexité autorisant des combinaisons linéaires comme référents possibles aux exploitations évaluée est souvent décriée dans les activités agricoles qui peuvent être caractérisées par certaines indivisibilités. Dès lors, par rapport au modèle standard DEA, l'approche FDH basée sur de l'optimisation en mixte entier peut apparaître plus pertinente pour construire les frontières de production et/ou de coût qui sont désormais construites seulement à partir d'unités réellement observés. Cependant comme toute méthode d'estimation non paramétrique, FDH est très sensible à la présence éventuelle de données extrêmes. Dans cette perspective, nous avons mobilisé le concept de « frontière robuste » introduit par Cazals, Florens, and Simar (2002) qui, par de nombreuses itérations ré-échantillonnant l'ensemble de référence initial, permet de diminuer fortement l'influence des outliers sur les scores d'efficacité.

Les résultats montrent que parmi les exploitations « coût efficaces », les possibilités de réduction de pesticides à l'hectare pourraient encore atteindre 24% en moyenne ce qui représente une valeur de 2600€ par exploitation soit environ 7,4% du coût global. De plus, une régression within en données de panel, montre clairement que ces possibilités de réduction de pesticide diminuent en fonction des niveaux de production à l'hectare. Ceci indique que les agriculteurs ont moins de flexibilité dans les utilisations de pesticides au fur et à mesure que les rendements techniques des cultures s'accroissent.

Le troisième essai se focalise sur un échantillon différent situé en Eure & Loir regroupant plus de 700 exploitations spécialisées en grande culture et pour l'année 2008. Il explore la relation de dominance coût entre les technologies utilisant plus ou moins de pesticide à l'hectare à la fois dans les dimensions de l'échelle de production et de choix de mix d'outputs.

Ce dernier essai s'appuie sur le même type d'estimation non paramétrique de fonction de coût utilisé précédemment. Il se distingue, néanmoins, des deux précédents sur plusieurs points méthodologiques. Premièrement, s'appuyant sur le travail développé par Lichtenberg et Zilberman (1986) qui considère que les pesticides ne sont pas des inputs influençant directement la production mais plutôt des facteurs de contrôle des dommages causés par les attaques de pestes (insectes, mauvaises herbes, champignons, …), la fonction de coût retenue n'inclut que les dépenses en inputs directs comme la terre, les fertilisants, le travail, les équipements ou l'énergie. Cette exclusion des pesticides de la fonction de coût direct permet de distinguer les deux technologies fortement ou faiblement utilisatrice de cet intrant à partir du critère désormais complétement exogène « dépenses de pesticides à l'hectare ». Deuxièmement, il ne s'agit plus ici d'évaluer des plans de production observés comme dans les premières analyses mais de simuler pour un mix donné d'activités, différentes tailles d'un plan de production. Ensuite, sur l'ensemble de l'intervalle de taille de ce plan de production, des comparaisons des coûts directs optimaux sont faites entre les deux technologies à fort ou faible niveau de pesticides à l'hectare. Troisièmement, les données comptables utilisées ne permettent pas de repérer pour chacune des 25 cultures recensées, les quantités produites ; seules sont mentionnées leurs surfaces et un output global agrégé (la somme des productions en valeur). Ainsi pour garantir une homogénéité d'activités et donc de comparaison de coût entre les entités retenus dans les ensembles de référence, des contraintes de répartition de terres entre les cultures et de surface agricole utilisée totale ont été explicitement introduites dans les programmes d'optimisation des coûts des plans de production simulés. Enfin, les fonctions de coût estimées reprennent l'approche robuste du précédent essai mais développée maintenant dans le cadre d'une technologie convexe tel que DEA. Ces trois originalités méthodologiques permis l'avancer que les résultats obtenus sont des estimations hautes des coûts de production. En ce sens, ils ne risquent pas d'aboutir à des sous-évaluations des fonctions de coût et donc à des exagérations des potentiels de réduction d'intrants.

Sur le plan empirique, les résultats indiquent une « dominance coût direct » de la technologie faiblement utilisatrice de pesticide sur l'autre. Avec des écarts respectifs de 10% et de 14% en coût direct et coût total à l'hectare, cette dominance se traduit par une différence de 28% en termes de dépenses de pesticides à l'hectare. L'inégalité de coût en faveur de la technologie peu utilisatrice de pesticides est une conclusion robuste tant sur la dimension échelle de production que sur la dimension mix d'outputs. De plus, elle confirme totalement les résultats précédents établis dans cette thèse mais sur une période et une localisation géographique différentes.

En conclusion, il apparaît que l'objectif du Grenelle de l'environnement de réduire de 50% l'utilisation des pesticides dans un horizon de dix années peut déjà être en partie atteint via l'adoption de pratiques culturales existantes. En gérant plus efficacement l'ensemble des intrants directs et notamment les pesticides, les agriculteurs ont la possibilité de réduire substantiellement leurs coûts de production et donc d'aligner leurs intérêts économiques individuels avec le souci sociétal de bénéficier d'une agriculture plus verte.

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CHAPTER I

Assessment of pesticide use in French crop farming systems through Non Parametric Cost Function Estimations

1. General Introduction

1.1. Background to pesticide use: The global perspective

Around 1.5 billion hectares (ha) of arable land is available globally. Agriculture faces competition for suitable land resources from forests (800 million ha), nature reserves (200 million protected ha) and urbanization (60 million ha). The potential to increase food and fibre production by expanding the area farmed is reduced by this competition. It is estimated that by 2050 the amount of arable land will expand by less than 5%. Consequently, 90% of the growth in crop production will need to come from higher yields per hectare and increased cropping intensity (from 84% in 2000 to 92% in 2050) (Bruinsma, 2009; Fischer, 2009). The lack of suitable land for agricultural expansion is an important argument for agricultural intensification. However, it largely negates the argument that agricultural intensification is sparing land for nature (Balmford et al., 2005). Past intensification has been characterized by more production with the use of more inputs, thus affirming the fact that intensification was based on more fertilizer, more pesticides, more irrigation, more intensive cropping, and mechanization. The imperative for ecologically based land management arises from concerns about the negative consequences of agricultural intensification (WBCSD, 2000). The ‘ecological’ imperative places further demands on agriculture to reduce its dependence on nonrenewable resources, to maintain soil fertility and biodiversity, to minimize off-site consequences such as soil erosion, pollution of groundwater and eutrophication of rivers and lakes and to reduce GHG emissions. This therefore ensures the production of more food per unit resource while minimizing the impact of food production on the environment.

Over 1990s, the global pesticide sale remained relatively constant, between 270 to 300 billion dollars, of which 47% were herbicides, 79% were insecticides,19% were fungicides/bactericides, and 5% the others. Over the period 2007 to 2008, herbicides ranked the first in three major categories of pesticides (insecticides, fungicides/bactericides, herbicides) while fungicides/bactericides increased rapidly and ranked second. Europe is now the largest pesticide consumer in the world, seconded by Asia. As for countries, China, the United States, France, Brazil and Japan are the largest pesticide producers, consumers or traders in the world. Most of the pesticides worldwide are used for growing fruit and vegetable crops. In the developed countries pesticides, mainly herbicides are mostly used to grow maize. Since the 1980s hundreds of thousands of pesticides have been developed, including various bio pesticides. In view of the world's limited croplands and growing population (Zhang et al., 2006; Zhang, 2008), it is necessary to take all measures to increase crop production in order to ensure food safety (2008c; Zhang, 2009).

It is however very important to note that advances in plant protection have contributed considerably to increasing yields and ensuring regular production. Easy to obtain and apply, and rather inexpensive, chemical control products have proved to be extremely efficient and reliable in a very large number of cases, on large surface areas. More than in many other countries, French farming has developed production systems based on using these products; it is currently highly dependent on pesticides and France now ranks third in worldwide global pesticide consumption. However, today, the systematic use of pesticides is being called into question, with the increasing awareness of their negative impacts, the demonstration of undesirable adverse effects on ecosystems, on non-targeted useful or domestic species and on human health. The European Union, including France, has therefore now engaged in a process of reducing pesticide use in agriculture. Pesticides are chemicals that require particular attention because most of them have inherent properties that make them dangerous to human health and the environment.

The European Thematic Strategy on the sustainable use of pesticides (currently being developed) identifies a set of policy objectives that will have to be reached in the coming years to achieve a higher level of sustainability in chemical-based agricultural production. Minimizing the hazards and risks to health and the environment from the use of pesticides is a key point in this strategy that will need to be supported by several policy actions. Amongst other things, the EU strategy includes: encouraging the use of low input or pesticide-free crop farming, particularly by raising users' awareness; promoting the use of codes of good practice; and consideration of the possible application of financial instruments. The strategy assumes: i) the imposition of penalties on users by reducing or cancelling benefits provided by support schemes; ii) the introduction of special levies on pesticides to raise awareness of the detrimental effects of over-intensive pesticide use and further reduce reliance on chemical inputs in modern agriculture (Travisi and Nijkamp, 2008).

1.2. Pesticide use intensity in France: is there a need for concern?

From the above context, an interministerial plan to reduce pesticide risk in France was established in June 2006 and the Grenelle of the Environment has confirmed the guidelines of this plan by taking a number of precautionary measures. This involves the reduction in the use of synthetic pesticides by half if possible over 10 years (Ecophyto plan, 2018). In 2008, several measures were taken which include the prohibition of 30 products that are considered most toxic, introduction of a tax on pesticides based on their level of toxicity and granting of tax credits for organic farming. In the 2018 Ecophyto plan, various actions are aimed at improving farmers' information (creation of an epidemiological surveillance network), to disseminate good agricultural practices (establishment of networks of reference farms), to develop training and improved use of equipment needed for agricultural productivity (Champeaux, 2006).

As mentioned earlier, France ranks third in the world for pesticide consumption and is the leading user in Europe, with a total volume of 76,100 tonnes of active substances sold in 2004. Fungicides account for 50% of this volume, herbicides for 34%, insecticides for 3% and other products for 13%. Before 1993, when Directive 91/414/CE was first implemented, 800 active ingredients (AI) of plant, mineral or synthetic origin could be used as pesticides in Europe. The review of AI and the obligation to register them on a positive European list has since led to the gradual withdrawal of many products. In 2005, 489 AI, belonging to around 150 different chemical families, continue to be available. They can be broken down according to use into 165 fungicides, 139 herbicides, 95 insecticides, 11 nematicides and 79 other products. These AI are formulated and marketed in the form of commercial preparations or products: approximately 6000 are registered, but only around 2500 are actually sold.

An analysis of consumption data, estimated on the basis of sales figures from the major crop protection product companies, provides an initial understanding of how pesticides are used, and how practices are changing.

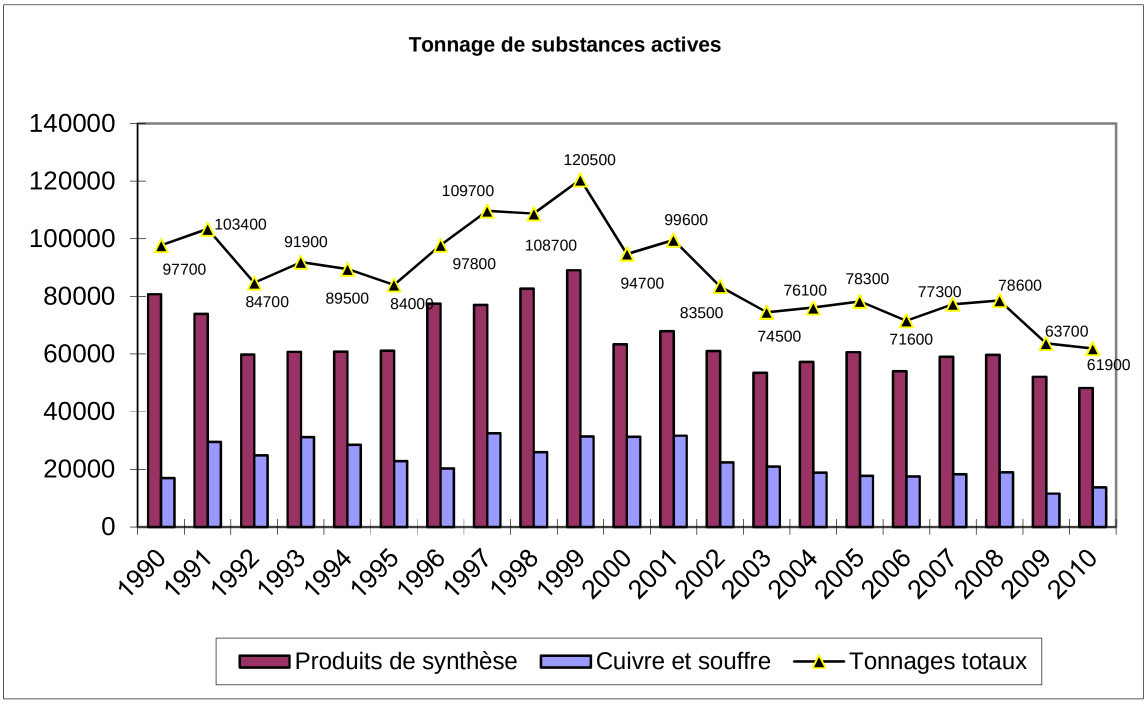

Figure 1: Sales of plant protection products in France from 1990 to 2010

(Source: UIPP, "Les chiffres clés" 2010)

Note: “Produits de synthèse” means synthetic substances, while “Cuivre et souffre” means copper and sulphur, lastly “tonnages totaux” means total tonnage.

In view of the above context, the significant increases which could be made in augmenting the output of French Agriculture with the fewest possible resources are needed to be put into maximum consideration. Hence, a concern should be placed on the unresolved relationships between technology, productivity, and quality of life. We can and should be concerned because agriculture continues to be plagued with excess capacity to produce, low prices, and, for many, inadequate incomes. Fertilizer use has become suspect as a possible source of nitrates in streams and underground water supplies. Intensive cultivation has been criticized for its contribution to sedimentation problems as well as the alteration of landscape through removal of natural vegetation. Finally, chemical pesticide use has been seriously attacked for the discharge of toxic chemicals into the environment, allegedly damaging wildlife, fish, domestic animals, and humans. So, while providing an adequate supply of food and maintaining the income of farmers have been challenging, there is now the additional challenge of finding and maintaining the right relationship between agriculture and the natural environment, this explains the fact that a balance must be struck between greater environmental protection from reduced pesticide applications and the continued contribution of agriculture to production.

Based on a favorable price regime and opportunities guaranteed by the initial orientations of the Common Agricultural Policy, the French agriculture has, until recently, widely favored a productivity-bias based on intensive use of inputs. France, consuming more than 85 500 tonnes of active ingredients (estimated three-year [2001-2003]) represents over 10% of consumption in the OECD (OECD, 2008). Although it must report this use to a large acreage of 19.5 million hectares of cultivated land, it nevertheless appears to be in the 6th place in the European Union for pesticide consumption with 4.4 kg of pesticide per hectare of arable and permanent crops (thus excluding grassland) for that period. In recent years (2007, 2008), the tonnage of active ingredients increased but decreased by 10% between periods [1990-1992] and [2001-2003] in France which is beyond the OECD average (5%) and even more so in European countries (4% for the EU-15), but well below Denmark (37%).

At European level, the framework directive on pesticides (DCP, 2009/128/EC), enacted October 21, 2009 for implementation in 2011 by member states, establishes a framework for Community action to achieve sustainable use of pesticides. Nationally, the Grenelle Environment Forum has set itself a target of reducing use of pesticides by 50% in less than 10 years. Corresponding to this objective, the Action Plan Ecophyto 2018 was submitted to the government (Paillotin, 2008). A major objective of this plan is to develop efficient cropping systems with the use of pesticides. Among the major means envisaged include i) the extension of crop rotation practice among cereals, oilseeds, legumes, other crops and grasslands ii) the elimination of inefficiencies in conventional agriculture; iii) improving scientific and technical knowledge in agronomy.

Table 1: Table showing the consumption of different categories of pesticide in France from 2000 to 2009 (tons)

Category	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Insecticides	3250	3103	2488	2308	2224	2460	2506	2140	2101	1300	1100
Herbicides	40430	30845	32122	28779	24508	26102	29209	23068	26808	27200	22600
Fungicides &Bactericides	61345	52834	54130	43351	39317	37175	35921	35957	36919	39200	32500

Source: FAO (2011)

In 2006, field crops represented 80% of the total cultivated land and accounted for 68% of the pesticides used in agriculture. Most of the French production of field crops is grown using intensive conventional techniques. Although some farmers use less intensive techniques, it is difficult to know exactly what proportion of the total field crop area is concerned (Butault et al., 2010). The above table shows that Fungicides & Bactericides are the most used pesticides in France. In total 36,919 tons of fungicides, 2,101 tons of insecticides and 26,808 tons of herbicides were consumed during 2007 (Lan and Bo, 2009). Overall, the proportion of pesticide consumption declined in the last decades as reflected below in the graphical representation of pesticide consumption in France.

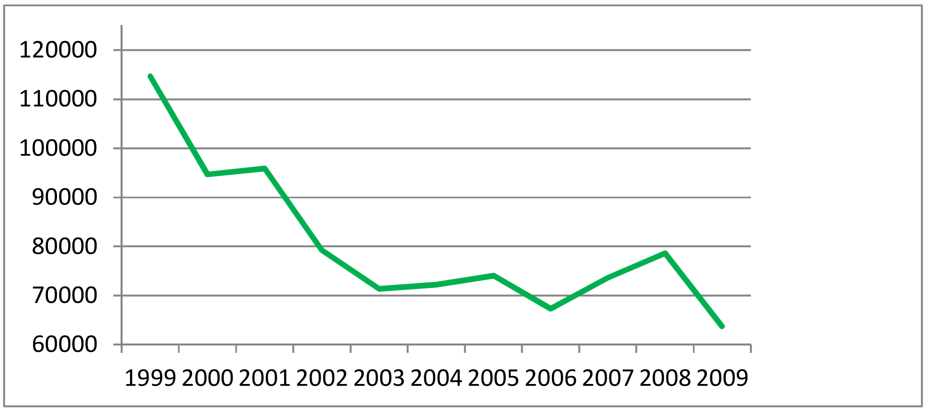

Figure 2: Pesticide consumption (in tons) in France from 1999 to 2009

Figure 2 (drawn from table 1) illustrates that consumption of plant protection products in France drop since 1999. The phenomenon behind the declining trend of pesticide consumption should be interpreted with caution, this may be as a result of the increased awareness of the harmful side effects of intensed use of pesticide. It could also be explained by the development of new active substances over the last few years. These substances are usually more toxic, hence more effective in low doses. This trend therefore helps to ascertain whether sustainable agriculture will guarantee long term productivity since it is concerned with the ability of agro ecosystems to remain productive in the long term.

Many authors distinguish ecological (or environmental), economic and social sustainability. Ecological sustainability is defined as the maintenance of the global ecosystem or of "natural capital" (the stock of environmentally delivered assets which provide a flow of useful goods or services) both as a "source" of inputs and as a "sink" for waste. The ecological dimension of sustainability is fundamental to overall sustainability, as it is a prerequisite for the economic and social dimensions. As reflected in figure 3, farmers adjust their production practices (e.g. tillage operations, sowing, fertilization) in order to optimally combine inputs based on natural capital (soil, solar energy, rain, fossil energy) and inputs from human-made capital (fertilisers, seeds, pesticides) yielding desired outputs (products) and undesired emissions to the environment. The level of production of agroecosystems largely depends on inputs from natural and human-made capital. Herdt and Steiner (1995) point out that it is hard to know whether current agroecosystems are sustainable in the sense of remaining productive in the long run, as the continuous increase in human-made inputs applied in most agroecosystems has increased yields but may offset reductions in the quality of the natural capital (e.g. land degradation) and thus of the underlying productive capacity. (Hayo et al, 2002)

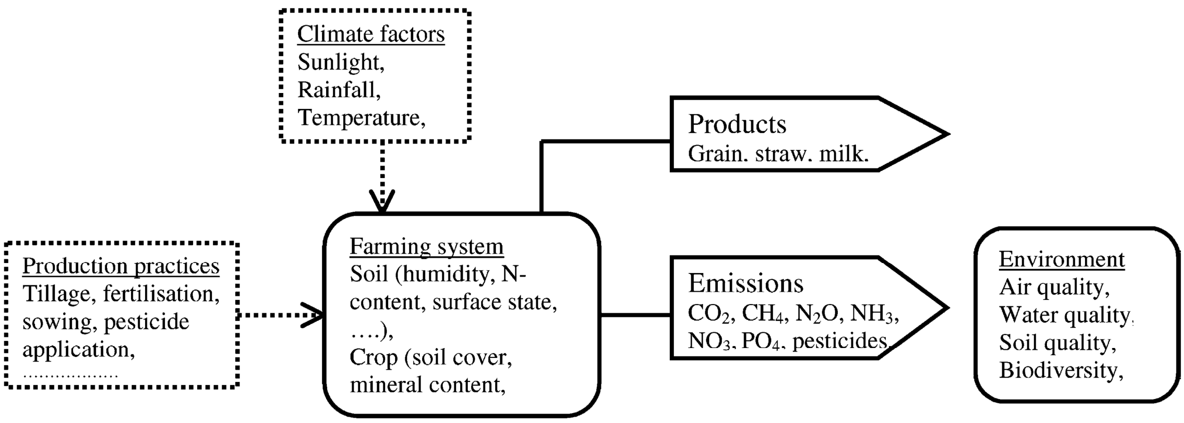

Figure 3: Environmental effect resulting from different production practices

From a more elaborate perspective, Figure 4 explains the evolution of pesticide, intermediate inputs and output quantity indexes in logarithmic terms (in constant prices) over a 50 year period. Distinguishably, two periods can be noticed, the first one is the period from 1959 to 1989 and the second one is the period from 1990 to 2011. It will be discovered that output volume increases in the first period with a sharp increase of pesticide consumption while there is deceleration of output growth implying a stabilization of pesticide use in the second period. This could be due to the fact that the intervention of new AIs which are more effective in low doses resulted to this stagnation, thus new attention are paid to promote agricultural practices that tries to stabilize or diminish chemical input utilization. This shows that the use of (more or less) pesticide by farmers does have an indirect effect on output volume unlike intermediate inputs (land, labor, and capital) which has a direct effect. Suffice to note here that damage control agents such as pesticide is one of the most important classes of factors of production that do not increase (in fact, they may decrease) potential output. Their distinctive contribution therefore lies on their ability to increase the share of potential output that producers realize by reducing damage from both natural and human causes. (Lichtenberg and Zilberman, 1986)

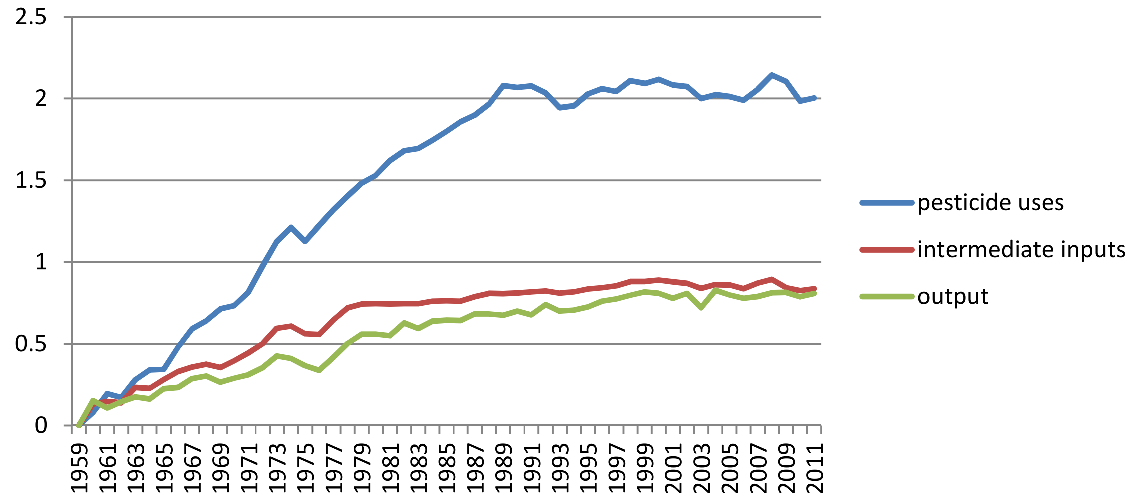

Figure 4: Evolution of pesticide and intermediate inputs as compared to output quantity indexes in logarithmic terms (100=1959)

Recent studies (Abbott et al. (2008), Baier et al. (2009)) point out that the increase in worldwide biofuel production induced an increase in biofuel feedstock prices between 2006 and 2008. This therefore prompts the possibility of asking whether in the case of the principle biodiesel crop (rapeseed), high prices induce an increase in the use of pesticides in France. The 2007-2008 period of worldwide cereal production corresponds to a context of high crop prices for rapeseed, wheat, and corn. In this context of high crop prices, farmers could be tempted to increase the amount of pesticide they use in order to increase their agricultural productivity and coping with risks associated with crop production. (Nelson and Robertson 2008, p. 518).

1.3. Problem Statement

The harm initiated by pesticides to human health and the environment is a major concern which involves some striking issues such as drinking water contamination, the health of users and the harmful effects on wildlife and biodiversity. The common concern of reducing pesticide use has begun in the environmental policy debates in France and several other European countries, and therefore in 2009 the European Union (EU) adopted a common framework (directive 2009/128/EC) that requires each member state to submit a 2012 action plan to reduce pesticide use in agriculture. The EU directive gives the policy launched in France a broader perspective. However the objectives set in 2008 are still under discussion: is the 50% reduction target realistic? What are the economic incentives needed to encourage such a reduction? What would be the consequences of such a level of reduction on French agricultural production and on farmers' income?

In any discussions of agricultural productivity, it is important to clarify what is being produced, for how long, for whose benefit and at whose cost, over what area and measured by what criteria. Answering these questions on sustainable agricultural productivity is difficult, as it means assessing and trading off values and beliefs. This is simply because most transitions involve trade-offs. A gain in one area is accompanied by a loss elsewhere. A farm that eschews the use of pesticide benefits biodiversity but may produce less food. This thus explains the fact that the reliability of production is economically important to any producer. It is no good having an adequate harvest for three years if there are large losses in the fourth year. By reducing the risk of catastrophic loss to pests and diseases, pesticides are a tool to help deliver food security and dependable livelihoods from farming. Conversely, as earlier noted, it is important to note here that intensive use of these chemical inputs contribute to water and soil quality in one situation and in others, it generates soil erosion, pollution of soil and water as well as unpleasant smells. Some pollution problems are directly related to the level of agricultural production and would therefore be alleviated if agricultural production is diminished.

On the other hand, some positive externalities are dependent on the maintenance of some level of agricultural production on specific lands or in some regions. Externalities are those consequences of a production process, imposed on society or the environment, which are not taken into account in the product price. They are produced whenever production processes, or consumers' utility, are affected by variables not controlled by themselves, but by other economic agents. These effects may be positive (external benefits) or negative (external costs). The fact that these costs and benefits are not included in the price, and thus, not taken into account by the market, produces a market failure, as the price is the market assignment tool. This failure produces in turn an inefficient assignment of resources and the general rule is that positive externalities are often under produced while the negative ones are often overproduced which is referred to as unsustainable resource use pattern by Pigovian. The existence of externalities goes a long way to determine the extent to which the environment could be sustainable in terms of effectiveness in the resource use pattern by the burgeoning population. With this, if the resources are not well managed, then the long-term sustainability of agricultural production will be endangered, thus implying a non recognition of the essential tradeoffs between short-term productivity and long-term sustainability.

Pesticide application as a means of pest control is becoming an increasingly more important issue most especially in French Agriculture and this is attracting more attention of economists. Its production system seems to be very dependent on the use of these products. It is pertinent to understand that there are good reasons to believe that French farmers overuse pesticides as a means of insurance against pest damages on their crop surfaces. In the face of some unforeseen circumstances, their practice could be the right strategy for the individual producer but as pest damage predictions are improved, it becomes imperative to suggest the best technology (from a wide range of production practices) for the farmers in terms of their cost of production thus allowing for better management or maybe a good ecological improvement not only for their benefits (farmers' benefit) but also for the benefit of the increasing population (society's benefit). This involves identifying the effect of a reduction in pesticide use on farmers' total cost of production and on the society. The cost borne by the farmer includes price of pesticide and other inputs while those imposed on society entail risks to human health and diminished environmental quality from pollution externalities. For the time being, only few applied economic studies focus on this topic. Agricultural economics literature on pesticide use is concentrated especially on yield losses caused by pest damages and economics evaluations of banning pesticides as revealed by Sexton, Lei and Zilberman (2007).

1.4. Literature Review

An official recognition of the necessary tradeoffs between short-term productivity and long-term sustainability will not result to the threatening of long-term agricultural production. Therefore, in French Agriculture, 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). 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. 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.

Indeed, when analyzing the academic literature, two approaches emerge. On one hand, a view, known as the "Porter hypothesis" (Porter, 1991; Porter & van der Linde, 1995) affirm that stringent environmental standards can spur innovations which enrich competitiveness and contribute to making firms more profitable. This virtuous mechanism is said to lead to the so-called "win-win" situation in which both a better environment and a higher financial performance are achieved. This view has benefited over the past decades from a growing interest among politicians and practitioners. On the other hand, conventional economic thinking suggests that introducing more rigid environmental regulations always implies some private costs, since it displaces firms from their first-best and forces them into a more compromised position. Porter challenged this view, claiming that just the opposite might be true. His main argument was that environmental regulations can open up new investment opportunities, encourage decision makers to innovate and generate long-term gains that can partly or more than fully offset the costs of complying with them. This claim is now commonly known as the Porter Hypothesis. Porter's view has received a skeptical response from economists working within the bounds of standard economic theory. They are of the opinion that since firms are always willing to implement changes that they see as beneficial, if producing environmentally friendly products were really as profit-enhancing as Porter claims it to be, then they would have moved in that direction on their own accord without governmental interference. In the face of such skepticism, other economists have recently portrayed a number of scenarios for which the Porter result may hold (Francisco et al., 2009).

In French farming systems, measures for increasing the competitiveness of the agricultural sector dominate (Latruffe, 2010). In the economy, competitiveness is seen as a balance between the use of resources, operations management and human resource management, which are expected to strengthen farmers to compete more effectively. Control over resources (Barney, 1991), management skills, organisational process and routines, information and knowledge (Barney et al., 2001) are keys for gaining competitive advantage. Efforts to analyze this competitiveness among French crop producers have already been made [Saint-Ges and Bergouignan (2009), Jacquet et al. (2011)]. These studies emphasize that during the next ten years, the goal of a 50% reduction in the use of pesticide by farmers can be achievable if they can embrace the challenge of developing a more productive and yet environmentally attractive production practices. Essentially, this entails an improvement in the efficiency with which pesticides (and other inputs) should be used in a sustainable manner (Gregory and Ingram, 2000) thus ensuring a potential cost reduction for farmers and of course invoking a sound effect on the environment. This therefore contributes to a positive effect on the health of the farmers and the society at large.

In 2007, the Environment Round Table, i.e. "Grenelle de l'Environnement", proposed more than 250 environmental commitments. The French government made an important commitment to reduce the use of pesticides by 50% during the next ten years. Nevertheless, the use of pesticides is often the only means for farmers to maintain their yields by a better control of pest damages.

In this context, the evaluation of the effect of a reduction in pesticide use on agricultural production raises the question of how to take account of the possible changes in the production techniques used by farmers. Most of the recent work on analyzing the effects on European agriculture of a reduction in pesticide use based on economic simulation models does not consider this aspect. Because of this they lead to the conclusion that reinforcement of the regulation of pesticides would have dramatic consequences on the supply of agricultural products and farmers' income (Nomisma, 2008; Adenauer and Witzke, 2008). However in Europe, particularly Denmark, there have been successes with policies for reducing pesticides allowing significant reduction without harm to production or to farmers' income (Neumeister, 2007; Nielsen, 2005). Taking account of farmers' change of practices in the analysis of the effects of medium and long-term policies is the main difficulty of approaches based on econometric estimations (Carpentier, 2010).

From this point of view, mathematical programming has the advantage of allowing an analysis of modifications in the production decisions of farmers, independently of what has already been observed in the past. A detailed representation of the production technologies can be embodied in the economic models. It thus makes it possible to study the environmental impacts of agricultural production considering the joint production of agricultural outputs and environmental externalities. This explains why this approach has been adopted by many economists analyzing the impacts of changes in agriculture practices on the environment (Falconer and Hodge, 2001, Havlik et al., 2005, Buysse et al., 2007, Peerlings and Polman, 2008, Van Calker et al., 2008, Mosnier et al., 2009). However it is difficult to obtain the data needed for such analysis at an aggregated level. Consequently, the economic studies addressing the issue of pesticide use reduction are generally based on data from observations on a few farms, or data from agronomic experiments (Falconer and Hodge, 2001, Kerselaers et al., 2007, Van Calker et al., 2008).

In the specific context of one of the départements under study (Meuse département), the percentage of cost savings gotten as well as percentage of pesticide reductions totally converge with the conclusions drawn by Saint-Ges and Bergouignan (2009) at the farm level and Jacquet et al. (2011) at the national level for crop activities. Despite the dissimilarity between these approaches with respect to the regions, periods under consideration, types of farming systems and the cost definitions, they corroborate the fact it is possible to reduce the amount of pesticide use per hectare without incurring additional production cost. Hence with a more competitive cost arising from the adoption of low input strategy, a win-win strategy can be achieved due to its great environmental impacts. Jacquet et al. (2011) described low-Input alternative techniques by combining statistical data and expert knowledge. Their data are used in a mathematical programming model to simulate the effects on land use, production and farmers' income of achieving different levels of pesticide reduction. Their result supports low pesticide use by farmers with the possibility of not having a negative effect on income. In addition, they noted that on the average, high use of pesticide appears not to be as efficient as techniques supporting low pesticide usage.

This thesis distinguishably adds to the numerous economic literatures by comparing the practicing farms of both intensive and extensive technologies and it reveals that farms under an extensive technology scenario dominates the intensive one in terms of cost. With respect to this, the implementation of more environmentally friendly practices can be adopted by farmers and it becomes a more interesting preference because this practice tends to be more efficient in terms of costs. Although it is not easy to take a broader view of these results in coherence with all European agriculture, the results established in French agriculture are also in conformity with the case of Dutch sugar beet growers (De Koeijer et al., 2002) where a positive correlation was found between managerial and environmental efficiencies and thus highlighting substantial potentialities to improve the sustainability of arable farming by better management. In a research by Pretty et al 2003, they examined the extent to which farmers have improved food production in recent years with low cost, locally available and environmentally sensitive practices and technologies. It is therefore very interesting to note that 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 exposes encouraging advances in the acceptance of practices and technologies that are likely to be more sustainable with substantial benefits.

Suffice to note that sustainable farming systems must obtain high yields while minimizing environmental influence through the implementation of a strategy that settles for a low pesticide use per hectare of farm land surface thus ensuring efficiency in terms of production cost. To affirm this, Gregory et al. (2002) stressed that environmental advantage of low external inputs systems may not occur if their outcomes are expressed per unit of product rather than per unit area. Therefore, new practices seek to limit environmental impacts and thereby increase the efficiency of external input costs in crop activities since fertilizers, manures and pesticides remain considerable challenges. Hence, the real challenge is to develop more productive agricultural practices that focus on the importance of developing technologies and practices that are environmental friendly, are accessible to and cost effective for farmers, and lead to improvements in food productivity. Notably, this means improving the efficiency with which pesticides (and other inputs) should be used in a sustainable manner (Gregory and Ingram, 2000) thereby ensuring the potential of cost reduction for farmers which constitutes the heart of this thesis.

1.5. Aim

Since pesticide application is a means of pest control, it is crucial to suggest the best technology for the farmers in terms of cost competitiveness thus allowing for both better management and good ecological improvement. It is therefore discovered that low pesticide use technology is more competitive in terms of cost than high use of pesticide. Productivity and cost-efficiency are often cited as indicators or measures of competitiveness, and the European Commission considers it as the most reliable indicator for competitiveness over the long term (European Commission, 2008). However, in empirical studies of productivity and efficiency in general, no explicit reference to competitiveness is made. A general definition of productivity is the ability of production factors to produce the output. It can be simply measured as a partial productivity indicator, relating output to one input (e.g. yields or partial productivity of labour), but this does not account for the possibility of either factor substitution or output substitution. By contrast, the more comprehensive measure of total factor productivity (TFP) (sometimes called the multi-factor productivity, MFP) is a ratio that relates the aggregation of all outputs to the aggregation of all inputs. Potential productivity improvement is evaluated when firms are compared to a benchmark. In cross-section data, firms are compared with each other in the same period which means that a firm can increase its productivity in comparison with other firms by improving its efficiency and/or by reaching an optimal scale of operation. This is shown in Figure 5 and it depicts a simple single output-single input case. The production function relating the output produced, y, with the input used, x, indicates the maximum output produced for a given level of inputs (the production possibilities).

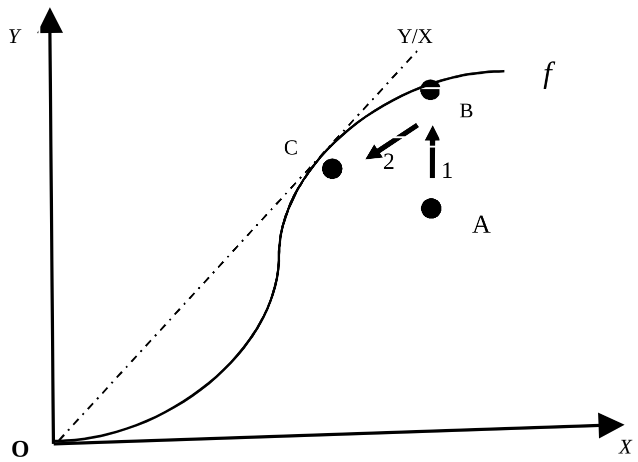

Figure 5: Productivity improvement for a firm

The components of productivity improvement entail efficiency increase and economies of scale which are explored below.

- ✓ *Efficiency increase*

In comparison with other firms, productivity improvement can result from more efficient use of the existing technology. In Figure 5, firm *A*, for example, would be able to produce more output with the same input use, that is to say it could use its input in a more efficient way. This is depicted by a movement from *A* towards the frontier *f*, parallel to the y-axis (movement 1). The movement could also be parallel to the *x*-axis and would correspond to a decrease in input use while the same output is produced. Clearly, the closer a firm operates to the frontier, the more efficient it is. Efficiency is therefore a measure of the distance from a given observation to the frontier. Firms operating on the frontier are said to be fully efficient in their use of inputs, e.g. firms *B* and *C*, and those operating beneath it are inefficient, e.g. firm *A*. This notion of efficiency refers to the neoclassical efficient allocation of resources and the Pareto optimality criterion. Considering a firm that uses several inputs and produces several outputs, it is efficient in the way it allocates its resources if a reduction in any input requires an increase in at least one other input or a reduction in at least one output (Lovell, 1993).

✓ *Exploiting economies of scale*

Economies of scale are reductions in average costs from increasing the scale of production, i.e., scale economies are present if $C(\lambda y) < \lambda C(y)$, where $C(y)$ = the cost function, y = output, and λ = a scalar > 1 (Panzar and Willig, 1977). This definition corresponds to the decreasing part of the familiar U-shaped cost function from economic theory. As inferred from figure 5, a second productivity improvement for a firm when compared with other firms can be achieved by exploiting economies of scale. Potential economies of scale can be identified by the scale elasticity, calculated as the ratio of the proportionate increase in output to the proportionate increase in all inputs. At point *C* the elasticity of scale is one and therefore firm *C* has an optimal scale. Firm *B* by contrast has an elasticity of scale less than one and therefore exhibits diseconomies of scale, while a firm situated on the left of *C* would have scale elasticity greater than one and hence exhibit economies of scale. Exploiting economies or diseconomies of scale is therefore a productivity improvement, characterized by a movement on the frontier *f* (movement 2 for example).

The above components of an improvement in productivity are used in assessing the cost competitiveness of farmers thus the effect of a reduced pesticide use on their cost of production which is the subject of this thesis is known. With this, cost functions are estimated thanks to a non-parametric activity analysis model (AAM) which helps to describe the performance of the efficiency situation of the farmers. Cost efficiency for a given farm is the ratio of the costs of a farm operating on the cost frontier (having the same output quantities and input prices) to the given farm's actual costs. Thus, the production of empirical evidence on farm efficiency is important for farmers' possibility to decrease their costs, or increase or maintain their output. Knowledge on the personal and environmental characteristics that influence farm performance can also be informative for policy and decision makers alike to create measures that can be designed to meet policy objectives. In the French farming system, increasing efficiency through the reduction of pesticide use by farmers is among the highly prioritized objectives of the French government.

Efficiency studies are a common way of analyzing the performance of agricultural production where highly efficient farms are considered to have higher probability of survival. Efficiency studies have been used to examine the importance of input utilization in gaining higher competitiveness and to identify factors that influence farm performance. Farm and farmer characteristics are the most important explanatory factors for attaining higher efficiency (Alvarez and Arias, 2004; Bojnec and Latruffe, 2009; Gorton and Davidova, 2004; Hansson, 2007c; Hansson, 2008a; Olson and Vu, 2009; Wilson et al., 2001; Bravo-Ureta and Evenson, 1994; Carvahlo et al., 2008). In other studies (Brümmer and Loy, 2000; Rezitis et al., 2003; Kleinhanß et al., 2007; Zhu et al., 2008), the implications on farm performance of different policy measures to strengthen the competitiveness of the agricultural sector have been analyzed, and suggestions for possible policy improvements have been offered. During the past decade, farm performance has been of great interest. Empirical evidence on the performance of farms and the factors influencing their performance has been seen important for efficiency in production. Existing studies are mainly focused on providing empirical evidence on: i) farm efficiency level; ii) the effect of outliers on efficiency scores (Bojnec and Latruffe, 2007); ii) how farm efficiency is influenced by types of crops produced (Latruffe et al., 2005); iii) the influence of farm size (Bojnec and Latruffe, 2007) and farmers' personal characteristics (Munroe, 2001) on farm efficiency.

This thesis contributes to the existing studies with the following objectives: (1) To provide empirical evidence as regards the cost efficiency performance of French crop producers and 2) to evaluate the potential impact of a reduced pesticide use on farmers' cost efficiency. Due to the fact that there is conflict of interest between individual farmers and society, an initial study (Paper I) attempts to find out if extensification is (or not) a more economically competitive practice than intensification in French agriculture (using Meuse Département as a case study) observed on a sample of 600 farms over a 12 year period. In addition, paper I also seeks to know if there is coherence between the economic interest of the farmer in terms of cost decrease and the global benefit of society in terms of pesticide reduction per hectare. Furthermore, paper II entails the evaluation of the differences in pesticide practices among cost efficient farmers in order to select the best practice in pesticide use, thus contributing to the fact that it is very possible for farmers to be cost efficient with either more or less pesticide use based on the substitution possibilities between land and chemical inputs (pesticides, fertilizers). More precisely, paper III discovers the direct-cost competitive advantage attached to low pesticide consumption in preference to high consumption of pesticide in French agriculture. This is different from paper I in the sense that it made use of 707 farms located in the Eure & Loir Département for only year 2008 and it follows that cost estimations are done empirically to assess the comparisons between two technologies characterized by different levels of pesticide per hectare. In addition, paper III laid more emphasis on the fact that pesticide cost should not be endogenously incorporated like other conventional inputs since they do not enhance productivity directly as compared to other standard inputs which has direct effect on productivity.

1.6. Thesis outline

This thesis is therefore based on four chapters comprising chapter one which entails the assessment of pesticide use in French crop farming systems through Non Parametric Cost Function Estimations and covers seven sections. Papers I-III comprises the subsequent chapters. Following this introduction, methodological aspects that contain efficiency analysis approach involving the presentation of basic models are detailed in Section 2 while section 3 gives an extension of the basic models discussed in section 2. Results and analysis are presented in

Section 4 with some conclusions drawn in Section 5. The overall contributions of the thesis are described in Section 6 while topics for further research are proposed in Section 7.

2. Efficiency Analysis Approach: Presenting the basic Models

Decision criteria play an important part in policy and planning process. One criterion that has tended to dominate contemporary policy development and evaluation is economic efficiency. The measurement of this economic efficiency has been intimately linked to the use of frontier functions. The modern literatures in both fields begin with the same seminal paper, namely Farrell (1957).

2.1. Different definitions of efficiency concepts

The recent literature has generated a wide variety of developments in non-parametric estimation of production and cost frontiers. Many of these efforts have concentrated on the statistical properties of the efficiency estimators, which were often naively depicted as deterministic in nature. A variety of different approaches to the measurement of technical efficiency coexist in the literature. Methodologically, they are categorized according to at least two criteria. First, one distinguishes between stochastic and deterministic methods. While the former make explicit assumptions with respect to the stochastic nature of the data, the latter do not. A second classification differentiates between parametric and non-parametric methods. In the parametric approach it is assumed that the boundary of the production possibility set can be represented by a particular functional form with constant parameters. The non-parametric approach on the contrary concentrates on the regularity assumptions of the production possibility set itself. Imposing some plausible restrictions on the production process, the latter methods directly construct a piecewise linear reference technology or best practice frontier on the basis of observed input-output combinations.

Michael J. Farrell, greatly influenced by Koopmans (1951)'s formal definition and Debreu (1951)'s coefficient of resources utilization introduced a method to decompose overall efficiency of a production unit into its technical and allocative components. Farrell characterized the different ways in which a productive unit can be inefficient either by obtaining less than the maximum output available from a determined group of inputs (technically inefficient) or by not purchasing the best package of inputs given their prices and marginal productivities (allocatively inefficient). Technical efficiency for a given firm is thus defined as the ratio of the input usage of a fully efficient firm producing the same output vector to the input usage of the firm under consideration. Productive efficiency can be decomposed into Technical efficiency (TE), i.e., efficiency relative to a variable returns to scale (VRS) frontier, and scale efficiency (SE), the distance between the VRS frontier and the Constant Returns to Scale (CRS) frontier.

The concept of technical efficiency is connected to a particular interpretation of the production function. Coupled with the technically possible frontier of the assessed unit, this function specifies the minimal level of inputs necessary to reach the observed level of outputs. Based on the best practices of the considered group, this benchmark defines a concept of relative efficiency which is not an absolute standard (Blancard, et.al. 2006). Figure 6 reveals that efficiency is given by the distance from the observed position of the entity, or more commonly, of the decision making unit *(DMU)*, to its production frontier.

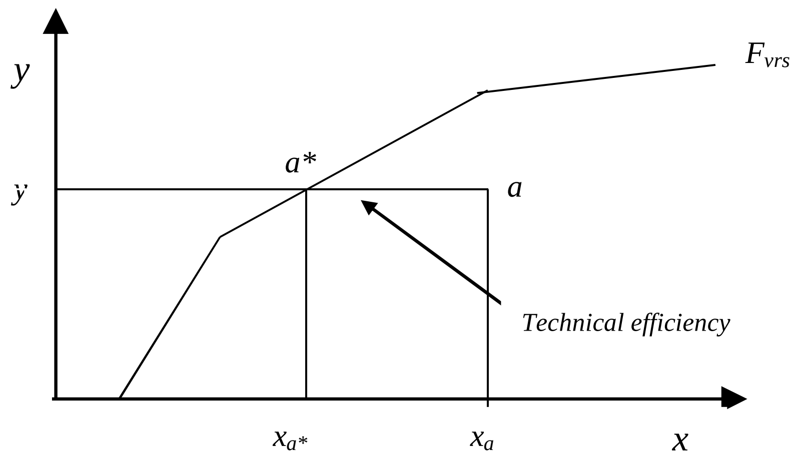

Figure 6: Production frontier and technical efficiency

According to this figure (6), if DMU *a* adopted the best practices of the group determined by the production frontier under variable return to scale assumption (F_{vrs}), it could reduce its inputs x_a to x_a^* maintaining its production quantity y_a. Its level of relative inefficiency $(1\text{-}f_a)$ measures the percentage of achievable economies on its total expenditure with:

$$\frac{x_{a*}}{x_a} = f_a$$

To determine the maximum level of productivity of *DMU a*, a production frontier with constant return to scale *(F_{crs})* tangent to the previous production function *(F_{vrs})* must be added.

In figure 7 below, it can be noted that in spite of the efforts of good input management in *a**, *DMU a* suffers from too big a size to obtain the maximum level of productivity observed with *DMU b* which is its optimal size. To reach such a level of productivity, it is necessary to reduce the inputs to x_{a**} and to project DMU *a* to *a*** on F_{crs}. The total efficiency given by the ratio $g_a = (x_{a**}/ x_a)$, $(1-g_a)$ measures the percentage of feasible economies on the whole of its inputs to reach the maximum level of productivity. Following Banker et al. (1984), this productive technical inefficiency breaks down into two components, the technical inefficiency measured as previously by $(1-f_a)$ and the scale inefficiency $(1-h_a)$ such that:

$$\frac{x_{a**}}{x_a} = g_a, \frac{x_{a*}}{x_a} = f_a, \frac{x_{a**}}{x_{a*}} = \frac{g_a}{f_a} = h_a$$

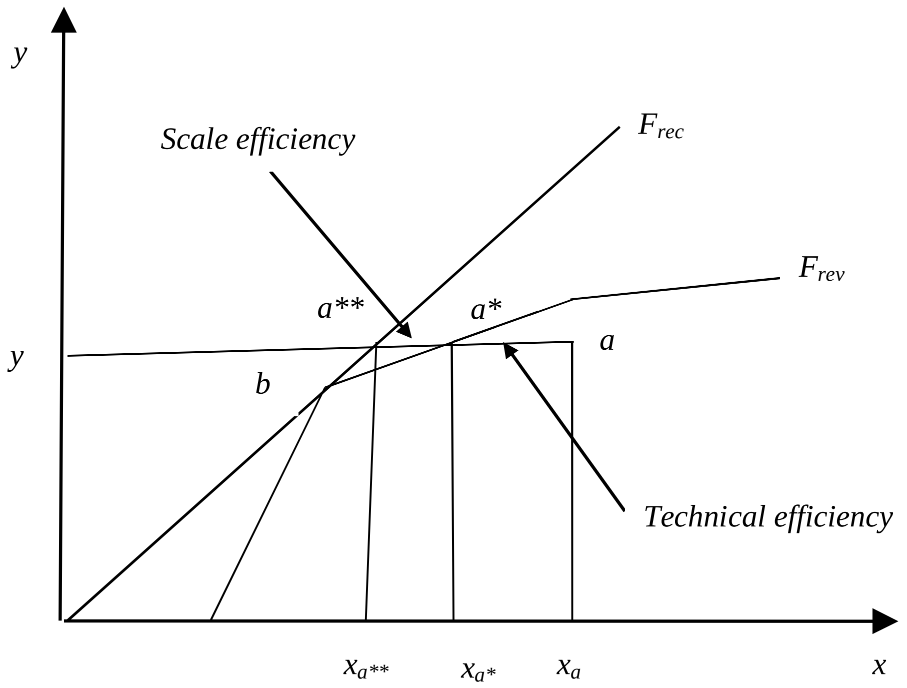

Figure 7: Return to scale and decomposition of total efficiency

Therefore, it seems so natural to think that an inefficient firm will prefer to visit the efficient firm that is most similar to it, rather than an efficient but very different firm. The most similar the efficient firms, the easier it will be for the inefficient firm to detect its own mistakes and therefore to correct them, hence under *VRS* frontier, a *DMU* can only be benchmarked against *DMUs* of a similar size (Coelli et al., 2005). Most empirical studies of Technical Efficiency *(TE)* use radial measures to quantify efficiency. Thus, it may be argued that the most similar firm is the radial projection of the inefficient firm on the isoquant. Radiality seems to be a reasonable proxy for similarity, because all firms on the same ray share the same combination of inputs. Furthermore, it has been noticed that radial measures impose a direction for improvement that does not take into account the information on input substitution possibilities that is available through empirically constructed isoquant (Bogetoft and Hougaard, 1999).

Another concept of efficiency is called cost efficiency or economic efficiency and it can be achieved when farms find a combination of inputs that enables them to produce their desired outputs at minimum cost. Hence cost efficiency is the product or mixture of the technical and allocative efficiencies which depends on output vector (y) and price of inputs (w), the cost function is thus expressed as: $C = C(y,w)$. Farms therefore achieve cost efficiency by adopting the best practice technology (becoming technically efficient) and choosing the optimal mix of inputs (becoming allocatively efficient (AE)) (Banker and Maindiratta, 1988). CRS cost efficiency is the product of technical, scale, and allocative efficiency: $CE_{CRS} = TE*AE*SE$. Revenue efficiency is defined as the ratio of the revenues of a given firm to the revenues of a fully efficient firm with the same input vector and output prices. Finally, profit efficiency is defined in terms of the firm's actual profits and optimal profits, i.e., the profits that could be obtained if the firm were fully efficient.

In addition, cost and profit efficiency definitions correspond, respectively, to two important economic objectives: cost minimization and profit maximization. Cost efficiency is the ratio between the minimum cost at which it is possible to attain a given volume of production and the cost actually incurred. Thus, an efficiency value of Ec implies that it would be possible to produce the same vector of production, saving *(1-Ec).100%* of the costs. Efficiency ranges over the *(0,1)*interval, and equals one for the best-practice farms in the sample. Profit efficiency is a broader concept than cost efficiency since it takes into account the effects of the choice of a certain vector of production both on costs and on revenues. It is therefore a useful metric because profit maximization is the ultimate goal of the firm and because profit efficiency shows the net effects of cost and revenue efficiency. However, it is also very important to estimate cost and revenue efficiency in order to trace the sources of inefficiency and test separately for cost and revenue economies of scope (Cummins et al., 2010).

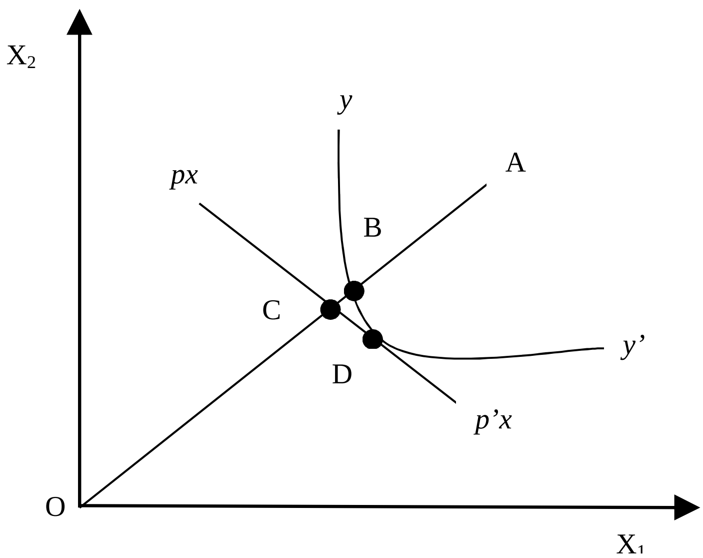

Figure 8: Economic efficiency in the input-oriented context

This figure (8) illustrates the economic efficiency in two-input oriented scenario where *yy'* represents the production frontier that captures the minimum combination of inputs needed to produce a unit of output. X_1 and X_2 are the two inputs used to obtain one output while *pxp'x* is the isocost line whose slope is the ratio of input prices (-px1/px2). Units that are technically efficient will be located at the frontier while those below the frontier are not technically efficient since they obtain less output than technically possible. The technical efficiency measure can be estimated as the relationship between the obtained output and what would be attained if the unit were located at the frontier. Point 'A' is the observed farm that uses two input quantities to obtain the output. The isoquant *yy'* represent the various combinations of the two factors that a perfectly efficient farm might use to produce the same output. So, the farm 'B' represents an efficient farm that produces the same output as 'A' but using a fraction OB/OA of each factor. This is the technical efficiency (TE) of the farm A. If information on market price is known and cost minimization is assumed in such a way that the input price ratio is reflected by the slope of the isocost line, allocative efficiency can be derived from the unit isoquant. D is the optimal method of production and, as B, this point represent 100% of technical efficiency. However, the cost of production at B will be only a fraction, OC/OB of those at D. This is the measure of allocative efficiency (AE). The full economic efficiency (EE) is achieved for the farm operating at the tangency point between the isoquant and the price line (farm D). Farm economic efficiency score for A is given by the ratio OC/OA, which is derived by the product for technical and allocative efficiency, EE = TE*AE = OB/OA*OC/OB = OC/OA

2.2. Activity Analysis Model (AAM) defining the Production technology and Cost functions

In order to estimate efficient production, cost, and profit frontiers by providing measures of technical, cost, and profit efficiency for each farm, the application of an Activity Analysis Model (AAM) is utilized. Estimating farm efficiency is very useful for cost frontier comparisons, thanks to an AAM which aids in evaluating each firm in an industry to a ''best practice" efficient frontier formed by the most efficient farms in the sample. A farm is fully efficient (efficiency of 1.0) if it is on the frontier otherwise it is inefficient (efficiency < 1) if it is not on the frontier. The principal alternative to AAM is stochastic frontier analysis (SFA). AAM has several advantages over SFA as follows: (1) It avoids the choice of a functional form for the technical, cost, or revenue function and requires no distributional assumptions. Such assumptions can create specification errors. (2) It also works on multiproduct/multi-inputs technology on the primal quantity side i.e. no price needed (3) AAM does not impose economic assumptions for the estimation of the technology such as technical efficiency and allocative efficiency (contrary to a traditional production function or a cost function) (4) AAM is individual-farm based, making it easy to decompose efficiency by farm, which is particularly convenient for studying scope economies and (5) It provides a convenient way to decompose cost or revenue efficiency into their pure technical, scale, and allocative components.

From a sample of K DMUs and technology producing a vector y of R outputs $r \in \{1, 2, ..., R\}$ from a vector of I inputs $i \in \{1, 2, ..., I\}$, the basic assumptions of AAM as described by Charnes et al. (1978) are under listed:

(i) Convexity: If $(\mathrm{x,y}) \in T$ and $(\mathrm{x',y'}) \in T$ then $(\lambda(\mathrm{x,y}) + (1-\lambda)(\mathrm{x',y'})) \in T$ for any $\lambda \in [0,1]$

(ii) Monotonicity or strong free disposability of inputs and outputs:

If $\begin{array}{l} (\mathrm{x,y}) \in T \text{ and } \mathrm{x'} \geq \mathrm{x} \text{ then } (\mathrm{x',y}) \in T \\ (\mathrm{x,y}) \in T \text{ and } \mathrm{y'} \leq \mathrm{y} \text{ then } (\mathrm{x,y'}) \in T \end{array}$

(iii) Inclusion of observations: Each observed DMU $(\mathrm{x_k, y_k}) \in T,\ \forall \mathrm{k} \in \mathrm{K}$

(iv) No output can be produced without some input. If $\mathrm{y} \geq 0$ and $\mathrm{y} \neq 0$ then $(0, \mathrm{y}) \notin T$

(v) Constant returns to scale:

If $(\mathrm{x,y}) \in T$ then $(\lambda \mathrm{x}, \lambda \mathrm{y}) \in T$ for any $\lambda \geq 0$

(vi) Minimum extrapolation:

T is the intersection of all sets satisfying (i)-(v)

A technology *T(*x,y*)*, satisfying the assumptions, can be constructed from the observed input-output correspondences at *n* DMUs as follows:

$$T^{AAM}(\mathrm{x,y}) = \left\{ (\mathrm{x,y}) \mid \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_r \text{ for all } r, \sum_{j=1}^{n} \lambda_j x_{ij} \leq x_i \text{ for all } i,\ \lambda_j \geq 0 \text{ for all } j \right\} \qquad (1)$$

Suffice to say that this AAM approach also has attractive statistical properties. First, as shown in Banker (1993), it is a maximum likelihood estimator. Second, its estimators are consistent and converge faster than estimators from other frontier methods (Grosskopf, 1996). Third, the estimators of *AAM* are also unbiased if an assumption is made that there is no underlying model or reference technology. If one believes in an underlying model, then the problem of bias in *AAM* estimates arises, but this bias decreases with sample size (Kittelsen, 1999). Fourth, Banker and

Natarajan (2008) show that an *AAM* is a non-parametric stochastic frontier estimation methodology that performs better than parametric procedures in the estimation of individual decision making unit productivity. This therefore connotes that this frontier efficiency methodology measures the efficiency of each farm in the sample relative to ‘‘best practice” frontiers consisting of the dominant (most efficient) farms in the sample. Assuming that farms *“abcd”* are more cost efficient than farms *“efgh”*, the implication is that *“abcd”* can produce their outputs at lower costs than if these outputs were to be produced by *“efgh”* farms (and vice versa if farms *“efgh”* are more cost efficient). Likewise, if *“abcd”* are more revenue efficient, the implication would be that they can generate more revenues, conditional on inputs, than *“efgh”* farms. Profit efficiency represents the net impact of cost and revenue efficiency and this shows the net importance of the cost and revenue effects. However, as earlier noted and as inferred by Cummins et al., 2010, it is very important to estimate cost and revenue efficiency separately in order to trace the sources of inefficiency.

In view of the afore mentioned, it is expedient to state that a focus is kept on cost frontier estimations and based on the assumption of being a price taker for the output prices, then a farm that is efficient in terms of profit will also be efficient in terms of cost. Cost efficiency analysis is therefore conducted in this thesis for papers I, II and III and most specifically, it is conducted in a two-step process in paper II as devised by Cazals, Florens and Simar 2002. The efficiency coefficients were calculated which thus selects the cost efficient farms in a first step. In a second step, the units that minimize the pesticide use per hectare while maintaining constant yields were revealed from the cost efficient farms selected in step1. Different cost efficient practices among farmers were evaluated in terms of pesticide per ha and the minimum uses were selected. This explains the fact that in terms of pesticide use per ha, all the diverse cost efficient practices among farmers were evaluated with the best ones selected and a regression analysis is used as a sub-staged step to describe the potential pesticide reductions by a common set of explanatory variables. This will help the farmers which constitute the targeted stakeholders to make a decision on whether or not to reduce their usage of chemical inputs. In French Agriculture, improved farm efficiency in terms of better input utilisation and achieving higher output at a reduced cost is expected to be achieved through the implementation of a technology that enhances a reduced use of pesticide inputs by farmers. Cost efficiency was estimated and the cost frontier comparison was implemented with the application of:

1) An *AAM* or a non parametric frontier analysis (notably *DEA*) through the development of an analytical framework to estimate cost functions empirically as initiated by Koopmans (1951) and Baumol (1958). (For Paper I)
2) A traditional Linear Program *(LP)* is solved to compute *FDH* efficiency scores since *LP* is much more efficient in solving optimization problem than Mixed Integer Problem *(MIP)* as noted by Agrell and Tind (2001) and Leleu (2006). (For Paper II)
3) A non-parametric activity analysis model *(AAM)* to estimate the cost functions as originated by Koopmans 1951; Baumol 1958 and a robust approach frontier is introduced to limit the sensitivity of the cost frontier to the influence of potential outliers as inspired by Simar and Wilson (2008). (For Paper III)

A number of studies have already set out to analyse how the efficiency of agricultural firms has evolved in recent years. Results are mixed, as these studies measure different types of efficiencies, using different techniques (parametric/non-parametric), different measures and definitions of inputs and outputs. Yet it seems that inefficiencies persist, and have quite a dynamic nature, since changes continue to take place. Both parametric and non-parametric techniques have been widely used, and the consensus is that neither technique is better than the other. Specifically, parametric techniques have the advantage that they allow for random error but the drawback that they impose a particular functional form that presupposes the shape of the frontier. On the other hand, non-parametric techniques tend to envelope data more closely, but they do not allow for random error. Data Envelopment Analysis *(DEA)* is one of the most widely used among the latter. This inability to allow for random error has induced many authors to label it as deterministic.

2.3. Production and Cost frontier estimations using non parametric (DEA) model

Estimation of production frontier is usually based either on the nonparametric data envelopment analysis (*DEA*: Farrell, 1957; Charnes et al. 1978) or on the parametric stochastic frontier analysis (*SFA*: Aigner et al., 1977; Meeusen and van den Broeck, 1977). While traditional SFA builds on the parametric regression techniques, *DEA* is based on linear programming formulation that does not assume parametric functional form for frontier, but relies on general regularity properties such as monotonicity and convexity. Although both *DEA* and *SFA* have their own weaknesses, it is generally accepted that the main appeal of *SFA* is its stochastic, probabilistic treatment of inefficiency and noise, whereas the main advantage of *DEA* lies in its absence of functional form for the frontier.

In recent years, many new semi and nonparametric stochastic frontier techniques have been developed both to relax some of the restrictive assumptions used in fully parametric frontier models and to narrow the gap between *SFA* and *DEA*. It is indeed noteworthy that most of the literature related to the measurement of this economic efficiency has based its analysis either on parametric or on non-parametric frontier methods. The choice of estimation method has been an issue of debate, with some researchers preferring the parametric and others the non-parametric approach (Luis R and Murillo-Zamorano, 2004). To measure the relative efficiency of farming systems, different parametric and non parametric techniques which have proven useful in a number of sectors and applications can be applied. Applied empirical work on efficiency and productivity measurement of individual firms is always confronted with the sensitivity of the results to the different approaches and assumptions. Therefore, to present the most robust image, diverse nonparametric model specifications are applied.

Data Envelopment Analysis *(DEA)* is a theoretically sound framework for performance analysis that offers many advantages over traditional methods such as performance ratios and regression analysis. Largely the result of multidisciplinary research during the last two decades in economics, engineering and management, *DEA* is best described as an effective new way of visualizing and analyzing performance data. Technically, it represents the set of nonparametric, linear programming techniques used to construct empirical production frontiers and evaluate the relative efficiency of production units. *DEA* is particularly effective in handling complex processes, where these units, customarily called Decision Making Units *(DMUs)*, use multiple inputs to produce multiple outputs. The starting point of the analysis is a production model. In its simplest form, it is constructed from the set of relevant inputs and desirable outputs of the process, together with some basic, standard assumptions on the nature of the production possibilities.

Thus, by analyzing the input/output data groups of programmers, *DEA* identifies: 1) The efficient frontier, or envelopment surface, consisting of the best practice units 2) Efficiency measures for each *DMU* that reflect its distance to the frontier 3) An efficient reference set, or peer group (a small subset of efficient units "closest" to the unit under evaluation), for each inefficient *DMU* 4) Efficient targets for each inefficient *DMU* (projections onto the frontier). Other important results that can be obtained from advanced *DEA* analyses include: returns to scale, technical and allocative inefficiencies (this requires the incorporation of specific managerial, perhaps subjective, goals into the analysis), managerial tradeoffs (marginal rates of substitution, etc.), productivity growth over time (time series analysis), and investigation of achievable targets for inefficient *DMUs*. Statistical tests are also customarily used to assess the effect of environmental variables or technological differences on efficiency, as well as the impact of efficiency on other factors important to managers, such as profitability, quality, etc.

In the originating study of Charnes, Cooper, and Rhodes (1978), they described *DEA* as a 'mathematical programming model applied to observational data [that] provides a new way of obtaining empirical estimates of relations - such as the production functions and/or efficient production possibility surfaces – that are cornerstones of modern economics'. Formally, *DEA* is a methodology directed to frontiers rather than central tendencies. Instead of trying to fit a regression plane through the centre of the data as in statistical regression, for example, one 'floats' a piecewise linear surface to rest on top of the observations. Because of this perspective, *DEA* proves particularly adept at uncovering relationships that remain hidden from other methodologies. For instance, consider what one wants to mean by "efficiency", or more generally, what one wants to mean by saying that one *DMU* is more efficient than another *DMU*. This is accomplished in a straightforward manner by *DEA* without requiring explicitly formulated assumptions and variations with various types of models such as in linear and nonlinear regression models.

As pointed out in Cooper, Seiford and Tone (2000), *DEA* has also been used to supply new insights into activities (and entities) that have previously been evaluated by other methods. For instance, studies of benchmarking practices with *DEA* have identified numerous sources of inefficiency in some of the most profitable firms - firms that had served as benchmarks by reference to this (profitability) criterion – and this has provided a vehicle for identifying better benchmarks in many applied studies. The main advantages of *DEA* are: (i) it allows the simultaneous analysis of multiple outputs and multiple inputs, (ii) it does not require an explicit a priori determination of a production function, (iii) efficiency is measured relative to the highest observed performance rather than against some average or ideal and (iv) it does not require information on prices.

In many recent papers, efficiency techniques are used and applied to different fields. Efficiency has been applied not just to measure efficiency itself but also for other purposes like capacity utilization (Vestergaard et al., 2002; Pascoe et al., 2001a,b), risk analysis (Herrero, 2004a,b), etc. This efficiency technique has both advantages and disadvantages relative to parametric efficient frontier techniques such as the stochastic frontier approach. As indicated earlier, the main advantage is that *DEA* allows technical and scale efficiency estimations without specifying a functional form, while being able to handle a multiple input- multiple output production process in a primal context without requiring any information on input/output prices. On the other hand, it is important to state that the disadvantage of the *DEA* technique is that it does not allow for deviations from the efficient frontier to be a function of random error. As such, *DEA* can produce results that are sensitive to outliers, model specification, and data errors, meaning that the major disadvantage of *DEA* is that they are susceptible to the influence of outliers.

In DEA, there are two measures of efficiency with different characteristics; radial and non radial. Historically, the radial models, represented by the CCR model (Charnes et al., 1978), was the first DEA model, while the non-radial models are the Färe asymmetric measure (1975), Fare-Lovell measure (1978), Zieschang (1984) and the SBM model (slacks-based measure by Tone, 2001). In the input-oriented case, the CCR deals mainly with proportionate reduction of input resources. For example, if a *DMU* has two inputs, this model aims at obtaining the maximum rate of reduction with the same proportion, i.e. a radial contraction in the two inputs that can produce the current outputs. In contrast, the non-radial models put aside the assumption of proportionate contraction in inputs and aim at obtaining the maximum rate of reduction in inputs that may discard varying proportions of the original input resources.

However, recent literature has silenced ''this tired refrain'', as Lovell (2000) defines it. In particular, Simar and Wilson (1998, 1999a, 2000) define a statistical model which allows for the determination of the statistical properties of the non-parametric estimators in the multi-input and multi-output case. The important practical implication of their findings is that statistical inference is possible. Hence, non-parametric methods to measure efficiency would still have all their advantages, but would somehow allow for random error. This possibility is opened up by bootstrap (Efron, 1979) a computer-intensive technique essentially based on the basic idea of approximating the unknown statistic's sampling distribution of interest by extensively resampling from an original sample, and then using this simulated sampling distribution to make population inferences. It is worth mentioning that stochastic *DEA* models (Land et al., 1993; Olesen and Petersen, 1995) also allow random disturbances to be incorporated in the input and output data as a measure of its productive efficiency.

The term 'productive efficiency' is commonly used to describe the level of performance of a production unit in terms of its utilization of input resources in generating outputs. Koopmans (1951) defined technical efficiency as a feasible input/output vector where it is technologically impossible to increase any output without simultaneously reducing another output i.e. Pareto Improvement. This analogy holds for a reduction in any input or both a reduction in any input and an increase in any output. Farrell (1957) demonstrated that a production unit 'overall efficiency' is composed of two separate efficiency measures called 'technical efficiency' and 'allocative efficiency'. Farrell measured technical inefficiency as the maximum equi-proportional reduction in all inputs consistent with equivalent production of observed output. A Farrell efficient unit however, may not be Koopmans efficient since even after Farrell efficiency is achieved, there may exist additional slack in individual inputs. Allocative efficiency is based on cost considerations namely input prices. The type of efficiency measured depends on the data availability and appropriate behavioural assumptions. When only quantities are available, technical efficiency can be calculated but when both quantities and prices are available, economic efficiency can be calculated and decomposed into technical and allocative components.

The DEA Techniques

DEA has proven to be a popular technique for performance analysis in general and in the agricultural sector in particular. In this regard, the agricultural sector has a series of characteristics that make it particularly suitable for study through *DEA*: its multiple-input and multiple-output nature, the irregularity of its input-output relationships, and the non-physical nature of some resources and products. Broadly speaking, the *DEA* technique defines an efficiency measure of a production unit by its position relative to the frontier of the best performance established mathematically by the ratio of weighted sum of outputs to weighted sum of inputs. The estimated frontier of the best performance is also referred to as efficient frontier or envelopment surface. The frontier of the best performance characterizes the efficiency of production units and identifies inefficiencies based on known levels of attainment. Thus, a production unit attains 100% efficiency only when it is not found to be inefficient in using the inputs to generate the output when compared with other relevant production units.

- *Basic DEA Models- the primal approach*

DEA begins with a relatively simple fractional programming formulation. Assume that there are *J DMUs* to be evaluated. Each consumes different amounts of *I* inputs and produces *R* different outputs, i.e. DMU_j consumes x_{ij} amounts of input to produce y_{rj} amounts of output. It is assumed that these inputs, x_{ij} and outputs, y_{rj}, are non-negative, and each *DMU* has at least one positive input and output value and that each input and output is used by at least one *DMU*. The productivity of a *DMU* can be written as:

$$h_j = \frac{\sum_{r=1}^{R} u_r y_{rj}}{\sum_{i=1}^{I} v_i x_{ij}} \qquad (2)$$

Where *h* refers to the efficiency, *j* is the *DMU* under study, x_{ij} the amounts of input consumed by DMU_j to produce y_{rj} amounts of output. In this formulation, *u* and *v* are the weights (shadow prices in economic terms) assigned to each input and output. By using mathematical programming techniques, DEA optimally assigns the weights subject to respectively two constraints, namely:

1- The weights for each *DMU* are assigned subject to the constraint that no other *DMU* has efficiency greater than 1 if it uses the same weights, implying that efficient *DMUs* will have a ratio value of 1.

2- The derived weights, *u* and *v* are not negative.

The CCR model of DMU_k is given by:

$$\begin{aligned} &\max_{u_r, v_i} h_k = \frac{\sum_{r=1}^{R} u_r y_{rk}}{\sum_{i=1}^{I} v_i x_{ik}} \\ &s.t. \\ &\frac{\sum_{r=1}^{R} u_r y_{rj}}{\sum_{i=1}^{I} v_i x_{ij}} \leq 1, \forall j \in J \qquad (3) \\ &u_r \geq 0, \forall r \in R \\ &v_i \geq 0, \forall i \in I \end{aligned}$$

This is a simple presentation of basic *DEA* model. According to Denizer, et. al. (2000), Charnes, Cooper and Rhodes (1978) employed the optimization method of mathematical programming to generalize the Farrel (1957) single-output/input technical-efficiency measure to multiple-output/multiple-input case. The characteristic of the Charnes, Cooper and Rhodes *(CCR)* ratio model is the reduction of the multiple-output/multiple-input situation for each *DMU* to a single virtual output and a single virtual input ratio. This ratio provides a measure of efficiency for a given *DMU*, which is a function of multipliers. The objective is to find the largest sum of weighted outputs of DMU_k, while keeping the sum of its weighted inputs at the unit value, thereby forcing the ratio of the weighted output to the weighted input for any *DMU* to be less than one.

$$\begin{aligned} &\max_{u_r, v_i} h_k = \sum_{r=1}^{R} u_r y_{rk} \\ &s.t. \\ &\sum_{r=1}^{R} u_r y_{rj} - \sum_{i=1}^{I} v_i x_{ij} \leq 0, \forall j \in J \\ &\sum_{i=1}^{I} v_i x_{ik} = 1 \\ &u_r \geq 0, \forall r \in R \\ &v_i \geq 0, \forall i \in I \end{aligned} \qquad (4)$$

The *CCR* model is also known as the constant return to scale model, and it identifies inefficient units regardless of their scale size. In the *CCR* models, both technical and scale inefficiency are present. Banker, Charnes and Cooper (1984) take into account the effect of returns to scale within the group of *DMUs* to be analysed. The purpose here is to point out the most efficient scale size for each *DMU* and at the same time to identify its technical efficiency. To do so, the Banker, Charnes and Cooper *(BCC)* model introduces another restriction (i.e. returns to scale) to the envelopment requirements and with this the constraint $\sum_{j=1}^{J} \lambda_j = 1$ is adjoined to the CCR models thus making it to be a BCC one. This model requires that the reference point on the production function for DMU_k will be a convex combination of the observed efficient *DMUs*. The *BCC* model, known as variable returns to scale model, gives the technical efficiency of *DMUs* under investigation without any scale effect.

In addition, it is possible to use models that provide input-oriented or output-oriented projections for both *CCR* (constant returns to scale) and *BCC* (variable returns to scale) envelopment. An input-oriented model attempts to maximize the proportional decrease in input variables while remaining within the envelopment space. On the other hand, an output-oriented model maximizes the proportional increase in the output variables, while remaining within the envelopment space. In order to simplify exposition, input space would be focussed on, however, the concepts described for the input space transfer easily to the output space. The linear program for calculating the technical efficiency in the input requirement space is illustrated in Model 5 below. A Shephard's input-distance function considers by how much the input vector may be proportionally contracted with the output vector held fixed. The input distance function may be defined on the input set, $L(y)$, as: $D_I(x, y) = max \{ \rho : (x/ \rho \in L(y) \}$ where ρ is the scalar "distance" by which the input vector can be deflated, and the input set L(y) represents the set of all input vectors, $x \in R_+^I$, which can produce the output vector, $y \in R_+^R$, That is, $L(y) = \{x \in R_+^I$: x can produce $y\}$. The Farrell efficiency measure is the inverse of the Shephard input distance function $\theta = 1/ \rho$. The Farrell efficiency measure for DMU_k is computed by the following linear program:

$$
\begin{aligned}
&\underset{(\theta_k,\lambda_j)}{Min}\, \theta_k \\
&\sum_{j=1}^{J} \lambda_j y_{rj} \geq y_{rk}, \forall r \in R \\
&\sum_{j=1}^{J} \lambda_j x_{ij} \leq \theta_k x_{ik}, \forall i \in I \qquad (5) \\
&\sum_{j=1}^{J} \lambda_j = 1 \\
&\lambda_j \geq 0, \forall j \in J
\end{aligned}
$$

Here, θ_k is the efficiency level. The linear program is solved once for each observation, $i = 1,...,J$ to compute the efficiency for that observation.

- *Basic DEA Models- the dual approach*

One important characteristics of DEA is its dual side, as represented by the dual program of the original linear program. This links the efficiency evaluation with the economic interpretation. Whenever Linear Programming *(LP)* problem is solved, then two problems are implicitly solved: the primal resource allocation problem, and the dual resource valuation problem. The study of duality is very important in *LP*. Knowledge of duality allows one to develop increased insight into *LP* solution interpretation. Also, when solving the dual of any problem, one simultaneously solves the primal (Mc Carl and Spreen, 2002). Thus, duality is an alternative way of solving *LP* problems. For example, the dual of model (4) is represented below:

$$\begin{aligned}
&\max_{u_r, v_i, u_0} h_k = \sum_{r=1}^{R} u_r y_{rk} + u_0 \\
&\sum_{r=1}^{R} u_r y_{rj} - \sum_{i=1}^{I} v_i x_{ij} + u_0 \leq 0, \forall j \in J \\
&\sum_{i=1}^{I} v_i x_{ik} = 1 \qquad\qquad\qquad\qquad (6) \\
&u_r \geq 0, \forall r \in R \\
&v_i \geq 0, \forall i \in I
\end{aligned}$$

The dual in (6) is specified for a *VRS* technology, and the variables u_r and v_i in this dual model represent the weights that DMU_k "assigns" to each one of its inputs and outputs so that its efficiency will be maximized. If the primal problem has *J+1* variables and *I+R+1* resource constraints, the dual problem will have *I+R+1* variables and *J+1* constraints. Dual variables can be interpreted as the marginal value of each constraint's resources. These dual variables are usually called shadow prices and seek to find the best method of the shadow prices needed to maximize the shadow profits of the farm under the constraint that no other farm could get a positive profit with these vector prices.

2.4. Basics of FDH

The Data Envelopment Analysis (DEA) approach is based on a linear combination of input and outputs in order to specify the efficiency frontier. Convexity of the set of input-output combinations is assumed since this method constructs an envelope around the observed combinations. Among the different non-parametric methods the Free Disposal Hull *(FDH)* technique imposes the fewest restrictions and it was a model which was originally designed as an alternative to *DEA* models.

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 technology 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 k, the output-input space can be partitioned into four quadrants as it is drawn in figure 9. The more efficient region pools all the possible situations which produce more than DMU k 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 k. 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 10). Here, we see that 'a', 'c', and 'e' represents the efficient DMUs in the sense that no other DMU dominate them while 'b' and 'd' represent the inefficient ones as they are

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

dominated by some of the efficient ones. For example, ‘a’ and ‘c’ belong to the more efficient region of b.

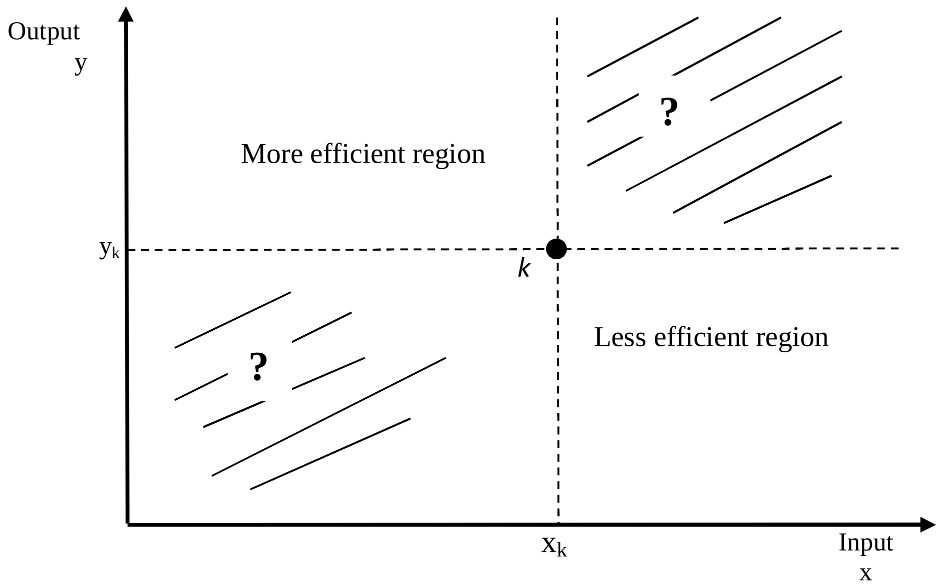

Figure 9: Dominance regions for an evaluated DMU

Third: for the illustrative case of one output and one input (see figure 11), FDH production set adds to (figure 10) 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”.

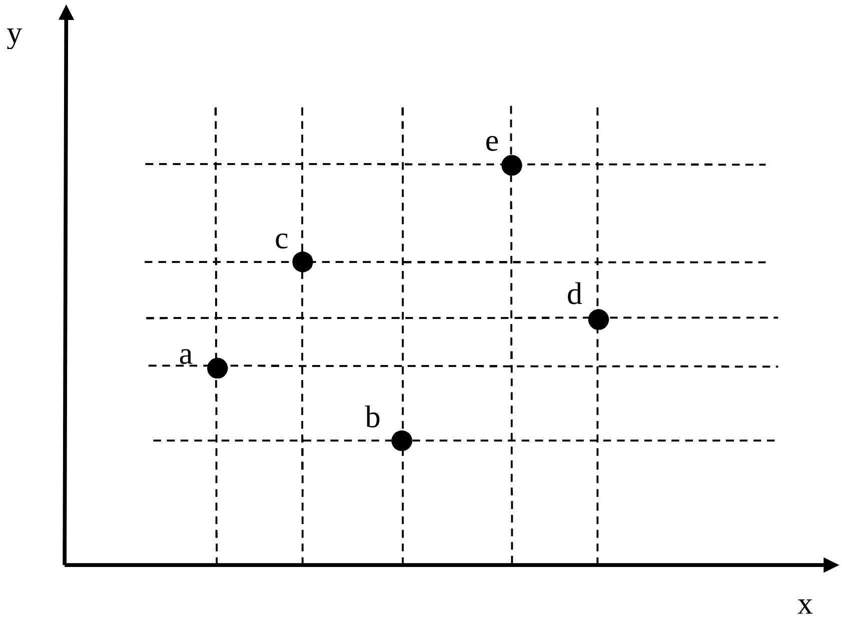

Figure 10: Efficiency comparisons among observed DMUs

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.

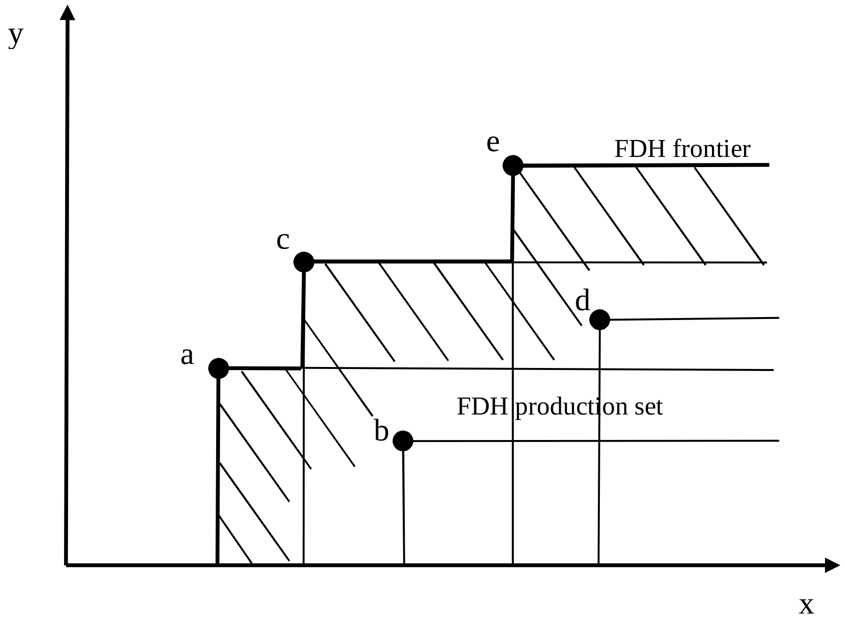

Figure 11: The production frontier of a strongly disposable FDH model

As introduced by Deprins et al. (1984), their main contribution was to relax the convexity assumption of DEA models. As such, the *FDH* model was initially presented as a variable returns to scale *(VRS) DEA* model in which activity variables were binary (Leleu, 2006). It follows a stepwise approach to construct the efficiency frontier. Comparing the two approaches the *DEA* method tends to assign fewer efficiency than the *FDH* method does.

Deprins, Simar and Tulkens (1984) suggested the Free Disposal Hull *(FDH)* as a new deterministic and non-parametric reference technology for the evaluation of technical efficiency. Compared to other existing methods, the FDH requires minimal assumptions with respect to the production technology. For example, it does not require convexity as opposed to the popular Data Envelopment Analysis *(DEA)* models. Convexity is assumed in most economic models of production, but there is some debate in the literature as regards the validity of this assumption. In fact, assuming convexity implies that some return-to-scale characteristics of a production set cannot be modelled. For example, convexity of the *PPS* excludes the possibility of modelling globally *IRS* or alternate behaviours of increasing and decreasing returns at different volumes

(Bogetoft et al.2000). In situations where commodities are not continuously visible, the assumption of convexity also does not apply. The main reasons for assuming the convexity of a technology T are, on the one hand, the neoclassical assumption of diminishing marginal rates of substitution and on the other hand, the fact that convexity is a necessary assumption for establishing the duality between input-output sets and cost-revenue functions (Kuosmanen, 2003). In order to model situations where the convexity of the *PPS* is not deemed appropriate, some nonconvex production possibilities have been developed.

A production unit is technically efficient if it produces the maximum output which is technically feasible for given inputs, or uses minimal inputs for the production of a given level of output. In other words, technical or productive efficiency of a production unit is defined in terms of the ability of the unit to produce on the boundary of its production set. Consequently, any methodology for evaluating technical efficiency requires the complete specification of the production possibility set as well as some concept of distance to relate the observed input-output combinations to the boundary of the specified set. The best known nonconvex technological set that only satisfies free disposability of inputs and outputs is free disposal hull *(FDH)*, which was first introduced by Deprins et al. (1984). The *PPS* of this technology is defined as:

$$T^{FDH}(\mathrm{x,y}) = \left\{ (\mathrm{x,y}) \mid \sum_{j=1}^{J} \lambda_j y_{r,j} \geq y \text{ for all } r, \sum_{j=1}^{J} \lambda_j x_{i,j} \geq x \text{ for all } i, \sum_{j=1}^{J} \lambda_j = 1, \lambda_j \in \{0,1\} \text{ for all } j \right\} \quad (7)$$

The particularity of a technology defined by T^{FDH} is that it rests only on the assumption of free disposability of inputs and outputs. The nonconvex nature of T^{FDH} is expressed in the binary constraints associated with the λ_j values. An interesting characteristic of T^{FDH} is the fact that the efficient subset of the production frontier is constituted by observed *DMUs* only, namely, the nondominated *DMUs*. This makes *FDH* a useful method to be applied for benchmarking purposes. As pointed out by Bogetoft et al. (2000, p.2), “fictitious production possibilities, generated as convex combinations of those actually observed, are less convincing as benchmarks, or reference DMUs, than actually observed production possibilities.” This is shown in the Mixed Integer Program below:

$$\begin{aligned}
&\underset{(\theta_k,\lambda_j)}{Min}\,\theta_k \\
&\sum_{j=1}^{J}\lambda_j y_{rj} \geq y_{rk}, \forall r \in R \\
&\sum_{j=1}^{J}\lambda_j x_{ij} \leq \theta_k x_{ik}, \forall i \in I \quad (8) \\
&\sum_{j=1}^{J}\lambda_j = 1 \\
&\lambda_j \in \{0,1\}, \forall j \in J
\end{aligned}$$

Here, θ_k is the efficiency level and the Mixed Integer program can be solved to compute the FDH efficiency scores.

2.5. Cost efficiency frontier measures

Following all that have been hinted as regards methodologies employed in efficiency analysis, it is important to answer the following questions. What is cost efficiency and in what ways can it be explained? Of what importance is it as regards its production system? It is crucial to state that getting the most output from the least inputs at a reduced cost of production (Cook and Hunsaker, 2001, p. 23), is one of the simplest definitions of cost efficiency. This therefore helps a great deal in assessing the gap between the cost frontiers. Efficiency has been represented as a degree of success that producers achieve by allocating the available inputs and the outputs they produce, in order to achieve their desired goals (Kumbhakar and Lovell, 2000, p 15). In this thesis, the analysis of cost efficiency was based on the activity analysis model developed by Koopmans (1951) who noted that a producer is said to be technically inefficient when it can produce the same amount of output with less of at least one input, or can use the same package of inputs to produce more of at least one output. This definition establishes a twofold orientation (output augmenting and input reducing) of the technical component of economic efficiency which explains efficiency through an input and output perspective, by considering it (efficiency) in technical, allocative and economic terms.

Interestingly, there exists no such distinction between definitions (as described in subsection 2.1) and measures of economic efficiency. Describing and measuring economic efficiency require the specification of an economic objective and information on relevant prices. If the objective of a production unit (or the objective assigned to it by the analyst) is cost minimization as retained in this thesis, then the measure of cost efficiency is provided by the gap between the minimum feasible cost and the actual cost. This measure depends on input prices. It attains a maximum value of unity if the producer is cost efficient, and a value less than unity shows the degree of cost inefficiency. A measure of input-allocative efficiency is obtained residually as the ratio of the measure of cost efficiency to the input-oriented measure of technical efficiency. Suppose that producers face input prices $w=(w_1,...,w_I)\in R^I_{++}$ and seek to minimize cost. Then a minimum cost frontier is defined as $c(y,w)=\min_x\left\{w^T x : D_I(y,x)\geq 1\right\}$. If the input sets *L(y)* are closed and convex, and if inputs are freely disposable, the cost frontier is dual to the input distance function in the sense of the minimum cost frontier described above. A measure of cost efficiency *CE* is therefore provided by the ratio of minimum cost to actual cost: $CE(x,y,w)=c(y,w)/w^T x$. A measure of input-allocative efficiency *AE* is obtained as $AE\ (x,y,w)=CE(x,y,w)/TE\ (y,x)$. It should be noted that $CE(x,y,w)$ and its two components are bounded above by unity, and $CE(x,y,w)=TE\ (y,x)\times AE\ (x,y,w)$.

$$
\begin{aligned}
& c(y_k,w)=\underset{(\tilde{x}_i,\lambda_j)}{Min}\sum_{i=1}^{I} w_i\tilde{x}_i \\
& \sum_{j=1}^{J}\lambda_j y_{rj}\geq y_{rk}, \forall r\in R \\
& \sum_{j=1}^{J}\lambda_j x_{ij}\leq \tilde{x}_i, \forall i\in I \qquad (9) \\
& \sum_{j=1}^{J}\lambda_j = 1 \\
& \lambda_j\geq 0, \forall j\in J
\end{aligned}
$$

In view of the above program, cost efficiency is estimated due to the fact that this input perspective is suitable for cost minimization goals and production, where output is assumed a fixed category with the possibility of having varying inputs. Therefore from the input-orientated perspective, cost frontier measures showed the ability of French crop producers to produce a given output with the smallest quantity of inputs (most especially a minimized quantity of pesticide input) possible given the production technology with a minimized cost.

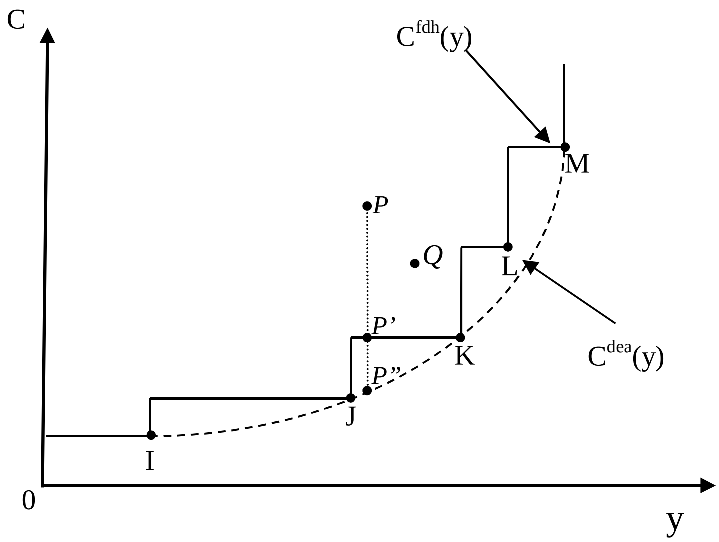

Figure 12: Cost frontier of a strongly disposable DEA model and the FDH

Figure 12 reflects some intuitions for the graphical representation of both DEA and FDH models for the case of one output. Observations I, J, K, L and M are FDH efficient. Observation *P* is inefficient. A typical cost frontier is given by the staircase-shaped line IJKLM. In contrast, a typical DEA cost frontier is depicted using the dashed line IJKM. The implication of the convexity assumption is thus revealed with observation L which is efficient relative to the FDH cost frontier and found to be inefficient relative to the convex combination of K and M on the DEA model. Using the cost-efficiency measure, inefficient observations are projected onto an orthant spanned by a single efficient producer which is weakly dominating in both cost and outputs. For example in Figure 12, the inefficient observation *P* is dominated by K and L as well as by *Q*, which is itself inefficient. Observation *P* is projected onto point *P'* situated on the orthant spanned by K, which is one of the dominating observations. This single producer can therefore be interpreted to function as a role model for the inefficient unit. In DEA, typically no such unique role model is available. Inefficient observations are projected onto a fictitious linear combination of efficient observations. For example, observation P is projected to point P'', which is a linear combination of observations J and K. In view of this, the number of efficient observations on FDH is typically larger than on DEA.

3. Extension of the Basic models applied

Indeed, in order to assess and compare the production cost frontiers, both the non-parametric frontier [originally developed by Koopmans (1951) and Baumol (1958)] and the Stochastic frontier approaches needs to be adopted. These models apply a frontier approach, where the cost frontier obtained represents the best practice technology among French crop producers in the sample, against which the cost efficiency of the other crop producers within the sample is measured.

3.1. The Robust Approach

The main disadvantage of the non parametric approaches is that they have the possibility of producing results that are sensitive to outliers, model specification, and data errors, meaning that their major disadvantage is that they are susceptible to the influence of outliers which can easily bias the results, this however echoes a message of cautiousness. To this regard, this thesis limits the influence of these outliers with the use of a robust *DEA* and *FDH* methodologies based on robust optimization approach to overcome the data uncertainty thus improving the results' quality. The implementation of the robust approach proposed by Bertsimas and Sim (2004) for *DEA* methods is a new linear programming problem which could be solved very easily. On the other hand, the implementation of a robust approach for *FDH* methods as devised by Cazals, Florens and Simar (2002) is utilized in this thesis.

The original Non parametric frontier Analysis *(DEA or FDH)* assumes the input–output vectors that are 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 perturbation in the data could lead to infeasible solutions for some benchmark optimization problems. Therefore, the results of the efficiency estimation and ranking could be unreliable in many cases especially when the efficiency of a particular firm is close to that of another. This could motivate using a robust model to achieve more reliable results. Robust optimization developed from studies by Ben-Tal and Nemirovski (2000), Bertsimas and Sim (2006) and Bertsimas, Pachamanova, and Sim (2004). To measure the relative efficiency of the French farms, a nonparametric technique that has proven useful in a number of other sectors and applications is applied. Applied empirical work on efficiency and productivity measurement of individual firms is always confronted with the sensitivity of the results to the different approaches and assumptions. Therefore, to present the most robust image, different nonparametric model specifications are used. This employs a nonparametric envelopment method that involves the use of linear programming methods to construct a nonparametric piecewise linear surface or frontier over the data and measures the efficiency for a given unit relative to the boundary of the convex hull of the input output vectors.

Monte-Carlo simulation to alleviate the effects of different sample sizes (sample sizes or technology employed; more or less pesticide use)

Monte Carlo-type approach limits the size of larger samples to the size of smaller samples in order to derive average sample efficiencies that are comparable across samples. Their approach is used in comparing efficiency scores derived for groups of crops, where the samples differ substantially in size and types of crop produced. Random sub-samples (without replacement) are drawn from the larger data set of the farms under observation. By using a sufficiently large number of replications and averaging over the results, the expected efficiency for larger samples is obtained. In this way, the sample size effects from efficiency differences across groups are separated. Thus, to deal with the fact that different models are estimated using different numbers of parameters, it is always possible to adjust the number of observations in the samples accordingly.

3.2. Controlling for heterogeneous production in cost functions through Hamming Distance

In farming systems, it is well known that output mixes influence the technological process and consequently the cost. Therefore, it is essential to take into account the production heterogeneity among DMUs to compare similar farming systems. In the previous model (9), the first set of constraints relative to the R productions ensure that the minimal cost is computed for a given output partition. Unfortunately, empirical estimations based on farm account data cannot be driven by output quantity data about each detailed crop and are generally based on a global aggregated output value (at worst) or with some different output values for a few types of main crops (for the best). Nevertheless, it is easier to collect statistical information concerning utilized surfaces for each specific crop which are highly correlated to the output mixes and the total cost. Hence, farm crop-mixes can be appropriately described through their own crop surface partition.

To deal with that conclusion, a relevant way of taking care of the detailed crop mixes is borrowed from fuzzy set theory. The Hamming distance (Kaufmann 1975) is able to measure the closeness between two farms a and b belonging to the technology based on their specific crop surface structure. This Hamming distance HD is calculated by the sum of absolute deviations between two vectors defined on crop surface partition. For example, the HD between DMUs p and q gives:

$$HD(p,q) = \sum_{r \in R} \left| S_p^r - S_q^r \right|$$

Where s^r is the share of crop surface r in total surface.

If p and q are characterized by totally different crop surface structures, HD gets a value of 2 otherwise when all crop surface shares are equal, it attains the minimal value of 0. Between this interval of variation, HD has a straightforward economic interpretation: for instance, a HD value of 0.2 means that in comparing q to p, 10% of its surfaces occur in different crops. Thus, by introducing the total crop income $I = \sum_{r \in R} p_r Y_r$ instead of the R output constraints and introducing linear constraints as regards crop surface partition and the HD value, the previous cost model (9) can therefore be adapted in order to control for heterogeneous production of the production plans included in the technology as shown below.

$$
\begin{aligned}
&\min_{\lambda, S^+, S^-} \tilde{C} = \sum_{j \in J} \lambda_j C_j \\
&\sum_{j \in J} \lambda_j I_j \geq I_k \\
&\sum_{r \in R} \sum_{j \in J} \lambda_j L_{r,j} = \sum_{r \in R} L_{r,k} \\
&\sum_{j \in J} \lambda_j L_{r,j} = L_{r,k} + S_r^+ - S_r^-, \forall r \in R \\
&\sum_{r \in R} (S_r^+ + S_r^-) \leq HD \sum_{r \in R} L_{r,k} \\
&\sum_{j \in J} \lambda_j = 1 \\
&\lambda_j \geq 0, \forall j \in J \\
&S_r^+, S_r^- \geq 0, \forall r \in R
\end{aligned}
\tag{10}
$$

It is also important to note that $S^+{}_r$ and $S^-{}_r$ are positive slack variables that measure the difference in the output profiles between the evaluated DMU k and the optimal DMU for each of the R land categories. Therefore the quantity $\sum_{r \in R} (S_r^+ + S_r^-) / \sum_{r \in R} L_{r,k}$ represents the value of $\sum_{r \in R} \left| S_p^r - S_q^r \right|$ in the HD definition.

3.3. Cost function estimation and reference set definitions

Traditionally, the technology defined in (1) is used to evaluate cost efficiency of all DMUs in an Activity Analysis Framework. Following Ruggiero's approach (1998), we depart from this usual framework by redefining the technology given a level of pesticide per ha *PU* as:

$$T(PU) = \{ (\mathrm{x}, \mathrm{y}) \mid \text{ x can produce y given } PU \} \tag{11}$$

where *PU* denotes the degree of intensification which is equal to the ratio of pesticide per ha.

Two technologies are defined based on more or less intensive use of pesticide. By denoting the $T^{HPU}(PU)$ for more or equally pesticide use than PU and $T^{LPU}(PU)$ the technology using less or equally pesticide use than PU, they are respectively defined by:

$$T^{LPU}(PU)=\left\{(\mathbf{x},\mathbf{y}):\sum_{j\in J}\lambda_j y_{r,j}\geq y_r,\forall r\in R,\sum_{j\in J}\lambda_j x_{i,j}\leq x_i,\forall i\in I,\sum_{j\in J}\lambda_j=1,\lambda_j\geq 0\ \forall j\in J,\text{ and } PU_j\leq PU\right\} \quad (12)$$

$$T^{HPU}(PU)=\left\{(\mathbf{x},\mathbf{y}):\sum_{j\in J}\lambda_j y_{r,j}\geq y_r,\forall r\in R,\sum_{j\in J}\lambda_j x_{i,j}\leq x_i,\forall i\in I,\sum_{j\in J}\lambda_j=1,\lambda_j\geq 0\ \forall j\in J,\text{ and } PU_j\geq PU\right\} \quad (13)$$

The definitions of “more or equally agricultural extensive” and “more or equally agricultural intensive” are now clear. $T^{HPU}(PU)$ contains observed DMUs in the reference set using more pesticide per ha than a given level of pesticide use per ha PU while $T^{LPU}(PU)$ contains only the observed DMUs that has an equal or higher ratio of pesticides per ha than PU.

The cost model

Formally, the production costs are equal to $C=\mathbf{w}\,\mathbf{x}^T$ where the superscript T denotes a transposed vector. Thanks to the previous definitions (12) and (13), two minimum costs can therefore be defined, respectively $\tilde{C}_{LPU}$ and $\tilde{C}_{HPU}$. For a DMU k with a production level $(\mathbf{y}^k)$, the minimum costs involve solving the two following models:

$$\begin{aligned}&\min_{\lambda,\tilde{C}_{LPU}} \tilde{C}_{LPU}\\ &\sum_{j\in J}\lambda_j y_{r,j}\geq y_{r,k},\forall r\in R\\ &\sum_{j\in J}\lambda_j C_j\leq \tilde{C}_{LPU}\\ &\sum_{j\in J}\lambda_j=0 \text{ if } \exists PU_j>PU_k\\ &\sum_{j\in J}\lambda_j=1\\ &\lambda_j\geq 0,\forall j\in J\end{aligned} \quad (14)$$

$$\begin{aligned}&\min_{\lambda,\tilde{C}_{HPU}} \tilde{C}_{HPU}\\ &\sum_{j\in J}\lambda_j y_{r,j}\geq y_{r,k},\forall r\in R\\ &\sum_{j\in J}\lambda_j C_j\leq \tilde{C}_{LPU}\\ &\sum_{j\in J}\lambda_j=0 \text{ if } \exists PU_j<PU_k\\ &\sum_{j\in J}\lambda_j=1\\ &\lambda_j\geq 0,\forall j\in J\end{aligned} \quad (15)$$

The gap between the two minimal costs $\tilde{C}_{LPU}$ and $\tilde{C}_{HPU}$ based on their respective programs (14) and (15) is evaluated and can assess *LPU* technology as a more cost-competitive practice (or not) than *HPU* for any evaluated farm k. The novelty of this methodology which aims to compare two different technologies consists to define various subsets of DMUs used in the reference subsets with respect to the evaluated producer's level of pesticide use.

Here it's worth to note that these models allow for inefficiencies in production (for any producer, observed cost could be higher than optimal cost of the benchmarks *LPU* or *HPU*). These inefficiencies could depend on many specific reasons as pedo-climatic conditions or farmers' risk attitudes. Nevertheless, these individual inefficiency scores are not considered in this research but rather kept more focus on the gap between the two cost frontiers which are not affected by any of these potential inefficiency parameters since two minimal costs are compared.

Most innovations introduced in the farming sector in the past few decades have included the introduction of special class of factors of production such as the damage control inputs. Profound examples of this kind of inputs in the farming sector include pesticides, weedicides, windbreaks, sprinklers for frost protection, immunization and antibiotics in feedlots etc. Unlike conventional factors of production (i.e., land, labor, capital), these special class of inputs do not increase farm's potential output directly since their distinctive feature lies in their ability to reduce the negative effect of the damage agents caused either from natural or human causes. In this line, a considerable amount of empirical work has been devoted in recent years on the quantitative analysis of the distinct role of conventional and damage control inputs on farm production. The first who have dealt explicitly with the appropriate specification of damage control inputs in farm production models and the subsequent measurement of their marginal productivities were Headley (1968) and Campbell (1976). Using a simple methodological approach they concluded that pesticides have been under applied in a sense that their marginal product exceeded marginal factor cost.

However, as noted several years later by Lichtenberg and Zilberman (1986), (Hereafter, *LZ*) the marginal productivities produced by Headley (1968) and Campbell (1976) model specification, were biased as they did not account for the indirect role of damage control inputs in the production process. Unlike with Headley (1968) and Campbell (1976), *LZ* suggested that conventional and damage control inputs should be treated asymmetrically. They put forward the fact that the contribution of damage control inputs to farm production may be better appreciated by conceiving realized output as a combination of two components: first, the maximum quantity of farm produce that is attainable from any chosen conventional input combination and, second the losses in farm production due to the action of damaging agents that are present in the environment like insects, weeds, bacteria etc. In addressing this issue, they introduced into the traditional production function model an output abatement or kill function capturing the abatement effort by damage control agents. Subsequently, they measured marginal productivity of damage control inputs according to their ability to reduce crop damage and not to increase directly farm output.

In view of the afore mentioned and starting from the damage control model initially proposed by *LZ* and more recently developed in a more general non parametric context by Kuosmanen, Pemsl and Wesseler (2006), the production technology that differentiates conventional inputs (land, fertilizer, seeds, etc) from damage control input (pesticides) can be defined by linking the maximal potential outputs obtainable from direct inputs takes into consideration potential losses from pesticide use as follows:

$$f(\mathrm{y}, \mathrm{x}^{\mathrm{D}}, g(x^{p})) = 0 \text{ with } g(x^{p}) \in [0,1]$$
$$\text{and } f(\mathrm{y}^{*}, \mathrm{x}^{\mathrm{D}}, 1) = 0$$
$$\text{with } \mathrm{x}^{D} \text{ vector of direct inputs as fertilizer, seeds, labor, ...}$$
$$x^{p} \text{ damage control input such as pesticide}$$

y* is the maximal potential outputs obtainable from direct inputs when no pest attack happens or when pesticide uses eradicate infestations. $g(x^{P})$ represents the damage control function modeled as a proportion of the pest population destroyed by the application of pesticide. It measures pesticide effectiveness and possesses the properties of a cumulative probability distribution. A complete eradication of pest damages is associated with $g=1$ while $g=0$ denotes zero elimination. Therefore, the abatement coefficients θ can be introduced as:

$$\theta = \left(\frac{y_1}{y_1^*}, \ldots, \frac{y_R}{y_R^*}, \right) \text{with } \frac{y_r}{y_r^*} \leq 1 \; \forall r \in R$$

Based on the fact, that the farmer plans his potential production with the notion of using his conventional inputs while not predicting the eventual future effects of pest attacks. It can therefore be assumed that he minimizes his direct cost without taking pesticide uses and abatement coefficients into consideration.

Focussing on the direct input technology $f(\mathrm{y}, \mathrm{x}^{\mathrm{D}}, g(x^p)) = 0$, a framework which characterizes the technology of all feasible direct input and output vectors can now be utilized:

$$T^D = \left\{ (\mathbf{x}^{\mathbf{D}}, \mathbf{y}^*) \in \Re_+^{I-1+R} : (\mathbf{x}^{\mathbf{D}}) \text{ can produce } \mathbf{y}^* \right\} \qquad (16)$$

Under a real circumstance, it is pretty difficult to obtain the information pertaining to the true cost model on a large sample sourced from farm account data since as it requires the knowledge of y* and the observed damage abatement coefficients. The question is: is it possible to replace $\mathbf{y}^*$ in the models (14) and (15) by the observed ex-post output $\mathbf{y}$ without altering the conclusions on the gaps between the two cost *HPU* and *LPU*?

As it is argued in paper 3, the omission of pesticide uses in the estimation of the cost function is always in favor of the *HPU* technology since pesticide applications increase the abatement coefficients without any additional direct cost. More so, if the *HPU* best practices are less cost efficient than the *LPU* ones, a real cost dominance of the *LPU* technology can be established. This cost dominance actually originates from factors of direct cost inefficiency and does not seem to be attributable to other causes such as pest infestations and treatment cost. As a final point, it is clear that the addition of this last input to the direct cost will result to an amplification in the gap between the two technologies since HPU technology consumes more pesticide per ha than the LPU.

4. Results and Analysis

In all the papers, database from two major French departments were used and the methodological approach which involve different levels of pesticide use were assessed to see the dominance effect of one over the other. For each paper, methodological specifics were defined by model selection, input orientation (global cost) and variable selection. The results and the analysis are presented below in three separate sections stating a brief presentation of the papers with an emphasis on the results obtained thus providing adequate information for the farmers and policy makers alike.

4.1. Summary of Paper I

Could Society's willingness to reduce pesticide use be aligned with Farmers' economic self-interest?

The cost frontier comparisons that favour a reduced use of pesticide constitute an uncompromising interest, this is due to the fact that farmers can be motivated to adopt practices that are friendlier to the environment and which are simultaneously most efficient in terms of cost. This constitutes the major content of Paper I which entails the assessment of intensification versus extensification of pesticide use in crop activities. To this regard, a sample of 600 farms were observed in the Meuse department over a 12 year period, hence cost efficiency dominance between technologies using non parametric cost functions involving different pesticide levels were assessed with the aid of a damage control input model. This paper checks to see if the minimized cost of production (individual interest of the farmer) is in coherence with pesticide reduction per hectare (global benefit of the society) thereby trying to know if a reduced use of pesticide is a cost-competitive practice or not. Results show that in 80% of cases, more extensive technology cost dominates the more intensive one. In addition, the results expose the fact that the interest of farmers and the policy makers could converge by attaining a win-win strategy. Certainly, the benefit for the individual producer to reduce his cost by approximately 25% through the adoption of less intensive practices leads to a reduction of pesticide per ha of about

29% which is parallel to the ecological wishes of society. This totally agrees with conclusions drawn by Jacquet et al. (2011) at the national level for crop activities. They confirm that reducing pesticide use by 30% could be possible without having a negative influence on farmers' income and that on average the intensive techniques appear to be less efficient than techniques using smaller level of chemical inputs. On a final note, it is therefore expedient to state that the cost frontier comparisons with respect to practicing farms of both intensive and extensive technologies shows that the latter dominates the former in terms of cost.

4.2. Summary of Paper II

The spread of pesticide practices among cost efficient farmers

Paper II analyses the spread of pesticide practices with respect to crop production (wheat, barley and rapeseed) in French agriculture. In view of this, a double step analysis was conducted with the use of a non-parametric robust technology thus first enabling the selection of cost efficient farms from a panel data of 650 farms over a 12 year period located in the French department of Meuse and second, a RFDH frontier analysis was run only on the selected cost efficient farms from the first step thus revealing the units which minimize the pesticide use per ha while maintaining constant yields. As a sub-staged step, a regression analysis was used in order to describe the link between pesticide reductions per hectare and the time variations of yields. In comparison to a traditional FDH methodology, thanks to this robust approach (the RFDH framework) which ensures the reduction of the potential effect of outliers on the frontier estimations. In the case of the robust FDH approach, more than 64% of observations are declared cost efficient instead of only 55% for a FDH frontier in the first step. Thus, the comparisons between the two benchmarks gives around 4% difference of pesticide per ha reductions in the second step. All the different total cost efficient practices among farmers were therefore evaluated in terms of pesticide per ha and the minimum uses were selected. The main results conclude that the spread of pesticide use among cost-competitive farmers is still large since the pesticide reductions per hectare could reach 24% on the average, thus leading to a global value of nearly 2,600€ which represents 7.4% of the global cost. In addition, with improved yield level, the within regression analysis clearly shows that potential pesticide reductions decrease which means that pesticide practices converge to the frontier over time. This therefore shows to a greater extent that farmers have less flexibility in their pesticide management as their yield level increases.

4.3. Summary of Paper III

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

Paper III deals with the framework which assessed the cost dominance between technologies exogenously distinguished that favour less or more pesticide levels per ha. With the use of a non-parametric activity Analysis model from a sample of 707 crop farms in the Eure & Loir Département observed in year 2008, direct cost functions excluding pesticide are estimated and with the introduction of a robust approach frontier, the sensitivity to the influence of potential outliers by the cost frontier is reduced. In view of this, two direct cost functions which are characterized by a relatively lower or higher level of pesticide per ha are compared. From a methodological point of view, the novelty of this study dwells on several elements. First, based on the fact that the selected criteria used in differentiating the two technologies is the level of pesticide per ha, then pesticide input was not treated endogenously. With respect to this, the definition of the technology is therefore mainly concentrated on the inputs which affect outputs directly. Therefore, the direct cost includes expenditures on land, fertilizer, labor, capital and other intermediate inputs but excludes pesticide cost. Second, farms with big surfaces specialized in cash crops are focused on instead of common mixed farming systems (crops and livestock) with relatively small crop surfaces. Third, competitiveness of technologies in terms of cost is established for different crop-mixes at several levels of size as an alternative to evaluating observed farms. This enhances the possibility of exploring the whole cost functions in their respective scale and scope dimensions. Fourth, based on the fact the level of pesticide use are influenced significantly by crop mixes, so in order to compare similar farming systems, it is crucial to take into account surface partition among these crops. Surface partition gathers 25 different crops in this case study. Hence, the concept of Hamming Distance is explicitly introduced in order to control the similarity of crop mixes when including farms in the AAM and lastly which is the fifth specificity, while non-parametric cost function is estimated with the intervention of an AAM which imposes very few assumptions on the production set, its main weakness lies in the sensitivity of the measure to potential presence of outliers. To attack this problem, the cost model is therefore reformed into a robust frontier approach.

Empirically, the results show a total cost difference of 10% in support of (direct input) cost competitive and environmental friendly practices and a gap of 28% of pesticide use per ha between the two technologies in favor of LPU. From the average observed use in pesticide leads to 15.6% reduction. This cost dominance is a robust phenomenon and economically inspires more environmentally friendly practices in terms of crop activities. Irrespective of the differences , it is interesting to note that these findings are consistent with the conclusions drawn by Saint-Ges and Bergouignan (2009); Boussemart, Leleu and Ojo (2011), they hinted 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. In view of the above simulations, the result clearly affirms that agricultural practices using more pesticide per ha induces other input substitution costs and are therefore not more cost competitive than practices that encourages less pesticide use. Thus settling for agricultural practices that uses less pesticide consequently results to a win-win strategy sourced from sound environmental friendliness at a more competitive cost. This stands as a motivating factor for policy makers and land users who are willing to promote environmentally improved practices in developed countries.

5. Conclusions

This thesis analysed the different performance of French crop farmers in cost efficiency terms, and evaluated the potential impact of a reduced use of pesticide in strengthening their competitiveness. The results obtained in the two regions (Eure&Loir and Meuse) indicated that substantial cost efficiency improvements are possible on the farms analysed based on the condition that the farmers can opt for a technology that motivates environmental friendliness rather than opting for the one that creates environmental burden. These two samples which utilized different years as well as different cropping systems are used in testing the results robustness and paper I shows that French crop producers have the potential for an approx. 25% decrease in cost if farmers can improve their input management thus leading to an approx. 29% decrease in pesticide per ha which correlates with the ecological wishes of the society. In addition, paper II considers the spread of pesticide use among cost efficient farmers only and the result shows that the pesticide reduction per hectare could attain 24% on the average which connote that the spread of pesticide usage among cost competitive farmers is still large. This percentage results to a global value of approx. 2,600€ which represents 7.4% of the global cost and may be particular to various types of cost efficient farmers. Moreover, it is also indicated from the result that potential pesticide reductions decrease with improved level of yields as revealed by the within regression analysis. This clearly shows that as yields are being increased, farmers tend to have less flexibility in their use of pesticides. Lastly in paper III, instead of evaluating observed farms, competitiveness of technologies in terms of cost is simulated for different crop-mixes and several levels of size. This allows the exploration of the whole cost functions in their respective scale and scope dimensions. This study reveals a total cost difference of 10% in support of (direct input) cost competitive and environmental friendly practices and a gap of 28% of pesticide use per ha between the two technologies in favor of *LPU* while on the average, observed use in pesticide leads to 15.6% reduction.

In view of the above, a distinction between some groups of farmers who are practicing an extensive use of pesticide as opposed to the intensive one is made in this thesis, thus suggesting that the extensive one which entails a reduced pesticide use and which is at the same time more cost competitive should be promoted. The findings also try to see how the conflict between the individual interest of the farmers and the ecological wishes of the society can be resolved. In response to this conflict, this finding is therefore very noteworthy since the results clearly reveal that the interest of farmers and the policy makers could converge by achieving a win-win strategy. The purpose of this thesis which concerns evaluating the differences in pesticide practices in order to assess the potential reduction of pesticide use is achieved by aligning and selecting the farmers with their respective best practices. Thanks to a Non Parametric frontier model which is used to assess the cost frontier comparisons between extensive and intensive technology. Hence, the methodological originality of this thesis is the cost dominance analysis between less pesticide uses versus more pesticide use which is done by defining the dynamic reference sets relative to the evaluated farm. They are therefore totally in convergence with previous researches using different methodological tools and other data in various European regions, thus seems to be a relatively general outcome. To this regard, this will update ongoing efforts to stimulate upstream policy interventions to reduce hazardous pesticide exposures for vulnerable farmers, thereby motivating sustainability in crop production.

Policy support for improving the managerial capacity and knowledge capacity of farmers through gradual implementation of a technology that subscribes to the school of thought of a reduced use of pesticide should be encouraged, thereby supporting the competence and capability of farmers to produce under a healthy and sound environmental condition. This is so because it is pertinent to note that the problem of farmers' health should be of interest to policymakers when considering the economic and efficiency of pesticides in agricultural production. The results gotten in this thesis are derived from the present technology of farms under study which ensures its likelihood by embracing the observed practices with low pesticide uses. This will enable the farmers and the society alike to opt for a win-win strategy. Therefore, the aim of 50% rate of reduction may be realizable in ten years time only with some technological advancement.

6. Contribution of the thesis

A cost efficiency analysis that offers the potential impact of a reduced pesticide use on the improvement of the French crop production sector would be beneficial in both an empirical and theoretical context for policy-makers, the actors engaged in crop production and the national level of the French Economy. This thesis represents a first attempt to evaluate the spread of pesticide practices among cost efficient farmers and this helps in order to reveal the units which minimize the pesticide use per ha while maintaining constant yield. This thus helps to know whether cost efficiency studies can be used as a checklist for goal achievement in crop production and can initiate corrective actions where critical points and opportunities for policy actions are identified most especially in respect of agricultural sustainability. In economic terms, cost efficiency is analyzed here in combination with a non parametric robust technology used in reducing the significant influence of outliers to the barest minimum. This combination is rare in important literature that concerns farm efficiency in crop production.

The damage control input introduced in the cost models for more or less intensive pesticide use in both Papers I and III has rarely been used previously to explain cost efficiency. Infact, the different crop mixes and scale orientation distinguished with the concept of Hamming Distance added more spices to paper III in the sense that it ensures the comparison of different groups of farms and thus helping to characterize their pesticide use as it affects their direct cost of production. Paper II makes a practical contribution by conducting a double step analysis based on *RFDH* technology which considers the potential presence of outliers and uses a Monte Carlo simulation to prevent the possibility of comparing a farm to an outlier. As such, this result builds up the managerial behavior of farmers on a sufficiently detailed level and can be of use when discussing ways to strengthen their managerial capacity. All three papers relate to specific farm practices, thus making practical contributions for policy-makers and decision makers, for whom crop productivity is of great importance. Farmers will benefit by obtaining information on whether or not they are required to minimize their use of pesticide input which thus leaves them more convinced rather than being confused on the numerous advantages attached to settling for a reduced use of pesticide input. Last but not the least, another important improvement that is made in the assessment of cost efficiency analysis is the damage abatement factor (pesticide) and thus distinguishing between inputs which affect output directly and inputs which reduce the possibility of damages in crop production. In paper III, the successful exclusion of this factor from the direct cost function is used in distinguishing differences in pesticide usage in diverse scale and scope dimensions.

7. Fields for further research

This thesis attempts to explain the different practices of French farmers in terms of their pesticide usage with the aid of some non parametric approaches (such as FDH and DEA) and a robust technology but it does not make use of Bootstrapping in its cost efficiency analysis. However, policy design and implementation could be based on more extensive economic research that examines the appropriateness of measures using other economic analysis approaches.

Generally, detailed data are still lacking on the pest infestation and also on impact of pesticides on human health and the environment as hinted by Pimentel, 2009a. In view of this, this thesis is silent as regards incorporating environmental variables in the model due to the fact that this information is not provided in the dataset and hence further research on the effects of related measures on crop production is necessary should detailed data be provided in the future.

A focus in this thesis is kept on crop production only from the input perspective. To make French farming more industry-orientated as regards transition from the farm to the national level then analysis of the sector from the output orientation is also necessary so that the entire chain of crop production is appraised. Lastly, the results gotten in this thesis are derived from the farm level and should be extended to national level for future research.

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CHAPTER II
Could Society's willingness to reduce pesticide use be aligned with Farmers' economic self-interest?
(Paper I)

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Could Society's willingness to reduce pesticide use be aligned with Farmers' economic self-interest?

Abstract

In the context of approximately 50% reduction in pesticide treatment according to the agreement of the "Grenelle de l'environnement" in France, the main part of this study involves the assessment of intensification or extensification of pesticide use in crop activities. This is done with reference to its use per ha thereby helping to proffer a solution to the persistent questions of farmers with regards to the use of inputs in an intensified manner or otherwise. With respect to this, a sample of 600 farms in the Meuse department was observed over a 12-year period. The analysis is essentially to assess cost efficiency dominance between technologies using non parametric cost-functions which involves different levels of pesticide use per ha. Our empirical application shows that less intensive processes in terms of pesticide level per ha are a better option not only for the society but also for the producers who could significantly reduce their costs in 80% of cases.

Keywords: agricultural intensification, agricultural extensification, pesticide reduction, environmental performance, non parametric cost-functions

1. Introduction

Use of chemical inputs (such as pesticides) by farmers dramatically increased in developed countries from the beginning of the 1950s to the mid 1980s. This increase was due to the cost effective manner in which pesticides have enabled producers to introduce new production technologies, enhance productivity, improve product quality, and reduce the use of more expensive inputs. This allowed pesticide use to be accompanied by numerous benefits. While on-farm economics have justified the extent to which pesticides have become part of agriculture in industrialized countries, there are external costs associated with their intensive use. However, negative externalities from such use which include damage to agricultural land, fisheries, fauna and flora have increased too. Thus, the main preoccupations embrace food safety, acute and chronic toxicity to humans, changing pest dominance, and environmental contamination from the disruption of natural water, air and soil functions (Brethour and Weersink, 2003). In addition, another major externality is the unintentional destruction of beneficial predators of pests thus increasing the virulence of many species of agricultural pests.

In this context, pesticides can be hazardous if they are not used appropriately. Hence, in order to ensure that users receive the benefits and are protected from the risks associated with its intensive use, pesticide should then be used in a reduced manner. The main advantages of a reduction in the use of pesticides include: (1) Benefits for the farmer through (a) savings in production cost, savings in energy (b) User-friendliness, improvement in time and work management, applicator safety. (2) Benefits for the environment through (a) improved biodiversity, improved water quality, wildlife protection, protection of beneficial arthropods, reduced packaging waste (b) facilitating the adoption of conservation agriculture practices, representing an opportunity for more sustainable farming methods. (3) Benefits for the consumer through improved food quality, less mycotoxin (Wood et al., 2000).

The costs from the above cited externalities are large and affect farmers' returns on the long run (land fertility, environment and health). However, despite these high costs, farmers continue to use pesticides in increasing quantities in a process known as intensification (Wilson, 2000). This could be partly due to the incentives given by pesticide industries thereby encouraging the farmers to use pesticide in an unsustainable manner (Wilson, Tisdell, 2001; Vanloqueren, Baret, 2008). But more fundamentally, previous studies, such as Campbell (1976) and Carlson (1977), found on average that the short run marginal returns to pesticide use were several times greater than the marginal factor costs (Carrasco-Tauber, 1990).

With such economical outcomes, the use of pesticide in an unsustainable way would not fall in line with the multiplication of initiatives for sustainable development by businesses, farmers' union and public French authorities according to the recent “Grenelle de l’environnement” agreements.

In view of this conflict of interests between individual farmers and society, this paper attempts to find out if extensification is or is not a more economically competitive practice than intensification for crop activities in French agriculture. The reduction of pesticide use by farmers is possible based on their individual interest to do so. In this paper we will also try to find out if there is coherence between the economic interest of the farmer in terms of cost decrease and the global benefit of society in terms of pesticide reduction per hectare.

By developing an analytical framework based on non parametric functions, some cost estimations are therefore done empirically to assess the comparisons between different technologies in terms of pesticide uses per ha for each evaluated farm. In the above mentioned context, Agricultural Intensification (*AI*) or Agricultural Extensification (*AE)* are respectively defined as technical practices with higher level of pesticide per ha and lower level of pesticide per ha relative to each observed farm.

Pesticide use has been high on the political agenda in many countries and many studies by agronomists have been conducted to look into the possibilities and the consequences of a reduction in its application. Most of these studies were carried out with methods that are very different from our approach. Indeed simulations or experiments on agronomical data generally assume constant returns to scale by retaining the gross margin per ha as the only economical criteria which is solely considered at the field level. As our approach is more from a managerial perspective, we choose to use economical data observed at the farm level. We analyse real and observed crop activities and we select both the best intensive and extensive practices in terms of production costs. Then we determine which of these two best practices (*AI* or *AE*) dominates the other on the production cost criteria without any a priori assumption about returns to scale. In that perspective, the study made use of a panel data located in a particular French department (la

Meuse) which consists of 600 farms over a 12 year period (1992-2003) producing wheat, barley and rapeseed (including rapeseed for diester).

The rest of the paper therefore unfolds as follows. Following this introduction, the next section briefly provides some of the major effects of pesticide reduction and discusses more precisely the definitions of agricultural intensification or extensification related to pesticide use. Section 3 presents the methodology to assess cost frontier comparisons between *AE* and *AI* while section 4 is devoted to empirical analysis, results and comments which identifies the variables and provides the data information used in this study. The final section (5) concludes the paper.

2. Agricultural sustainability, pesticide use and its cost implications

The success of industrialised agriculture in recent decades has often masked significant environmental and health externalities which have been well documented (Wood et al., 2000), but it is only recently that the scale of cost has come to be appreciated through studies in China, Germany, UK, the Philippines and the USA (Pretty et al., 2000). With this in mind, intensive forms of agriculture have been proven to cause severe environmental damage, such as soil erosion by water or wind (Deumlich et al., 2006), pollution of ground and surface water by pesticide as well as contributing to the deterioration of natural habitats and losses in biodiversity (Firbank, 2005). The central questions, therefore, focus on: (i) To what extent can farmers increase food production by using low cost and inputs? (ii) What impacts do such more sustainable methods have on environmental goods and services and the livelihoods of people who rely on them?

Systems that are high in sustainability are making the best use of nature's goods and services whilst not damaging these assets (Li Wenhua, 2001; 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.

In this context, maintenance of the agricultural production capacity of land resources is a fundamental element in the discussion on the choice of agricultural strategy for land usage – extensification, and/or intensification– (Bindraban et al., 2000). This choice is probably a reflection of both biophysical (e.g., climate and water) and socio-economic (e.g., market pull and access) factors (Erenstein et al., 2006).

Theoretically, it is important to give brief definitions of extensification and intensification. More significant use of agricultural land can take various forms. A first dimension would be extensification – increasing production by extending the area under cultivation while maintaining or reducing aggregate input levels per unit area. A second dimension would be intensification – increasing production per unit area through more intensive production practices. It thereby encompasses two distinct forms – land-use intensification (i.e., increasing the frequency of cropping per unit area) and technological intensification (i.e., increasing capital and/or input use per crop per unit area). Usually, practices with low amounts of external input uses per ha are considered to cause less ecological damage (Gregory et al., 2002). Consequently in the context of reducing pesticide uses, we refer our definition of Agricultural Intensification (*AI*) or Agricultural Extensification (*AE*) technologies as technical practices with a relatively high or low level of pesticide per ha.

It is important therefore to state that past increases in agricultural production have occurred as a result of both extensification and intensification but there are more common problems associated with crop intensification i.e. the excessive and inappropriate use of fertilizers and pesticides. As mentioned earlier, this problem contributes to the deterioration of water quality, poses serious negative effects on human health and the environment, and it also leads to resistance of pests to pesticides.

Special attention is therefore paid to the phasing out of these highly toxic pesticides and the encouragement of using inputs in an efficiently sustainable manner. For several years in France, public authorities and businesses have multiplied the initiatives for sustainable development. This is due to the general belief that concerns the intensive use of pesticides and fertilizers which has the possibility to disrupt or erode biodiversity in natural habitats and ecosystem services that surround agricultural areas especially when these inputs are used inappropriately. The most spectacular measure is the inscription of this sustainable development in the Charter of the environment since March 2005. This spurred the French government into action and it therefore recently established the National Council for Sustainable development (CNDD) and has invested a lot in the "Grenelle de l'environnement".

The purpose of the agreement is therefore to initiate a policy work that evaluates different scenarios in order to reduce the dependency of cropping systems to pesticides. This prompted the government to set a target of reducing pesticide used in French Agriculture by 50% which should be possible over the next ten years. Since 2008, several measures have already been taken by including the prohibition of 30 products considered as being the most toxic, introducing a tax depending on the toxicity of pesticides and subsidies for organic farming (Champeaux, 2006).
In fact, the existence of cost inefficiencies offer an opportunity to reduce input expenses without reducing outputs. This concept is of particular interest when related to possibilities of input reductions or substitutions that may cause environmental impacts, such as pesticide uses per hectare of land. The farmers can be stimulated to adopt agricultural practices which are the most efficient in terms of costs. These practices are not necessarily the most ecological technologies that use less pesticide per ha, the choice will depend on the relative input prices and the possibilities of input substitutions.

With this in mind, this paper will therefore assess the cost frontier comparisons with respect to practicing farms in both intensive and extensive technologies. If the latter dominates the former in terms of cost, then *AE* process has always attracted ecological interest due to its environmental arguments in reducing pollution; but because of its financial benefits, it is now an even more attractive option. Therefore, information on the input reducing capabilities of polluting inputs such as pesticides is useful to elucidate the possibilities of improving environmental performance while maintaining output levels and decreasing production cost (De Koeijer et al., 2002).

The paramount question now is: is pesticide reduction economically feasible in French agriculture? It is extremely obvious that an incorrect manner of pesticide application will definitely have negative effects on both health and the environment. The costs from pesticide pollution are high as a result of damage done to agricultural production from the proliferation of pests and its impacts on other production processes, the environment and human health and that is why the main objective of this research paper seeks to assess if a less pesticide use per ha is a cost competitive practice or not in crop activities by comparing cost frontiers between *AE* and *AI*.

3. Cost efficiency assessment with the use of non parametric cost functions

The firm's performance has been estimated using a number of efficiency concepts including production and cost. Cost efficiency is evaluated with reference to a cost function constructed from the observations of all firms considered within the sample set. The cost function which assumes the production cost of individual firms is dependent on the price of inputs, the quantity or value of outputs produced, and any other additional variables accounting for the environment or particular circumstances. Cost efficiency estimates how far the production cost of an individual firm differs from the production cost of a best practice firm operating under similar conditions and producing the same output. It is derived as the distance an individual firm has from the 'optimal' or 'best practice' firm existing on the cost frontier.

This hypothesized 'best practice' firm is defined with reference to all firms retained in the sample set. Farrell (1957) originally introduced a simple method of measuring firm's specific productive efficiency that employs the actual data of the evaluated firms to generate the production frontier. Thus this method assumes that the performance of the most efficient farmers can be used to define the benchmark. Transposing this in the cost function context, if a farm lies on the cost frontier, then it is perfectly cost-efficient but if it lies above the benchmark then it is inefficient with the ratio of the actual to the potential minimal cost that defines the level of cost inefficiency of the individual firm. This approach yields a relative measure as it assesses the cost efficiency of a farm relative to all other farms in the sample. Farrell argued that this is more appropriate as it compares a farm's performance with the best performance actually achieved rather than with some unattainable ideal.

Cost frontiers can be modelled, thanks to a Non Parametric Frontier Approach (NPFA) that can be evaluated with an Activity Analysis Framework (AAF) originally developed by Koopmans (1951) and Baumol (1958). AAF is a linear programming based technique for measuring relative efficiency where the presence of multiple inputs and outputs makes comparisons difficult. NPFA has both advantages and disadvantages relative to parametric frontier techniques such as the Stochastic Frontier Approach (SFA). The main advantage is that NPFA allows cost efficiency estimations without specifying any functional form between inputs and outputs. On the other hand, it is important to state that the disadvantage of the NPFA technique is that it does not allow for deviations from the efficient frontier to be a function of random error. As such, NPFA can produce results that are sensitive to outliers, model specification and data errors. As a solution to these drawbacks, an approach combining NPFA and SFA has recently been developed by Kuosmanen and Kortelainen (2010). Their framework which is known as Stochastic Non smooth Envelopment of Data (StoNED) encompasses semi-parametric frontier model that mixes DEA which satisfies monoticity and concavity with the SFA homoskedastic composite error term in a two stage-method. While StoNED seems to be a very promising approach, up until today it has been developed under the mono-output context. This framework should prove useful in the future since this approach would have also been extended to the multi-output setting.

The basic standpoint of relative efficiency, as applied in NPFA, is to individually compare a set of Decision Making Units or DMUs (they represent farms in our context). NPFA constructs the frontier and simultaneously calculates the distance to that frontier for the (inefficient) farms above the cost-frontier. The frontier is piecewise linear and is formed by tightly enveloping the data points of the observed 'best practice' activities in the observations, that is the most efficient farms in the sample in terms of cost. NPFA uses the distance to the frontier as a measure of inefficiency. The measure provides a ratio-score for each farm from 0% (best performance) to x% meaning that the evaluated DMU would reduce its cost of x% to reach the cost frontier. For a review of the NPFA techniques see Färe et al. (1994) or Thanasoullis et al. (2008).

3.1.The input damage control technology

We follow the damage control model proposed by Lichtenberg and Zilberman (1986) and by Kuosmanen et al. (2006) to define the production technology. In this approach, direct inputs (land, fertilizer, seeds, etc.) and damage control inputs such as pesticides are distinguished. In the Lichtenberg and Zilberman specification, the contribution of pesticides to production differs fundamentally from that of direct inputs. Pesticides do not directly increase output yields but they are used to limit potential losses caused by damaging agents such as insects, weeds or bacteria. We therefore distinguish the maximal potential outputs obtainable from direct inputs and the observed outputs, taking into account potential losses which depend on pesticide use.

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

Lichtenberg and Zilberman (1986) characterize the production function (in a mono output framework) as:

$$y = F\left[\mathbf{x}^{\mathbf{D}}, G(x^P)\right] \qquad (1)$$

Where $G(x^P)$ stands for the damage abatement function. It is modeled as a proportion of the pest population killed by the application of pesticide. It measures pesticide effectiveness and possesses the properties of a cumulative probability distribution. A complete eradication of pest damages is associated with $G=1$ while $G=0$ denoting 0 elimination. They also assume that $G(x^P) \to 1$ as $x^P \to \infty$.

We keep the spirit of Lichtenberg and Zilberman (1986), thus our model is developed in a multi-output context. Therefore, we use the more general framework of production set as developed by Shephard (1953). The production possibility set (*PPS*) of all feasible input and output vectors is defined as follows:

$$PPS = \left\{(\mathbf{x}^{\mathbf{D}}, x^P, \mathbf{y}) \in R_+^{N+1+M} : (\mathbf{x}^{\mathbf{D}}, x^P) \text{ can produce } \mathbf{y}\right\} \qquad (2)$$

And the technology is supposed to obey the following axioms:

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

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

A3: *PPS* is closed;

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

A5: *PPS* is convex.

3.2. Introducing AE and AI in the model

Traditionally, PPS in (2) is used to evaluate cost efficiency of all DMUs in an Activity Analysis Framework. Following Ruggiero's approach (1998), we depart from this usual framework by redefining the PPS given a level of pesticide per ha as:

$$PPS(I) = \left\{(\mathbf{x}^{\mathbf{D}}, x^P, \mathbf{y}) \in R_+^{N+1+M} : (\mathbf{x}^{\mathbf{D}}, x^P) \text{ can produce } \mathbf{y} \text{ given } I\right\} \qquad (3)$$

where *I* denotes the degree of intensification which is equal to the ratio of pesticide per ha.

We define two technologies based on more or less intensive use of pesticide. By denoting $PPS^{AE}(I)$ the PPS for more or equally agricultural extensive and $PPS^{AI}(I)$ the PPS for more or equally agricultural intensive, they are respectively defined by:

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

$$PPS^{AI}(I)=\left\{(\mathbf{x^D},x^P,\mathbf{y}):\sum_{k\in\mathfrak{K}}\lambda^k y_m^k \geq y_m, \forall m\in\mathfrak{M}, \sum_{k\in\mathfrak{K}}\lambda^k x_n^{D,k} \leq x_n^D, \forall n\in\aleph, \sum_{k\in\mathfrak{K}}\lambda^k =1, \lambda^k \geq 0\ \forall k\in\mathfrak{K}, \text{and } I^k \geq I\right\} \quad (5)$$

The definitions of "more or equally agricultural extensive" and "more or equally agricultural intensive" are now clear. $PPS^{AE}(I)$ contains observed DMUs in the data set using less pesticide per ha than a given level of intensification *I* while $PPS^{AI}(I)$ contains only the observed DMUs that has an equal or higher ratio of pesticides per ha than *I*.

3.3.The cost model

Formally, the production costs are equal to $C = \mathbf{w^D}(\mathbf{x^D})^T + w^P x^P$ 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. This assumption implies that farmers have the same market power which is quite plausible given their similar structure and size within a homogenous geographical area.

Thanks to the previous definitions (4) and (5), we are now able to define the two minimum costs including the direct input and pesticide costs, respectively $\tilde{C}_{AE}$ and $\tilde{C}_{AI}$. For a DMU *o* with a production level $(\mathbf{y^o})$, the minimum costs involve solving the two following models:

$$
\begin{aligned}
&\min_{\lambda,\tilde{C}_{AE}} \ \tilde{C}_{AE} \\
&\sum_{k\in\mathfrak{K}}\lambda^k y_m^k \geq y_m^o, \forall m\in\mathfrak{M} \\
&\sum_{k\in\mathfrak{K}}\lambda^k C^k \leq \tilde{C}_{AE} \\
&\sum_{k\in\mathfrak{K}}\lambda^k = 0 \text{ if } \exists I^k > I^o \\
&\sum_{k\in\mathfrak{K}}\lambda^k = 1 \\
&\lambda^k \geq 0, \forall k\in\mathfrak{K}
\end{aligned}
\qquad (6)
$$

$$
\begin{aligned}
&\min_{\lambda,\tilde{C}_{AI}} \ \tilde{C}_{AI} \\
&\sum_{k\in\mathfrak{K}}\lambda^k y_m^k \geq y_m^o, \forall m\in\mathfrak{M} \\
&\sum_{k\in\mathfrak{K}}\lambda^k C^k \leq \tilde{C}_{AI} \\
&\sum_{k\in\mathfrak{K}}\lambda^k = 0 \text{ if } \exists I^k < I^o \\
&\sum_{k\in\mathfrak{K}}\lambda^k = 1 \\
&\lambda^k \geq 0, \forall k\in\mathfrak{K}
\end{aligned}
\qquad (7)
$$

In line with Ruggiero (1998), model (6) explicitly restricts the comparison set to exclude DMUs that face a higher level of pesticide per ha than the DMU *o* under analysis. A similar condition in (7) excludes DMUs with a lower degree of intensification.

The solutions to these models result in minimum costs $\tilde{C}_{AE}$ and $\tilde{C}_{AI}$ for the evaluated DMU *o* with an observed cost C^o. Therefore $\left(1-\frac{\tilde{C}_{AE}}{C^o}\right)$ and $\left(1-\frac{\tilde{C}_{AI}}{C^o}\right)$ reflect the potential decreases in % of C^o when the evaluated DMU *o* reaches the minimum cost of the best *AE* or *AI* practices, respectively. For each $\lambda^k \neq 0$, DMU k forms a part of the optimal linear combination which minimizes cost of farm *o* and can be considered as benchmark referents. The linear programs are therefore solved once for each observation in order to compute its two minimal costs.

Comparing the two minimal costs $\tilde{C}_{AE}$ and $\tilde{C}_{AI}$ based on their respective programs (6) and (7), one can evaluate the gap between the two technologies in order to know if *AE* is a more cost-competitive practice than *AI* for the current evaluated farm o. The originality of our approach is to consider the various subsets of DMUs used in the definition of the production possibility sets with respect to the evaluated producer's level of intensification. An exogenous choice of the threshold of pesticide use practices could be difficult to justify and that is why we use a relative and endogenous degree of extensification (intensification). With respect to their own degree of intensification, the evaluated DMUs are compared to more or less intensive DMUs. At this stage, it is essential to highlight the fact that our model allows for inefficiencies in production (for any DMU, observed cost could be higher than optimal cost of the benchmarks *AE* or *AI*). It is a common knowledge that these inefficiencies could depend on many different factors and more specifically farmers' risk attitudes or climatic effects. However, the gap between the two technologies is not affected by any of these potential inefficiency factors since we focus on the comparison of two cost optimal benchmarks.

4. Empirical application: data, results and discussion

4.1.Data for Efficiency Analysis

A total of 600 farms were observed in the Meuse department between 1992 and 2003 forming an unbalanced panel. We used a database of "Centre d'Economie Rurale de La Meuse" which assists farmers when auditing their accounts. Three outputs and four inputs were used to specify the technology of the farms for a total of 7135 observations. As the previous cropping plans are not directly available, the technology opts for a multi-output cost function model in order to limit the potential effects of crop rotations on pest management. Thus, the cost minimization models allow potential substitution effects between chemical inputs and land but constrain the optimal referents to produce the same (or more) quantities of the three retained outputs (wheat, barley and rapeseed including rapeseed for diester) than the evaluated DMUs which are significantly linked to the most frequent crop rotation observed within this geographical area. The outputs are measured in quintals.

The production cost (evaluated in constant Euros) comprises variable farm costs which are linked to the physical process of crop growth such as fertilizer, seed and pesticide plus land cost specifically dedicated to the three outputs. Land surface measured in hectares is the observed surface weighted by a quality index of soil which gives a measure of effective hectares of land.

This index is exogenously estimated thanks to soil and agronomical parameters available at the micro-region level. The unit price of land was estimated by the hired cost that the farmer paid to the owner when the land was leased. As regards to owned land, a fictitious price equal to the hire cost of his leased land was used. The yearly average land price over the sample was applied uniformly to all the observations.

We omit the quasi fixed primary inputs (labour and capital) for several reasons. Firstly, these two inputs cannot be split among the different output categories (crops, milk, meat, other products) in our data, they are only available at a global level. Therefore we cannot include them in our crop production function without any clear and consensual allocation keys. Secondly, our main focus is related to potential substitution effects between land and most important inputs contributing to environmental pollution caused by growing cash crops such as pesticides or fertilizers. Although Piot-Lepetit et al. (1997) argue that manual and mechanical pest control can be considered as substitutes to pesticides, we follow De Koeijer et al. (2002) with a consideration that they are secondary order effects. In fact mechanical weeding is a new practice and was not widely spread among French farmers during the period (1992-2003). Mechanical costs are also linked to output mixes and the farm size. As our cost minimization models constrain the optimal referents to produce the same quantity of each output as the evaluated DMUs, this guarantees that the two minimal costs are constantly evaluated for the same output quantities which are correlated to the level of capital goods and surfaces.

Thirdly, two points can be mentioned regarding labour. There is no consensus among agronomists as to the fact that pesticide reduction incidentally increases labour quantity in crop supervision. Some low input strategies which can be characterized by a decrease in sowing density or fertilizer application rate could help to lower yield loss resulting from the absence of fungicide application. Thus, it seems that the preventive use of fungicides on high-yielding wheat crops in the intensive cropping systems of northern Europe has obscured the fact that there are other ways of controlling diseases (Loyce et al., 2008). Moreover, on French arable farms, family labour is generally not used to its full capacity and does not significantly affect the operating cost given the farm's cropping plan and the cultivated surface.

Finally, despite the fact that the increase in price over time is known, the sample does not contain prices at the farm level for seed, fertilizer and pesticides, but only costs per input category. If we assume that all farms face identical input unit-prices each year (most inputs are procured within the same regional markets where prices between farms differ a little), we can use the two previous minimum cost models (6) and (7) in this application. The descriptive statistics showing the different inputs and outputs of farms are presented in table 1.

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

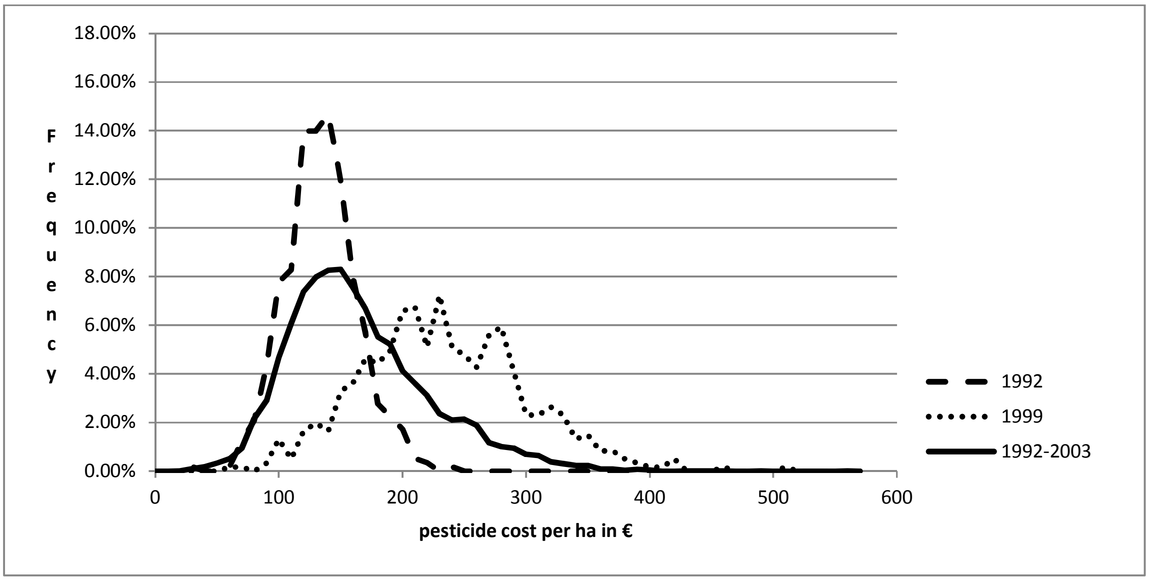
	Mean	CV	ROG (%)
Barley (quintals)	1096	0.988	3.71
Wheat (quintals)	2854	0.760	1.42
Rapeseed & diester (quintals)	984	1.033	3.65
Surface (ha)	89	0.743	2.46
Cost (€)	43002	0.837	1.98
Pesticide per ha (€)	160	0.357	1.16

ROG: tendency rate of growth, CV: coefficient of Variation

Data reveals a rather low and stable spread for the inputs (the coefficients of variation are less than one as well as the cost, surface and pesticide per ha). In addition, barley and rapeseed outputs increase at a higher level than wheat production. It can be noticed that the growth rate of cost is lower than the surface, hence the ratio of cost per ha is decreasing.

From figure 1, even though the standard deviation of pesticide per ha was relatively small during the period, one can notice that the sampling distribution can vary quite significantly depending on the different years of the period. This reveals some heterogeneity of pesticide uses among farmers who can individually adopt some different practices in order to respond to climatic or other random effects. In such a context, it is preferable to estimate cost function year-by-year in order to impose minimal assumptions with respect to the nature of annual technological shifts. Therefore, thanks to the panel nature of the sample, it is possible to define the previous different possibility sets (4) and (5) separately for each year between 1992 to 2003.

Figure 1: Sampling distribution of pesticide cost per ha[a]



a. Sampling distributions of pesticide cost per ha are drawn for the whole sample as well for years 1992 and 1999 which present the annual lower and higher standard deviations respectively.

4.2. Results

Consequently the linear programming problems (6) and (7) given in the methodology section of this paper are solved for each of the observations, meaning that all farms observed at year *t* are evaluated against two different annual technologies. One is composed of less extensive DMUs *(AE)* relative to the evaluated farm and the other is composed of more intensive DMUs *(AI)* also relative to the current evaluated farm. Then for each year, the two minimum costs are compared in order to select the best cost-practice for the evaluated farm. Annual cost analyses are presented in table 2.

Table 2: Observed and minimum costs between AE and AI

Year	% of cases where AE dominates AI	Observed Cost (€)	Minimum cost (€) for AE	Minimum cost (€) for AI	Gap between AI and AE (%)
1992	80.48	30 982	25 924	27 506	6.10
1993	73.01	26 761	21 089	23 244	10.22
1994	79.25	35 263	25 983	30 518	17.45
1995	85.81	49 683	34 490	42 363	22.82
1996	81.80	48 282	33 835	42 273	24.94
1997	82.07	47 829	36 614	41 964	14.61
1998	88.14	51 220	38 624	46 055	19.24
1999	87.34	58 321	40 156	50 588	25.98
2000	79.90	54 803	36 708	46 119	25.64
2001	70.18	39 660	32 800	33 466	2.03
2002	73.21	37 282	30 846	33 189	7.60
2003	77.53	33 148	26 502	28 975	9.33
Total	80.03	43 002	32 065	37 385	16.59

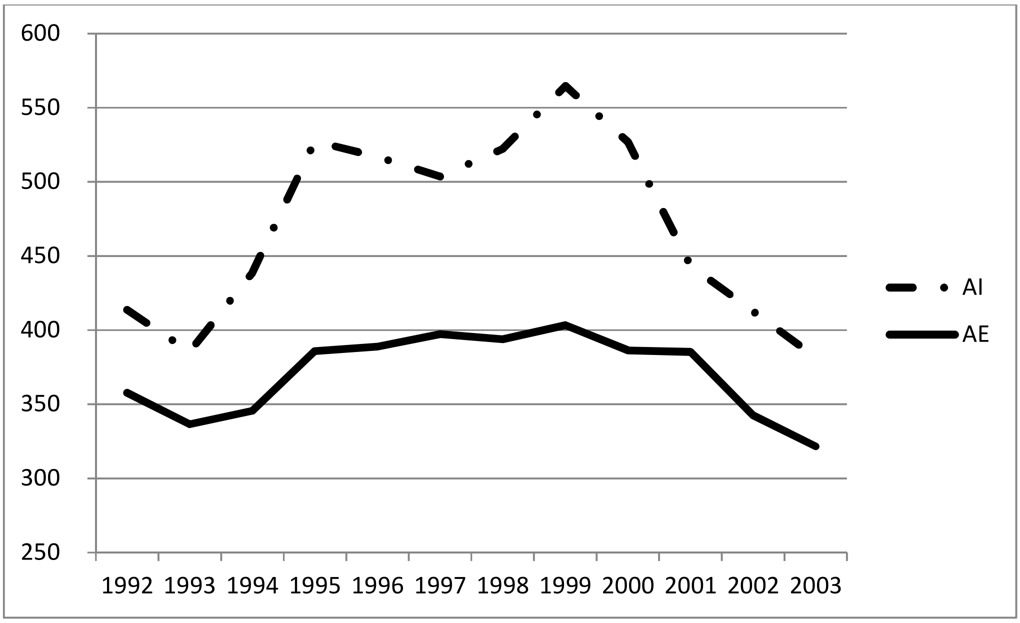
AE = Agricultural Extensification ; AI = Agricultural Intensification

Table 2 clearly shows that extensification dominates intensification in terms of cost irrespective of the annual context. Depending on the year, between 70% and 88% of farmers should operate under a more relatively extensive technology than a more intensive one (cf. column 1). The mean average of the total sample is around 80% of cost dominance in favour of the *AE* practices. The minimized costs of production under the two technologies and their gaps are shown in the last columns of table 2. Over the whole period, there is a positive gap between the two minimum costs in favour of *AE* practices which varies from 2% to 26%, the mean average of the gap is around 17%. Therefore from their actual practice, the cost reductions would be 25.4% if the farmers adopt *AE* technology against 13.1% for *AI*.

Where the results are presented in terms of cost per ha instead of global cost, the *AE* dominance is more spectacular. On average, the observed cost is 483 Euros per hectare while the costs of the *AI* and *AE* frontiers are respectively 477 and 374 Euros per hectare. Hence, between the two technologies, the difference is more than 104 Euros (28%). This confirms that the cost frontier under an extensive scenario is below that of an intensive scenario.

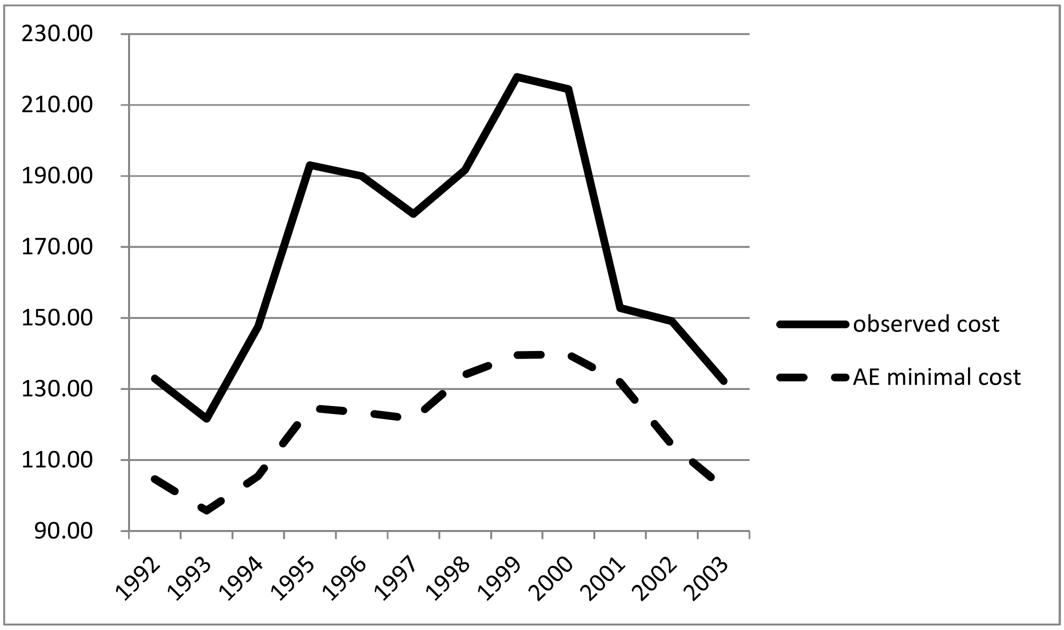
As shown in figure 2, the technology-gap varies in terms of Euros per ha between 49 Euros (15%) and 161 Euros (40%) always in favour of *AE* according to the different years. Therefore, in order to improve the cost of production, it is preferable to reduce the amount of pesticide use per hectare.

Figure 2: Minimal cost per ha in € (sample mean)



Now focusing our attention on pesticide uses per ha, it can be noted that the potential reductions of pesticide from the actual situations could reach 29% (sample mean) if the farmers adopt the best extensive practices. This is reflected by figure 3 where the gaps between the observed pesticide cost per ha and the *AE* minimal cost vary between 13% and 36% over the whole period, thus resulting in a huge saving of pesticides.

Figure 3: Cost of pesticide per ha in € (sample mean)



4.3.Discussion

The cost frontier comparisons with respect to practicing farms of both intensive and extensive technologies shows that the latter dominates the former in terms of cost. This is of particular interest because farmers can be stimulated to adopt more environmentally friendly practices which are at the same time the most efficient in terms of costs. However, the significant technology-gap between *AE* and *AI* lead us to wonder why intensive pesticide technique is still chosen by some farmers. Risk aversion is often cited as an explanation. On the other hand, few studies were able to precisely quantify this effect and no obvious conclusions can be stated (Carpentier et al., 2005). Moreover in this application, as mentioned earlier, the gap between the two technologies is not affected by any of potential inefficiency factors such as risk aversion since we focus on the comparison of two optimal benchmark costs. Other reasons may also be mentioned such as the brakes that agri-supply industries and farm consultants apply to the scattering of low pesticide or low input processes. This has been shown to be an important barrier to the adoption of low pesticide techniques in the case of French field crops (Barbier et al., 2010). In the case of UK cereal farmers, Sharma et al. (2010) have examined pest control strategies and they identified some other determinants of technologies adopted to manage pests. They found out that more recent farmers' technological choices may be path dependent on the previous adopted technologies and linked to socio economic constraints. More efficient practices seem to be better adopted by young and full time status farmers as they require innovative skill and greater managerial efforts.

Our results in the specific context of the Meuse department indicate cost savings of 25 % and a 29% reduction in pesticides which totally converge with conclusions drawn by Jacquet et al. (2011) at the national level for crop activities. Combining statistical data and expert knowledge to describe low-input alternative techniques, their data are used in a mathematical programming model to simulate the effects on land use, production and farmers' income of achieving different levels of pesticide reduction. They show that reducing pesticide use by 30% could be possible without reducing farmers' income and that on average the intensive techniques appear to be less efficient than techniques using smaller level of chemical inputs.

Although it is not easy to generalize them in conformity with all European agriculture, all these results established in French agriculture are also in line with the case of Dutch sugar beet growers (De Koeijer et al., 2002) where a positive correlation was found between managerial and environmental efficiencies and thus highlighting substantial potentialities to improve the sustainability of arable farming by better management. Despite the fact that numerous influencing factors (site conditions, regional pedo-climatic factors, etc.) considerably impact the environmental performance of farming (Pacini et al., 2003), the implementation of management practices directly modifiable by the farmer (farming system, crop rotation, tillage intensity, chemical application, etc.) has a significant influence on the efficient use of limited resources and, accordingly, on the potential of environmental endangerments.

This means that existing management techniques can concur with the principles of Good Agricultural Practices (GAP). A GAP protocol can serve as a reference tool for deciding at each step in the production process (e.g. seed choice, soil preparation, weed control), on practices and/or outcomes that are environmentally sustainable and socially acceptable, in order to produce safe and high quality crops in an economically sustainable manner. The implementation of GAP can help in opting for less hazardous agricultural technologies. Thus, sustainable farming systems must obtain high yields while minimizing environmental influence by using less chemicals per ha such as pesticides, thereby ensuring cost efficiency. To support this Gregory et al. (2002) highlighted that environmental advantage of low external inputs systems may not occur if their outcomes are expressed per unit of product rather than per unit area. Therefore, new practices seek to minimize environmental impacts and thereby increase the efficiency of external input costs in crop activities since fertilizers, manures and pesticides remain considerable challenges. Hence, the real challenge is therefore to develop more productive, yet more environmentally friendly production methods. Essentially this means improving the efficiency with which pesticides (and other inputs) should be used in a sustainable manner (Gregory and Ingram, 2000) ensuring the potential of cost reduction for farmers as stated in our application.

5 Conclusion

This paper checks if the minimized cost of production which is the individual interest of the farmer is in convergence with pesticide reduction per hectare thereby helping to know if extensification is a cost-competitive practice or not. This was achieved by developing an activity analysis framework to assess the cost frontier comparisons between extensive and intensive technologies. It is therefore important to note that the methodological originality of this paper is the cost dominance analysis between *AI* and *AE* which is done by a definition of dynamic reference sets relative to the evaluated farm. Moreover it is important to state that the results gotten in this paper are derived from the current technology of farms, thereby ensuring its feasibility.

Our results show that in 80% of cases, more extensive technology cost dominates the more intensive one. In addition, the results clearly reveal that the interest of farmers and the policy makers could converge by achieving a win-win strategy. Indeed, the benefit for the individual producer to reduce his cost by approximately 25% through the adoption of less intensive practices, leads to a reduction of pesticide per ha of about 29% which is in coherence with the ecological wishes of society.

Finally, in response to the question “Can society’s willingness to reduce pesticide use be aligned with farmers’ economic self-interest?” our answer is clearly “yes”. Obviously we can only draw this conclusion based on the crop activity in the Meuse department. However it appears to be coherent to previous studies that pertain to other French and Dutch regions and thus seems to be a relatively general outcome.

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CHAPTER III

The spread of pesticide practices among cost efficient farmers (paper II)

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The spread of pesticide practices among cost efficient farmers

Abstract

The purpose of this paper is to analyse the spread of pesticide practices with respect to crop production (wheat, barley and rapeseed) in French agriculture. In line with the principles associated with Good Agricultural Practices (GAPs) as emphasized in the current EU legislation on the sustainable use of chemical inputs, we evaluate the potential pesticide reductions for cost efficient farmers. This is made possible by conducting a double step analysis based on non-parametric robust technology. First, from a panel data of 650 farms over a 12 year period located in the French department of Meuse, we selected the cost efficient farms thanks to a Robust Free Disposal Hull (RFDH) technology. A second RFDH frontier analysis was run only on the selected cost efficient farms thus enabling us to reveal the units which minimize the pesticide use per hectare while maintaining constant yields. Therefore, all the different total cost efficient practices among farmers were evaluated in terms of pesticide per hectare and the minimum uses were selected. Our main conclusion is that the pesticide reductions per hectare for the cost efficient farms could reach 24%.

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

Word count: 7103

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1. Introduction

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, agro-ecosystems also contribute to negative environmental externalities: greenhouse gas (GHG) emissions, soil erosion, reduction in biodiversity, wildlife habitat destruction, less attractive rural landscapes from specialized crop cultivation, nutrient and pesticide runoff (World Bank, 2008; FAO, 2001).

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). It is important to note that over the last 60 years, farmers and growers have changed the way they produce food in order to meet the expectations of consumers, governments and more recently, food processors and retailers. In doing so, they have made many changes to the way they farm, including the intensive use of pesticides. This has been done principally in order to prevent or reduce agricultural losses to pests, resulting in improved yield and greater availability of food at a reasonable price, all year round (Cooper and Dobson, 2007). This belief is still widely shared by farmers, although society, environmentalists, consumers and public health professionals increasingly debate its serious social, environmental and health impacts (Cole et al, 2000). It is simply due to the fact that excess pesticide 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). Irrespective of the disadvantages attached to lots of pesticide usage, farmers continue to use it in an unsustainable manner since their main individual target is how to reduce their production cost without putting into consideration the interest of the society which entails the minimization of pesticide per hectare.

Therefore 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, since 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. Hence, the marginal cost of the use of pesticides by farmer, which comprises items such as the price of raw material, cost of labour of the person applying the pesticide and the material used in the application does not frequently include the damage done to fauna and flora, to water and soil quality and more importantly 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 dual objective: first to be cost competitive by minimizing the production cost followed by environmental efficiency through a minimization in the use of pesticide per hectare. 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. 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. This brings to mind that it is very possible for farmers to be totally cost efficient with either more or less pesticide use, dependent 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). This corroborates the fact that although European farmers are constrained by the European legislation, there are still some ways to reduce pesticide use thanks to Good Agricultural Practices (GAPs) adoption.

It is therefore now admitted that severe and long-term pressure exerted by government regulations such as the current EU legislation on the Directive 2009/128/EC as regards the sustainable use of pesticide and the new regulation (EC 1107/2009) represent a significant incentive to reduce pollution. The European Commission (EC) is promoting low pesticide-input farming in Member States and individual governments will be expected to create the necessary conditions for farmers to implement Integrated Pest Management (IPM). IPM relies on minimizing pesticide use through the complementary adoption of alternative methods to control pests, diseases and weeds. Community-wide standards for IPM are being developed and this will become mandatory across the EU from 2014. The aim of the European Parliament in the short to medium term is that the use of pesticides in farming should follow a declining trend. The percentage of land cultivated with reduced or low pesticide-input cropping systems, sometimes called integrated production, is therefore expected to increase very significantly as noted by the 'Thematic Strategy on the Sustainable Use of Pesticides' (EC, 2010).

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 analyse 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 analyse the efficiencies of different organizations (Daraio and Simar, 2005, 2007a, b; Balaguer-Coll et al, 2007). However, most of these researches have 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 650 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. In contrast to DEA framework, our study gives priority to the Robust Free Disposal Hull (RFDH) approach which presents the advantage to compare an evaluated farmer to a real observed practice by relaxing the convexity assumption of the production frontier.

In view of this, we conduct a double step analysis based on RFDH technology devised by Cazals, Florens and Simar (2002). It is well known that deterministic approaches like FDH or DEA are very sensitive to outliers that may be selected as referents for estimating efficiency. RFDH considers the potential presence of outliers thanks to Monte Carlo simulations which allow a multiple comparison of a farm to a large number of randomized referent sub-samples instead of a single comparison to the whole sample as in the usual FDH approach. This prevents the possibility of comparing a farm to an outlier. The final efficiency score is estimated by the average of the sub samples' scores. In the first step, the cost efficient farms are selected using this RFDH technology. In the second step, another RFDH frontier analysis is run but only on the cost efficient farms that were selected from the first step, thus revealing the units that minimize the pesticide use per hectare while maintaining constant yields. Therefore, in terms of pesticide use per hectare, all the different total cost efficient practices among farmers are evaluated with the best ones selected.

The remaining part of this paper is therefore organized as follows. In the next section, we give the methodology for RFDH 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 Robust Free Disposal Hull model

The methodology used in this paper is introduced one after the other. First we develop the FDH cost frontier which aims at selecting the cost efficient farms. Second the technical frontier which selects the best practice of pesticide uses per hectare among cost efficient farms is revealed.

Lastly, we state the RFDH framework which circumvents the sensitivity problem of the frontier to outliers which is the main drawback of the traditional FDH.

2.1. The cost Free Disposable Hull (FDH) frontier: aims at selecting the cost efficient farms

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 technology but only compares evaluated DMUs (Decision Making Units) 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[2] (see e.g. Cherchye et al, 2000).

Since production technologies are not always known, inefficiencies must be measured relative to some cost '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.

Let us consider that K DMUs are observed and we denote the associated index set by $\mathfrak{K} = \{1, \ldots, K\}$. 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 $\mathfrak{M} = \{1, \ldots, M\}$ and $\aleph = \{1, \ldots, N\}$ where $y = (y_1, \ldots, y_M) \in R_+^M$ $x = (x_1, \ldots, x_N) \in R_+^N$ and $w = (w_1, \ldots, w_N) \in R_+^N$ 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.

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

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 of the FDH:

A1: $(0,0) \in PPS, (0, y) \in PPS \Rightarrow y = 0$, that is, no free lunch or no production of output(s) without input(s);

A2: the set $A(C) = \left\{ (u, y) \in PPS : u \leq C \right\}$ of dominating observations is bounded by $\forall C \in R_{+}$, 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). In words, if it costs *C* to produce *y* then it is feasible to produce less than *y* at the same level of cost *C* or to produce an equal output amount *y* at a higher cost than *C*. Intuitively, wastes are always feasible and so producers can freely dispose of their productions.

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

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

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 that will be used in solving (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:

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

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.

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

In the above first step we select 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 $\mathfrak{K}' = \{1, \ldots, K'\}$ as the index set of cost efficient DMUs. In addition, we define the technology as a production process with *M* crop yields per hectare 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 hectare 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:

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

The LP program (4) aims at minimizing the pesticide use per hectare while maintaining or increasing yields of outputs per hectare. Therefore the efficient use of pesticides per hectare 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.

2.3. Robust Free Disposal Hull Frontiers: aims at preventing the influence of outliers

As stated above, with the usual input-oriented FDH an evaluated production plan is compared to all DMUs with higher outputs or the production plan using the lowest inputs. Therefore if an outlier defines the reference technology, the calculated efficiency score can be biased and some efficient farms could be probably not included for the second step analysis. To prevent this drawback, a selection of a large number of sub-samples from the reference set which allows the resampling and computation of the final score was done. It is estimated as the average of the FDH scores computed over all the previous sub-samples. With such an approach, the reference set changes over the different samples and the evaluated DMU is not constantly benchmarked against potential outliers which can be sometimes or not in the reference set. The final score can be interpreted as the inefficiency measured comparatively to the expected level of cost needed to reach the observed output level.

Following Dervaux et al (2009), we now describe its computational algorithm. First, for a given evaluated production plan $\left(C_j,\ y_j\right)$, a random sample of size m with replacement is drawn from the reference set which is defined by:

$$\Lambda(C_j, y_j) = \left\{(C_k, y_k) : y_j \le y_k, k \in \mathfrak{K}\right\} \qquad (5)$$

Afterwards, the FDH score relative to this sample is then computed:

$$\delta_m(C_j, y_j) = \text{Min}\left\{\delta : (\delta C, y_j) \in \Lambda(C_j, y_j)\right\} \quad (6)$$

The optimal value δ_m^* is smaller than unity for inefficient observations and is equal or greater than one for efficient ones since the evaluated DMU j can be included or not in the random sample. More explicitly, if an evaluated DMU is efficient but is not a member of the sample, its score is greater than one and can be considered as "super-efficient".

Lastly, where B is the number of Monte-Carlo replications, we repeat this for b = 1…B, therefore our final score is computed as:

$$\delta(C_j, y_j) = \frac{1}{B} \sum_{b=1}^{B} \delta_m^{*b}(C_j, y_j) \qquad (7)$$

Thus, all evaluated DMUs with $\delta(C_j, y_j) \geq 1$ are qualified to be cost efficient and are selected for the second step used in evaluating the best practice of pesticide uses.

Referring again to the efficiency in terms of pesticide utilization, we reconsider the previous alternative technology which links output yields per hectare to the intensity level of pesticide use per hectare and described in subsection 2.3. On that technology we repeat the RFDH approach described earlier.

First, for a given cost efficient production plan $\left(C_j,\, y_j\right)$ characterized by its vector of output yields $\left(\frac{y}{l}\right)_j = \left(\left(\frac{y}{l}\right)_j^1, \ldots, \left(\frac{y}{l}\right)_j^M\right) \in R_+^M$ and its ratio of pesticide per hectare $\left(\frac{p}{l}\right)_j \in R_+$ a random sample size m with replacement is drawn from the reference set which is defined by:

$$\Omega\left(\left(\frac{p}{l}\right)_j, \left(\frac{y}{l}\right)_j\right) = \left\{\left(\left(\frac{p}{l}\right)_k, \left(\frac{y}{l}\right)_k\right) : \left(\frac{y}{l}\right)_j \leq \left(\frac{y}{l}\right)_k, k \in \mathfrak{K}\right\} \quad (8)$$

Afterwards, the FDH Score relative to this sample is then computed

$$\phi_m^*\left(\left(\frac{p}{l}\right)_j, \left(\frac{y}{l}\right)_j\right) = \text{Min}\left\{\phi : \left(\phi\left(\frac{p}{l}\right), \left(\frac{y}{l}\right)_j\right) \in \Omega\left(\left(\frac{p}{l}\right)_j, \left(\frac{y}{l}\right)_j\right)\right\} \quad (9)$$

As before, we repeat this for b = 1…B, therefore our final score is computed as

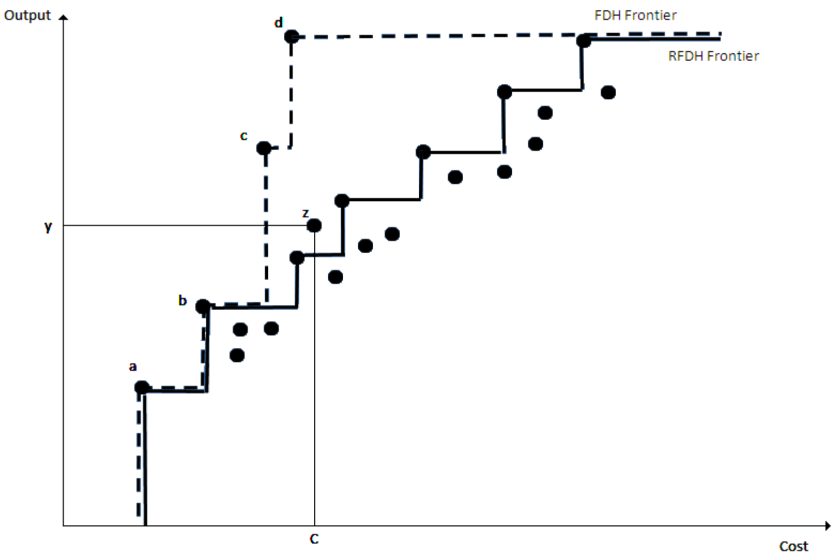
$$\phi\left(\left(\frac{p}{l}\right)_j, \left(\frac{y}{l}\right)_j\right) = \frac{1}{B} \sum_{b=1}^{B} \phi_m^{*b}\left(\left(\frac{p}{l}\right)_j, \left(\frac{y}{l}\right)_j\right) \qquad (10)$$

ϕ is equal or greater than one for pesticide minimizers and is smaller than unity for farms that could reduce their pesticide use intensity of $(1-\phi)\%$

Under such a RFDH approach, two parameters 'B' (number of replications) and 'm' (size of the sub-samples) are introduced to measure the efficiency scores. As it will be shown in our application, 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 'm' plays a more decisive function. One can note that if 'm' is tending to infinity, usual FDH scores are recovered since all DMUs have a very high probability to be included in each sub-sample and consequently each firm is evaluated against all production plans of the initial reference set. For any applied analysis, a value of m has to be chosen. In fact, in most applications the sub-sample size of potential referents for each evaluated firm varies a lot (from 1 to 624 in our data). 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 size of the dominant sub-sample instead of a specified absolute value of the parameter 'm'. It guarantees the same proportion of observations in each sub-sample used in the 'B' replications independently of the size of the sub-sample.

Figure 1 illustrates the RFDH framework compared to the usual FDH model in the case of a cost function with only one output. The broken line indicates the FDH frontier which is built with two observations (a, b) and two outliers (c, d) initially present in the total reference set. Therefore, all other DMUs will be declared as cost inefficient and are excluded from the second step. Thanks to the RFDH approach, DMU 'z' for instance, will be evaluated as cost efficient. First, all the 12 production plans producing more or equal to farm 'z' are considered as potential dominants. Among them, B random sub-samples of relative size m are drawn (for instance, if B = 100 and m=0.75, 100 random subsamples of 9 observations are obtained). Then one hundred FDH scores are calculated (one by sub-sample) and the final efficiency measure is estimated as the mean of all the scores. Typically, this average measure is less influenced by the outlier 'c' than the usual FDH score. Indeed, DMU c will not always be the referent of 'z' which therefore can obtain a final average score greater or equal to one and thus declared as cost-efficient. Here it is important to state that with a traditional FDH frontier, the presence of outliers tends to reduce the number of cost efficient farms on which the pesticide reduction analysis has to be established in the second step. In the same vein, the RFDH model transposition of step 2 aims at estimating the cost reduction in terms of pesticide per hectare with a given level of yield. For any evaluated farm, this is robustly estimated compared to the FDH score which is largely influenced by the presence of outliers.

Figure 1: Comparison of cost frontier estimation between Robust Free Disposable Hull (RFDH) and Free Disposable Hull (FDH) approaches:
an illustrative case with one output



Having this in mind, we conducted a two-step application with the use of this RFDH approach in order to characterize the farms with the best practice. Firstly, RFDH 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 hectare, 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 hectare in percentages and Euros.

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 around 650 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 7813 observations[3]. 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 hectares.

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 hectare 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 hectare.

[3] Contrary to a balanced panel data where each farm is observed every year over the whole period, an unbalanced panel is characterized by farms which can disappear or appear during specific years. As a result, the total number of observations may vary according to the different years as it is shown in table 3.

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

	Mean	CV[1]	ROG[2] (%)
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 (hectares)	85.2	0.726	2.1
Cost (€)	34742	0.826	2.3
Pesticide (€)	11523	0.905	3.7
Pesticide per hectare (€)	128	0.277	1.6

(1)CV = coefficient of variation is calculated by the division of standard error and the mean of the considered variable
(2)ROG = tendency rate of growth is estimated by a linear regression between the considered variable expressed in logarithm terms and the time

3.2. Results and discussion

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

Following the computational algorithm described in subsection 2.4, the first LP problem (3) is solved for each of the observations to select the cost efficient farms. The RFDH cost frontier is defined year by year in order to take eventual climatic or other contextual effects into account.

Table 2 presents the sensitivity of the results from the Monte-Carlo replications for different values of ‘B’ and ‘m’ for only year 1992. It appears that the number of replications ‘B’ does not influence the results significantly and even with a small number of replications, the selection of cost efficient farms is a robust procedure. Therefore, our application will limit B = 100. The relative size of the sub-sample ‘m’ plays a more central role. Including only 5% or 10 % of the farms in the replicated sub-samples, the percentage of cost efficient farms is near 100%

indicating that for each evaluated DMU the number of comparisons is too small to find more efficient farms with lower costs. By contrast, the FDH specification ($m = \infty$) reveals the significant impact of outliers that decrease the number of costs efficient farms to 55%. Although there is no regular rate of m, 0.75 seems to be a good trade-off between reducing the influence of outliers (as in the FDH approach) and including a sufficient number of production plans in the sub-samples to guarantee a reasonable set of possible comparisons among farms.

Table 2: Monte-Carlo replication results showing
the percentage of cost efficient farms for year 1992

m =	0.05	0.1	0.25	0.5	0.75	1	∞ (FDH)
B = 1000	98.6	96.7	85.9	71.7	64.5	59.1	54.8
500	98.6	96.8	85.5	71.9	64.5	59.5	54.8
100	98.4	96.5	85.5	71.2	64.1	58.5	54.8
50	98.7	96.5	85.4	71.9	63.9	59.6	54.8

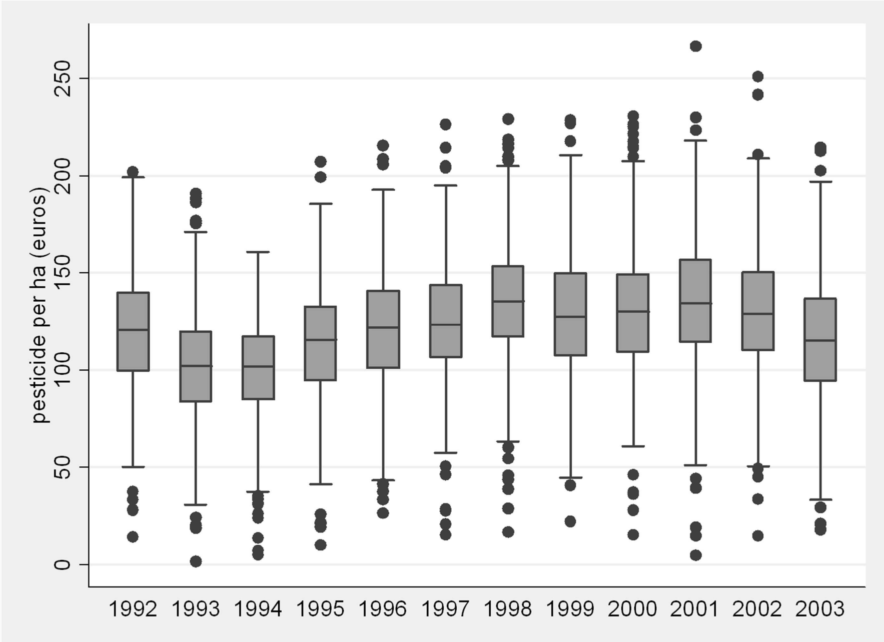
In the first step, the selection of the cost efficient farms is therefore conducted for B=100 and m=0.75 over the whole period (1992-2003). The results are presented in table 3. It shows a selection of 4605 cost efficient farms out of a total of 7813 observations (approximately 59%). This percentage does not vary too much over all the period with a minimum of 55% observed in 2001 and a maximum of 64% in 1992.

Table 3: Selection of cost efficient farms from the total observations for the first step analysis with B= 100 replications and a relative size of the referent subsample m=75%

Year	Total number of observations	Number of cost efficient farms	Percentage of efficient farms
1992	629	403	64.1
1993	651	400	61.4
1994	661	389	58.9
1995	687	413	60.1
1996	664	407	61.3
1997	676	404	59.8
1998	672	378	56.3
1999	665	389	58.5
2000	655	371	56.6
2001	634	351	55.4
2002	620	353	56.9
2003	599	347	57.9
Total	7813	4605	58.9

For these cost efficient farms, the spread of pesticide per hectare practices is illustrated by a yearly box plot in figure 2. Over the period, the median fluctuates between 102 and 136 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 33% of the mean of pesticide cost. The gap between the lower and upper adjacent values is quite large (around 150 euros each year), thus reflecting how large the spread of cost efficient farmers are in pesticide practices. This therefore reveals 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 2: Spread of farmers' pesticide cost per hectare
for the cost efficient farms selected in step 1



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 frontier which links the yields and pesticide cost per hectare is also defined year by year. In table 4 the RFDH results are compared to the FDH ones. One can note that the presence of outliers in the FDH approach overestimates the potential of pesticide per hectare reduction between 2.7% and 7% depending on the years.

Retaining the RFDH results, if all the cost efficient farms align with the best practices to the frontier, one could reduce pesticide cost per hectare with 24% at the sample mean and between 17% and 28% according to the different years. As reflected in table 5, these percentages lead to an average pesticide expense of 29€ per hectare which means a global value of pesticide reduction of more than 2600€ per farmer. Thus, this amount represents 7.4% of his production cost.

Table 4: Pesticide per hectare for the cost efficient farms: comparison between Free Disposable Hull (FDH) and Robust Free Disposable Hull (RFDH) cost frontiers

Year	Pesticide per hectare reduction (%) FDH	Pesticide per hectare reduction (%) RFDH[1]	% Difference FDH-FRDH
1992	34.8	27.7	7.1
1993	26.5	22.3	4.2
1994	27.9	23.5	4.4
1995	27.8	24.2	3.6
1996	28.4	24.2	4.2
1997	27.4	23.7	3.7
1998	26.2	22.1	4.1
1999	28.7	23.8	4.9
2000	20.3	17.5	2.8
2001	28.8	23.8	5.0
2002	26.9	23.0	3.9
2003	32.4	28.0	4.4
Total	28.0	23.6	4.2

[1]RFDH estimated with m=0.75 and B=100

Table 5: Cost reductions in pesticides with the Robust Free Disposable Hull (RFDH) cost estimation

Year	Pesticide reduction/hectare (€)	Value of pesticide reduction (€)	% pesticide reduction share in total cost
1992	33.4	2 922	9.2
1993	22.9	1 489	5.7
1994	23.6	1 708	6.0
1995	27.6	2 302	7.1
1996	29.5	2 612	7.2
1997	29.6	2 865	7.1
1998	29.9	3 233	7.4
1999	30.6	2 830	7.2
2000	22.9	2 375	6.1
2001	32.2	3 195	8.5
2002	30.1	3 084	8.3
2003	32.4	3 031	9.4
Total	28.7	2 622	7.4

Table 6 gives us a more detailed analysis and shows that nearly 18% of the total sample has good pesticide practices in the sense that they are not dominated by other DMUs, 39% of the total sample could reduce pesticides between the range of 0 and 25 while 43% 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 6: Frequencies of farms for different classes of pesticide per hectare reductions (%)

Year	Class 1 no reduction (0%)	Class 2 from 0% to25% of reduction	Class 3 Greater than 25% of reduction	Total number of farms
1992	10.4	35.7	53.8	403
1993	19.8	42.0	38.3	400
1994	20.8	33.9	45.2	389
1995	21.5	35.1	43.3	413
1996	16.2	40.0	43.7	407
1997	17.3	38.4	44.3	404
1998	15.3	46.3	38.4	378
1999	15.9	42.9	41.1	389
2000	22.1	52.0	25.9	371
2001	14.0	43.3	42.7	351
2002	23.2	35.1	41.6	353
2003	18.2	29.7	52.2	347
Total	17.9	39.5	42.6	4605

These frequencies are directly linked to the characterization of the above pesticide reductions into classes as reflected in table 7, thus showing its eventual relationship with some structural variables such as age, land size, labour quantity per hectare, degree of crop specialisation, and 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 the 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 7: Characterization of pesticide reduction and its link with some structural variables

Variables	Class 1 no reduction (0%)	Class 2 from 0% to25% of reduction	Class 3 Greater than 25% of reduction	Average total
Age	43	43	44	44
Total Land Surface (hectare)	188	186	176	182
Total labour per hectare[1]	0.013	0.013	0.013	0.013
Subsidies on total turnover (%)	20.8	21.5	21.1	21.2
Crop specialisation(%)[2]	46.0	48.6	45.5	46.8
Wheat share on crop turnover (%)	52.0	51.6	56.3	53.7
Barley share on crop turnover (%)	20.6	20.7	19.4	20.1
Rapeseed share on crop turnover (%)	27.4	27.8	24.3	26.2

[1]In equivalent full time person per year and per hectare
[2]Crops on total turnover

This average reduction of 24% in pesticide uses in the specific context of the Meuse department is in line with conclusions drawn by Jacquet et al. (2011) at the national level for crop activities. Mixing statistical data with expert knowledge to describe low-input alternative techniques, they used a mathematical programming model to evaluate the effects on land use, production and farmers' revenue of attaining different levels of chemical reduction. They revealed the possibility of diminishing pesticide by 30% while maintaining the farmers' revenue thanks to a low yield decrease. Beyond the fact that numerous conditions (sites, local pedo-climatic effects, etc.) influence the environmental performance of farming (Pacini et al., 2003), management practices directly adjustable by the farmer (farming system, crop rotation, tillage intensity, chemical application, etc.) significantly impact the use of limited resources and, therefore the potential of environmental threatening. This means that existing cost efficient management techniques in conformity with the present national and/or European legislations can concur more or less with the principles of Good Agricultural Practices (GAP) promoted by the European directives. Thus among the different types of cost efficient agricultural practices, sustainable farming systems with low chemical inputs compared to more intensive practices are able to obtain comparable yields while minimizing environmental influence by using less pesticides per hectare.

However, this significant pesticide gap between the different agricultural practices leads us to wonder why intensive pesticide technique is preferred by some farmers. Infestation level is often mentioned as an explanation. At this junction it is important to note two elements. First all farms in the sample data are located in a homogenous pedo-climatic area and as such they receive the same recommendations for pesticide treatments by the local monitoring authorities. Second all our results are evaluated only for the cost efficient farmers which are simultaneously technically and allocatively efficient. If some producers are locally infested, they would be excluded from the final analysis thanks to the first selection step as they would probably appear technically inefficient. Risk aversion is also mentioned as another explanation. On one hand, few studies were able to precisely quantify this effect and no obvious conclusions can be stated (Carpentier et al., 2005).

On the other hand in this application, as mentioned earlier, the pesticide reduction possibilities are estimated only for the cost efficient group and therefore risk averse farmers who would use more pesticides (all things being equal) may also be considered technically and/or allocatively cost inefficient and would be excluded from the final results. Finally we have to mention that our application infers that a lower cost of pesticide is correlated to a less toxic compound of pesticide treatment. This is not always the case as new chemical components considered more environmentally friendly could be more expensive. Unfortunately, data concerning quantity and toxicity of the different molecular components are very rarely available at the farm accounting data level.

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 RFDH frontier approach. The first step is a RFDH analysis used as a filter to select all the cost efficient farms. Then a second step runs a RFDH 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.

Compared to a traditional FDH methodology, our RFDH framework allows us to reduce the effect of potential outliers on the frontier estimations. Thanks to this robust approach, more than 64% of observations are declared cost efficient instead of only 55% for a FDH frontier in the first step. In addition, the comparison between the two benchmarks gives a difference of pesticide per hectare reductions around 4% in the second step. Our main report concludes that the spread of pesticide use among cost-competitive farmers of the French Department of la Meuse is still large since the pesticide reductions per hectare could reach 24% on the average. Although it is not easy to generalize it in conformity with all European agriculture, this conclusion established for our sample totally converges with results drawn by Jacquet et al. (2011) at the National level for crop activities. This pesticide reduction of 24% leads to a reduction of nearly 2,600€ per farmer which represents 7.4% of his production cost and may concern various types of cost efficient producers of this department. Results show that in French agriculture where pesticide expenses per hectare is high, there are still lots of improvements to be achieved in terms of pesticide practices.

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This appendix comes from an earlier version of the paper and presents an econometric analysis of the relationship between pesticide reductions and output yields over time.

APPENDIX

Relationship between pesticide reductions and output yields over time

We now focus on time variations of the three output yields (*wheatY, barleyY, rapeseedY*) 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 (11). To control for size, crop specialisation and climatic effects, we introduce the land surface *(SAU),* the crop value share on total turnover *(CropSpe)* 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 the table below.

$$pestred/ha_{it} = \beta_w wheatY_{it} + \beta_b barleyY_{it} + B_r rapeseedY_{it} + \gamma SAU_{it} + \theta CropSpe_{it} + \alpha_i + \delta_t t + \mu_{it} \quad (11)$$

With respect to table 8, it is clearly obvious that yield increases over time for wheat, barley and rapeseed negatively affect potential pesticide reductions due to their respectively high level of significance. The effects of a yield variation on pesticide per ha reduction appears more ample for rapeseed and wheat than for barley. These results therefore conclude 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 flexibility in the management of pesticide.

Table showing the within model Regression Analysis Results

Variable	*Coefficient*	*Erreur Std*	*P-value*
wheatY	-0.0038	0.0003	0.0000
barleyY	-0.0019	0.0001	0.0000
rapeseedY	-0.0054	0.0003	0.0000
SAU	0.0001	0.0001	0.1670
CropSpe	0.0886	0.0391	0.0240
d1	-0.0005	0.0118	0.9670
d2	-0.0011	0.0112	0.9220
d3	-0.0383	0.0109	0.0000
d4	0.0157	0.0108	0.1440
d5	0.0648	0.0118	0.0000
d6	0.0255	0.0109	0.0190
d7	0.0391	0.0115	0.0010
d8	0.0622	0.0111	0.0000
d9	-0.0202	0.0111	0.0700
d10	-0.0264	0.0108	0.0150
d11	-0.0064	0.0111	0.5640
_cons	0.6508	0.0303	0.0000

+ or - : sign of estimated coefficient

CHAPTER IV

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

(paper III)

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

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. In this paper we consider pesticide as an indirect input which does not impact output directly but they act as a damage abatement input controlling pest infestations. We therefore asses the cost dominance in direct inputs between technologies using less or more pesticide levels per ha. Direct cost functions excluding pesticide input 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 differentiated 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 in direct inputs 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).

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 in inputs influencing output directly (such as land, fertilizer, labor, energy or equipment) than systems with higher pesticide consumption in French agriculture. Using data from 707 farms located in the Eure & Loir Département[4] in year 2008, cost estimations including all direct inputs but excluding pesticide 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 direct 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 five specificities. First, as our chosen criteria to distinguish the two technologies is the level of pesticide per ha, pesticide input has to be exogenously treated. In that way, the definition of the technology is solely focused on the inputs which directly influence outputs. Therefore, the direct cost regroups expenses concerning land, fertilizer, labor, capital and other intermediate inputs but excludes pesticide cost. Second, 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. Third 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. Fourth, 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

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

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. Fifth, 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.

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.

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.

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.

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. 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. Thus, the production technology links the outputs y obtainable from direct inputs, taking into account potential losses which depend on pesticide use as follows:

$$f(\mathrm{y},\mathrm{x}^{\mathrm{D}},g(x^p))=0 \text{ with } g(x^p)\in[0,1]$$
$$\text{and } f(\mathrm{y}^*,\mathrm{x}^{\mathrm{D}},1)=0$$

y* can be interpreted as the maximal potential outputs obtainable from direct inputs when no pest attack happens or when pesticide uses eradicate infestations.

Therefore, the abatement coefficients θ can be introduced as:

$$\theta=\left(\frac{y_1}{y_1^*},\ldots,\frac{y_M}{y_M^*},\right)\text{with } \frac{y_m}{y_m^*}\leq 1\ \forall m\in\mathfrak{M}$$

As we can consider that the farmer plans his potential production through the direct inputs but ignoring the eventual future pest infestations, it can be reasonably assumed that he minimizes his direct cost without taking into consideration the abatement coefficients and the pesticide uses. Thus, focusing on the direct input technology $\mathrm{y}^*=f(\mathrm{x}^D,1)$, and using the general framework as developed by Shephard (1953), the production possibility set (denoted as *T)* of all feasible input and output vectors can be defined as follows:

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

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

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

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

A3: *T* is closed;

A4: for all $(\mathbf{x}^{\mathbf{D}},\mathbf{y}^*) \in T$, and all $(\mathbf{u}^{\mathbf{D}},\mathbf{v}) \in \Re_+^{N+M}$, we have

$(\mathbf{x}^{\mathbf{D}},-\mathbf{y}^*) \leq (\mathbf{u}^{\mathbf{D}},-\mathbf{v}) \Rightarrow (\mathbf{u}^{\mathbf{D}},\mathbf{v}) \in T$ (free disposability of direct inputs and outputs);

A5: *T* is convex.

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

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

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

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:

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

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

The basic true cost model

Formally, the direct cost is equal to $C = \mathbf{w^D}(\mathbf{x^D})^t$ 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[5]. Thanks to the previous definitions (3) and (4), we are now able to define the two cost functions including the direct input costs, respectively C_{LPU} and C_{HPU}. They are therefore defined as:

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

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

Then for the above two technologies, the estimation of a direct 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 $(\mathbf{y^{*o}})$.

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

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

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

[5] 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).

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.

Unfortunately, the maximal potential outputs $\mathbf{y}^*$ obtainable from direct inputs are unobserved in our sample since we do not have piece of information about pest infestations and their effects on outputs. Therefore we cannot directly estimate models (7) and (8). In the following, we describe the strategy used to circumvent this difficulty.

The estimated cost model

The true cost model defined above requires the knowledge of y* (as the expected output level or ex-post observed output) and the observed damage abatement coefficients. However in real world, these pieces of information are very difficult to obtain on a large sample sourced from farm account data, as it is the case in this paper. A non obvious question is: can we replace $\mathbf{y}^*$ in the model by the observed ex-post output $\mathbf{y}$ without altering the conclusions on the direct cost dominance between the two technologies HPU and LPU?

We argue that it is effectively possible by distinguishing two situations. First, in event of no pest attack, it is clear that $\mathbf{y}^*=\mathbf{y}$ and models (7) and (8) estimate the true direct cost. Second, if there are pest infestations, then damage becomes a key factor. If pesticide uses fully eradicate pest infestations without output damages, obviously $\mathbf{y}^*=\mathbf{y}$. Otherwise, in a context of damage occurring and if the use of pesticide is assumed with a consideration of the fact that its application protects crop then $\mathbf{y}^* \geq \mathbf{y}^{\mathbf{HPU}} \geq \mathbf{y}^{\mathbf{LPU}}$. In this last situation, effective cost dominance can be stated in favor of the LPU technology when optimal solutions of models (7) and (8) show that $\tilde{C}_{LPU} \leq \tilde{C}_{HPU}$ even though $\mathbf{y}^{\mathbf{HPU}} \geq \mathbf{y}^{\mathbf{LPU}}$. In the other case where $\tilde{C}_{LPU} \geq \tilde{C}_{HPU}$, no conclusion can be drawn.

At this stage, it is worth to note that while $\mathbf{y}^* \geq \mathbf{y}^{\mathbf{HPU}} \geq \mathbf{y}^{\mathbf{LPU}}$, replacing $\mathbf{y}^*$ by $\mathbf{y}$ in models (7) and (8) will lead to estimating an upper bound of the true direct cost.

Indeed, the omission of pesticide uses in the estimation of the cost function is always in favor of HPU technology since pesticide applications increase the abatement coefficients without any additional direct cost. Consequently, if the HPU best practices are less cost efficient than the LPU ones, a real cost dominance of the latter technology can be established. Actually, this cost dominance comes from factors of direct cost inefficiency and does not seem to be attributable to other causes such as pest infestations and treatment cost. Finally, because HPU technology uses more pesticide per ha than the LPU, it is clear that the addition of this last input to the direct cost will lead to an amplification in the gap between the two technologies.

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.

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 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 $s^o = (s_1^o, s_2^o, ..., s_M^o)$, a sample b of size G with replacement is drawn from the reference set and is defined by:

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

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.

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, common concern as regards pesticide use in Eure & Loir Département in France is addressed through our empirical application, results and comments.

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 direct 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). The total cost is finally assessed as direct cost plus 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 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. Lastly the capital expenditures are evaluated by the amortization related to equipment and building.

The descriptive statistics showing 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 direct cost, 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
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
Direct cost	139 199	85.1	38.4
Pesticide	24 422	14.9	44.9
Total cost	163 621	100.0	38.2
Direct cost per ha	1 137		23.2
Pesticide per Ha	196		24.8
Total Cost per Ha	1 333		21.2

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 direct cost and/or 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

Simulation procedure

In our empirical work *LPU* and *HPU* direct 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 direct 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.

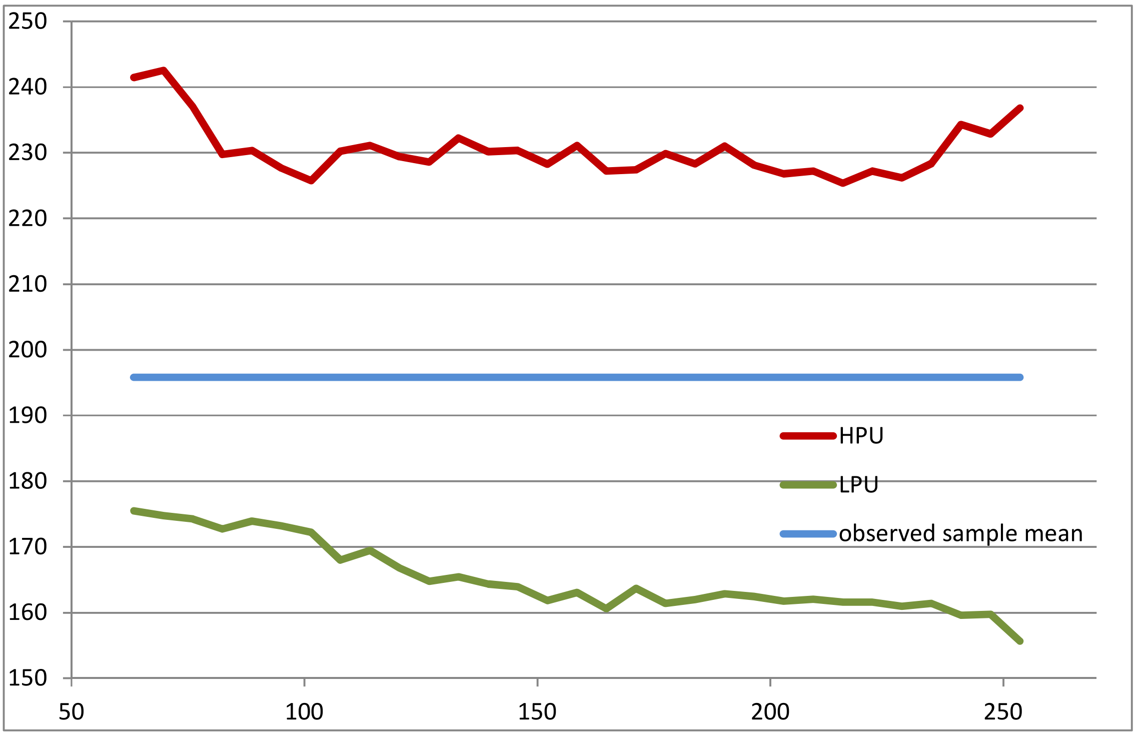
Results

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 10% on average and can reach 14% for a surface around 170ha while it is reduced around 8% 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 direct cost is the lowest (790€) while the optimal size for LPU technology is varying between 100ha and 170 ha at a minimum average cost of 730€. At this stage it is essential to recall that for each point of the two direct 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 direct cost per ha for Low Pesticide Uses (LPU) and High Pesticide Uses (HPU) Technologies

The direct 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 excluding 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 direct cost and exceeds 28%. If we consider the observed pesticide cost of 196€ per ha, by adopting the LPU technology farmers would be able to reduce this specific expense about 15.6% on average. Obviously, the gap of the total cost including pesticides between the two technologies is amplified to 14% on average with a maximum of 17% and a minimum of 11%.

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 20% on other operational inputs (fertilizer and seeds), 32.2% on capital amortization and 12.1% of labor. These inputs appear to be complementary with pesticide and indicate that a less intensive technology in the main elements of the direct cost induces lower pesticide treatments. Otherwise the LPU technology seems to use a bit more other intermediate consumptions than HPU (+7.4%) as reflected in table 3.

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

	Fertilizer +Seeds	Land	Intermediate Consumptions	Capital Amortization	Labor	Pesticide
LPU	189	190	164	104	124	164
HPU	237	190	153	153	141	230
differences (%)	20.1	0	-7.4	32.2	12.1	28.8

Therefore as displayed in table 4, the structures of the two direct cost functions 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. Direct Cost Shares by Specific Inputs (in % of direct cost)

	Fertilizer + Seeds	Land	Intermediate Consumptions	Labor	Capital Amortization	Total
LPU	24.5	24.7	21.3	16.1	13.5	100.00
HPU	27.1	21.8	17.5	16.1	17.5	100.00
differences	-2.6	2.9	3.8	0.0	-4.1	

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 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
Direct cost per ha (€)	1 384	1 031	1 045	1 221	1 288
Total cost per ha (€)	1 664	1 255	1 250	1 457	1 508
Revenue/ha	1 957	1 290	1 274	1 760	1 742
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

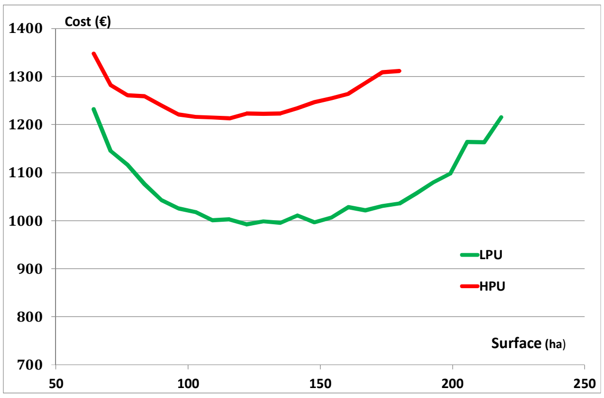
This follows that for each crop mix, the initial procedure is duplicated by varying the size dimension in a same scale interval between 60ha and 250 ha. Table 6 and figure 3 show that LPU technology dominates HPU technology for all output mixes. The gap between the two technologies appears to be highest for mix "legumes-durum-corn" and lowest for mix "wheat-rapeseed-proteaginous peas" respectively 17% and 5.7% on average. In addition, one can notice that for all mixes, the LPU technology presents a quite large interval of optimal size (approximately around 120-165 ha) characterized by constant returns to scale which does not seem so big for their respective HPU technologies (104-123 ha). In terms of pesticide use per ha, the LPU direct cost dominance permits to save between 25.6% and 31% of pesticide inputs according to the different crop mixes. All these figures reveal to a greater extent that direct 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. Consequently, as HPU uses more pesticides the total cost dominance of LPU is strengthened.

Table 6. Cost Dominance Characteristics by Crop Mix

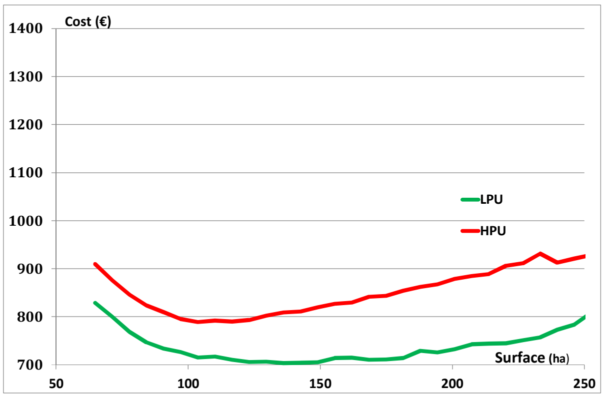
	Legumes-Durum-Corn	Wheat-Winter Barley-Rapeseed	Wheat-Rapeseed-Proteaginous Peas	Sugar beet-Spring Barley-Hard Wheat	Durum-Corn-Potatoes
LPU cost per ha (€)	1046	742	783	991	966
HPU cost per ha (€)	1246	870	835	1064	1075
Direct cost difference (%)	19.1	17.1	6.7	7.4	11.2
LPU pesticide per ha (€)	185	161	156	164	162
HPU pesticide per ha (€)	261	237	216	219	224
Pesticide difference (%)	40.7	44.2	39.0	33.3	37.6
LPU optimal size (ha)	110-150	125-150	140-170	120-200	103-155
HPU optimal size (ha)	96-115	103-117	115-121	115-139	92-121

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

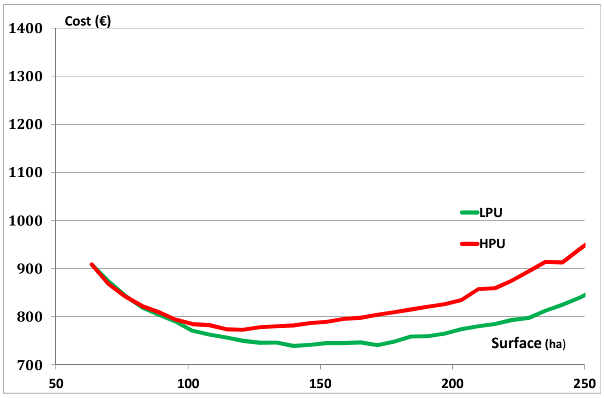
Mix Legumes-Durum-Corn



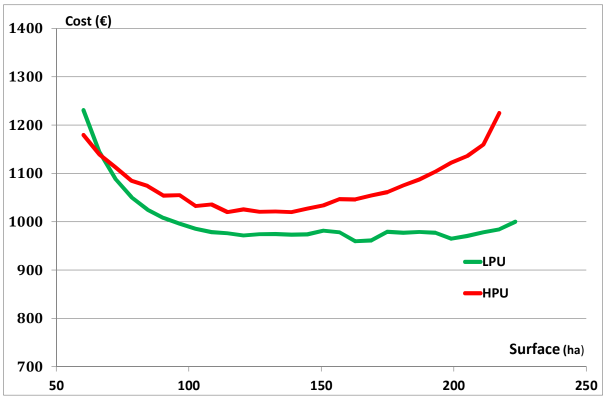
Mix Wheat-Winter Barley-Rapeseed



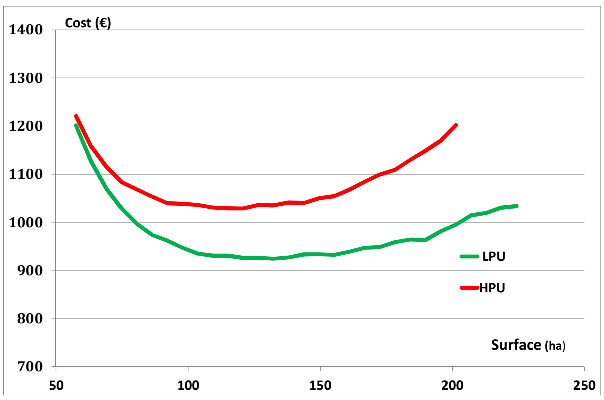
Mix Wheat-Rapeseed-Proteaginous Peas



Mix Sugar beet-Spring Barley-Hard Wheat



Mix Durum-Corn-Potatoes



Discussion

Our results in the specific context of the Eure & Loir Département in 2008 therefore signifies a difference of 10% for direct input cost and a gap of 28% of pesticide use per ha between the two technologies in favor of LPU. But from the average observed use in pesticide, this leads to 15.6% 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.

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, Karagiannis and Tzouvelekas (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 specifications 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.

Conclusion

A competitiveness of technologies in terms of direct input cost excluding pesticide is established for different surface sizes, crop-mixes and pesticide uses by exploring the direct cost function over its whole domain of definition. Thus, it deals with a framework which aims at assessing the cost dominance between technologies exogenously distinguished by 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 direct cost in comparison to a high pesticide use which stimulates environmental burden. Consequently, by including pesticide expenses to obtain the total cost , the above conclusion is reinforced. 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, direct 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.

It is worth to recall that our work differentiates the maximal potential outputs obtainable from direct inputs from the ex-post observed output level conditioned by the low or high level pesticide uses. Therefore, the omission of pesticide uses in the estimation of the cost function is always in favour of *HPU* technology and will lead to estimating an upper bound of the true direct cost. Since our results strongly show that Low Pesticide Use *(LPU*) dominates High Pesticide Use (*HPU*) in terms of direct and total costs, we can conclude unambiguously that *LPU* is more cost effective than *HPU.* This 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 year 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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