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CONSISTENCY BETWEEN ENVIRONMENTAL AND COMPETITIVENESS OBJECTIVES OF AGRICULTURAL POLICIES :

THE ROLE OF HETEROGENEITY IN NATURAL RESOURCE ENDOWMENT

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1. Introduction

In creating a new legal framework for agricultural policies and trade, the Uruguay Round Agreement on Agriculture has initiated a movement towards liberalisation of international markets for agricultural products. Such a movement is likely to intensify competition in world agricultural markets and lead the main exporting countries (particularly the European Union and the United States) to establish goals of enhancing the competitiveness of their agricultural sectors. At the same time, in these main exporting countries, and more generally in the majority of developped countries, there is a growing public concern with the impacts of agricultural production on environment quality. Thus, most governments have introduced environmental goals in their agricultural concerns.

Thus, one of the main question as regards to the future of agricultural policies in developped countries on the one hand and to the future of multilateral negotiations under the World Trade Organisation (WTO) on the other hand is whether both competitiveness and environmental objectives are consistent or not within agricultural policies. In other words, is a competitive agricultural sector necessarily a polluting one ?

This question is at the core of this paper. More precisely, our purpose is to examine the link between competitiveness and pollution process in the case of the French crop sector. The basic idea is that the key factor as regards to this link lies in the level of intensification choosen by crop producers. In fact, it is well recognised that intensive cropping practices both improve competitiveness of national crop sectors and generates pollution.

Therefore, the first step in this paper is to analyse the producer decisions in terms of intensification levels in order to highlight the main factors affecting this decision. French farm data analysis shows that crop producer behaviors are not homogeneous. Particularly, input uses and obtained yields are quite different from one region to a another. In France, the economic conditions are relatively homogenous within the whole country. Thus, heterogeneity in micro-market conditions cannot explain heterogeneity among French farm behaviors. Following Mundlak (1961), human capital can generate management bias which can be a source of heterogeneity in farm behaviors. But as this argument appears as pertinent to partly explain heterogeneity accross farms, it cannot be considered as a source of heterogeneity accross French regions. Still following Mundlak (1978, 1990, 1992), heterogeneity may be due to differences in technologies (variants of a common technology) implemented by the farms. And sources of heterogeneity in farm behaviors (through differences in implemented techonologies) may likely be related to variability in natural ressources endowments, especially soil quality (slope, structure, composition, water flows; availability of nutrients for plant intake,...), water supply (irrigation, rainfall) and its adequation with soil quality, sun (temperature and photosynthesis and their adequation with soil quality)[1].

Thus, the basic idea in this paper is that heterogeneity between crop producer behaviors observed at the regional level in France may be explained by differences in chosen intensification levels, and that variability in natural ressources endowments must explain this observed heterogeneity in intensification levels.

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[1] See for example, Mundlak (1990, 1992), Caswell and Zilberman (1985, 1986), Lichtenberg (1989), Caswell, Lichtenberg and Zilberman (1990), Antle and Just (1991), Just, Lichtenberg and Zilberman (1991).

The second step is then to examine wether the link between intensification levels and pollution emission levels is positive or negative. Firstly, the principle of intensification is to increase yield by i) using highly productive seeds, lenghtening the growing season and increasing seed density and then ii) using high loads of nutrients to meet the nutrient requirements of the seeded plants. Hence, the success of intensive cropping patterns heavily relies on the capacity of the soil to provide nutrients to the plant. Secondly, given that in intensive cropping technologies, nutrient management is now considered as a stock management, considering the long-run steady state (that matters for the environment), the plant intake of nutrients equals the nutrient quantity supplied minus the nutrient quantity wasted.

The plant potential intake of nutrients depends on the efficiency of the plant photosynthesis (thus on the sun and on the potential productivity of the plant), on the density seeded, on the length of the growing season and on the plant protection level (thus on pesticide use, ...). Thus, the plant potential intake of nutrients depends on the sun and on the intensification level.

On the other hand, the potential waste of nutrients depends on the quality of the soil and on the supply of nutrients (following a convex relationship, Antle and Just, 1991).

Finally, it appears that since the waste of nutrients generates pollution a key factor in explaining the effects of crop production on the environment is the quality of the soil. This relationship between production technology (efficiency) and pollution process is obviously well known but has only rarely been explicitly used in applied economic models (see, e.g., Caswell, Lichtenberg and Zilberman, 1990). In fact, this relationship creates an incentive for farmers to "internalize" the negative effects of their production decisions on the environment. The greater the quantity of inputs is likely to be wasted, the less likely farmers are incented to intensify their crop production process.

Thus, while an increase in the optimal use of inputs on a farm obviously leads to an increase in pollutions generated by this farm, a farm with higher optimal use of inputs than another does not necessarily generate more pollution. In other words, while the correlation between (optimal) input uses and pollution emission levels they generate is positive when considering farms with identical resource endowments, this correlation is not necessarily positive when considering farms with different resource endowments. This point has received attention by Antle and Just (1991) in a (log-linear) stylized model. However, they implicitely consider the production process and the pollution process as separated.

In this paper, as done by Caswell, Lichtenberg and Zilberman in there respective (and some times joint) studies of irrigation, we formalize and use the relationships between the production and the pollution process.

The paper is organised as follows. In section 2, we develop a theoretical model, where the quality of the soil is explicitely taken into account, which is aimed at highlighting the link between the profitability of intensification and the generation of pollution by the crop production. In section 3 we analyse the impact of changes in economic conditions on producer decisions to illustrate the most salient facts as regards to the intensification process of the French crop sector originated by the CAP implementation. In section 4, we show, within a simplified framework, that taking into account the existing heterogeneity in natural resource endowments may lead to ia negative link between the level of input uses and the level of pollution emissions (see also Antle and Just, 1991).

2. Analytical framework

2.1. Notations and definitions

Consider a mono-product farms with fixed land stocks sufficiently small so that their acreage is homogenous in quality. Following Lichtenberg (1985, 1989) or Antle and Just (1990, 1991), let q be a scalar measure of land quality, normalised to lie between zero and one[2]. $G(q)$ represents total acreage of quality no less than q in the considered region. Accordingly, $g(q)=dG(q)/dq$ is the amount of acreage having quality q. Each available technology is described by a well-behaved neo-classical production function. We will also assume that the production function exhibits constant returns to scale in land of equal quality and will our study on a per area unit basis. This assumption seems reasonnable since decreasing constant returns to scale in land are often associated to a decrease in the quality of used land, the better quality lands being used for production first in this Ricardian framework (Mahé and Rainelli, 1987; Guyomard and Mahé, 1994; Guyomard, Baudry and Carpentier, 1997). Here the measure of land quality q is assumed to be an aggregated measure representing properties of soils, climate and their interactions. Denote the per area unit production function $y = f(\mathbf{x},q,u) \geq 0$ where $\mathbf{x}$ is a vector of K (variable) inputs used to produce the considered crop when the u^{th} technology is employed. The parameter u lies between u^- and u^+ so that the greater is u, the more intensive is the technology.

2.2. Standard assumptions

We now consider the properties of q, $\mathbf{x}$, and u in $f(.)$ that are suitable for this model to represent the agricultural production technology currently used in France. For convenience, we assume throughout the paper that:

(A0) $f(.)$ is twice continuously differentiable in q, $\mathbf{x}$, and u.

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[2] It would probably be preferable to use a multivariate index to represent what we label land quality since this notion of agronomic quality of a site includes numerous heterogenous factors. Indeed, using Topkis' (1995) work, it can be shown that the results presented in this paper hold if the multivariate index set is a chain and if the conditions imposed on the scalar index q throughout the paper hold for each element of the multivariate index. A necessary condition for a subset of R^n (ordered by the standard component-wise ordering) to be a chain is that the component-wise ordering provides a total order for this subset. In other words, this condition requires that if an element of the multivariate index increases its other elements do not decrease. This would provide a good reason to use a scalar index as an approximation for the true multivariate index. Otherwise this limits the domain of applicability of the framework presented in this paper to situations where the agronomic quality of land can be represented by a chain of multivariate indices. This suggests that only comparable situations can be investigated within this framework. It can be noted that regions specialized in identical productions should meet this comparability condition.

Let assume that each per hectare production functions satisfies the following standard assumptions:

(A1) $f_{x_k}(.) > 0$

(A2) *f(.)* is strictly concave in *(***x** *, u)*

(A3) $f_q(.) > 0$

As in standard notations, subcripts denotes partial derivatives. Assumptions A1 and A2 indicate that variable inputs are assumed to display a positive and decreasing marginal productivity while assumption A3 indicates that land quality is considered as increasing yields, *ceteris paribus*. As shown by Milgrom and Shannon (1994) and Milgrom and Roberts (1994), assumption A2, as well as the differentiability and continuity assumptions, is not necessary for our model to exhibit desired comparative statics properties but is imposed for simplicity.

2.3. Assumptions related to the interactions between intensification level, land quality and input applications

We then assume that the considered technology is normal in Rader's (1968) sense in **x**:

(A4) $f_{x_k x_h}(.) \geq 0$ where $h \neq k$.

This assumption states that each input is cooperant in Rader's (1968) with the others, i.e. an increase in the use of a given input leads to an increase in the marginal productivity of the others. Generally standard production function functional forms (e.g. Cobb-Douglas, ...) are normal. More generally, a function *f(.)* statisfying (A4) is said to be supermodular in **x** (Topkis (1978); Milgrom and Roberts (1990); Milgrom and Shannon (1994))[3].

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[3] The supermodularity assumption is also used in the context of consumer behavior analysis. Assuming that the conosidered consummer's utility function is supermodular (i.e. statisfies the so-called Auspitz-Lieben-Edgeworth-Pareto assumption within this context) leads to the conclusions that the commodities are non-Giffen and normal (Chipman, 1977; see also Samuelson (1974), Kannai (1980) and Barten (1990) for a discussion of this cardinal assumption).

This assumption of cooperation or supermodularity expresses a kind of complementarity. The relevancy of this assumption, as the relevancy of the ones presented below, may be highlighted by considering technical aspects of the agricultural production. In a normal technology, inputs are supposed to have well-defined non-substituable roles in production. For example, fertilizer applications are used to feed plants whereas pesticide applications are used to protect plants. Since plant nutrition and plant protection are two different aspects of the production technology, it is natural to assume that pesticide applications and fertilizer applications are cooperant. It can be noted that this cooperation is reinforced by the fact that fertilizers applications tend to increase the likelihood of pests damages such as fungi damages or weed damages (Harper and Zilberman, 1989; Meynard, 1991). It should be noted that, even though cooperation may appear rather intuitive for the characterization of the interactions of many inputs (or groups of inputs, assuming a consistent separability structure), this notion may not hold for some input pairs. This case may occur when one of the considered input has several roles. For example, ploughing is primarly used to prepare the soil for sowing. But it also eliminates weeds already present in the field. In this case, ploughing has two roles: soil preparation for sowing and plant protection against weed competition. Thus, it is difficult to say *a priori* if ploughing cooperates with herbicide applications or not. We argue here that such cases are of relatively minor concern in the context of the French agriculture. In the cropping technologies used the last two decades in France, the use of highly specialized industrial inputs have been substituted to more integrated cropping patterns where the interactions between different aspects of the agricultural production process were recognized and used in order to manage the plant growth and development. Thanks to the relatively low price and the efficacity of the industrial inputs, the cropping technologies that have been implemented in France are rather simple because divided into several complementary sub-production processes: soil preparation, plant nutrition, plant protection, harvest, ... that are associated to applications of specific inputs. It can be noted that the environmentally friendly technologies that are currently suggested rely on more integrated cropping patterns in order to reduce industrial input uses and their associated negative effects on the environment.

A first characterization of effects of the use of intensive cropping techniques on agricultural production may be expressed as assumption (A5):

(A5) $f_{ux_k}(.) \geq 0$ with a strict inequality for at least one input.

Assumption (A5) indicates that technology intensity is assumed to increase the marginal productivity of the considered inputs. More generally, a function *f(.)* statisfying (A5) is said to have the increasing differences property in *(**x**;u)* (Topkis (1978); Milgrom and Roberts (1990); Milgrom and Shannon (1994)). Also, , a function *f(.)* statisfying (A5) and (A4) is said to be supermodular in *(**x**,u)* (Topkis (1978); Milgrom and Roberts (1990); Milgrom and Shannon (1994)).

Assumption (A5) is easily shown to be relevant for variable inputs such as fertilizers and pesticides. This relationship lies indeed at the root of the properties of intensive cropping technologies (Meynard, 1991). Main characteristics of intensive cropping technologies are the use of high yields varieties, a large seed density, an early sowing, ... The objective of these intensive techniques is to achieve high yields. Even if relationships between the use of intensive cropping techniques and variable input use are not exactly of the same nature according to the considered input, fertilisers or pesticides for example, they generally lead to conclusions that provide arguments which support assumption (A5). In this sense, intensive production techniques involve a package of cooperant input (See also Antle and McGuckin, 1993). Let consider fertilizers or irrigation. In that case, the nature of the relationship is quite obvious. Early sowing of large density of highly productivity seeds is used to increase the growth potential of cultivated plants, i.e., their nutrient assimilation. The more intensive cropping techniques are used, the more the marginal productivity of inputs such as fertilisers is likely to be high. This is the logic of the cropping intensification process in itself. Let now consider inputs such as pesticides. In that case, the nature of the relationship between input use and intensive cropping patterns is quite different. Due to selection choices, highly productivity plants are generally more vulnerable to pests and diseases. In a similar way, long growing seasons and large seed density both increase the likelihood of severe pests and disease damages. To summarise, the use of intensive cropping techniques increases the vulnerability of crops to severe pests and disease damages and, as a consequence, calls for effective plant protection. In that context, the more intensive cropping techniques are used, the more pesticides are likely to be productive (Harper and Zilberman, 1989 ; Meynard, 1991). These points have also been considered in different contexts by, e.g., Just and Hueth (1993) and, Cowan and Gunby (1996).

Finally, to characterize the effect of what we call land quality, we impose the following assumptions:

(A6) $f_{uq}(.) \geq 0$

(A7) $f_{qx_k}(.) \geq 0 \quad f_{ux_k}(.) \geq 0$ with a strict inequality for at least one input.

Assumption (A6), respectively (A7), indicates that land quality is assumed to increase the marginal productivity of intensification, respectively of the considered inputs. More generally, a function $f(.)$ statisfying (A6), respectively (A7), is said to have the increasing differences property in $(q;u)$, respectively in $(q;\mathbf{x})$ (Topkis (1978); Milgrom and Roberts (1990); Milgrom and Shannon (1994)). Also, a function $f(.)$ statisfying (A4), (A5), (A6) and (A7) is said to be supermodular in $(\mathbf{x},u,q)$ (Topkis (1978); Milgrom and Roberts (1990); Milgrom and Shannon (1994)).

Let now first consider assumption (A7) which indicates that land quality is assumed to increase marginal productivity of variable inputs. If we consider that one of the most important attribute of land quality is its ability to provide water and nutrients (and pesticides) in sufficient quantities, adequate temperature and sunniness to the plant, assumption (A7) follows immediately. In that context, the quality of a soil mostly depends on its slope, its composition and its structure. The most soils are of high quality, the less inputs are likely to be wasted and the more the marginal productivity of the applied inputs is likely to be high (given that the plant is not satured, which should be the case at any economic optimum where inputs are not free). Thus, the relationship between soils quality and input use largely determines the "environmental" properties of a soil with respect to input use. In fact, assumption (A7) shows that the higher is the quality of the soil, the more inputs remain available to the plant and the less they may be harmful to non-targeted sites such as water resources. We shall return to this relation later. Similarly, adequate temperature and sunniness stimulate plants' efficient photosynthesis and increase the marginal productivity of applied inputs such as nutrient and plant protection inputs (since the higher is the potential yield to be protected, the higher is the marginal productivity of plant protection inputs). However, it could be argued that factors such as the avalaibility of nutrients in the soil (before applications of fertilizers) should be included in the definition of q. These factors are cooperant with some input applications (e.g., available nutrients and pesticide applications) but substituable to others (e.g., available nutrients and fertilizer applications). In the context of the French agriculture these factors are of limited interest, at least considering the crop sector, since the crop nutrient management is viewed as a stock management where the nutrient content of the soils is determined by past productions and q. Considering a steady state, it is simply a function of q.

Let now consider assumption (A6) which indicates that land quality is assumed to increase the productivity of intensive cropping techniques. This assumption clearly reflects the fact that intensive cropping techniques cannot be viewed as substitutes to land quality. In other words, if we consider that intensive cropping patterns are used to enable the plant to achieve its maximum productive potential, land quality must then be viewed as one of the factors allowing this achievement. For example, long growing seasons benefit to the plant growth as long as the soil remains in a good state (with respect to humidity and structure) during the entire growing period, sunniness is sufficient during the considered growing period, ... The higher is land quality, the more the use of intensive cropping techniques is likely to increase yields, *ceteris paribus*.

Finally, it is important to note that a negative marginal productivity of cropping technique intensification is not ruled out *a priori*[4]. A negative marginal productivity may occur when highly intensive cropping techniques are used on low quality land and/or with low input uses (especially fertilisers and pesticides).

At this stage, the three following remarks are in order. First, extensive cropping techniques may be warranted when high input uses are prohibited (due to the economic context or legal constraints) and/or when land quality is low. Second, the success of the cropping technology intensification process appears heavily dependent on the availability of high quality land and on the use of inputs such as fertilisers and pesticides. This dependence is theoretically formalised by assumptions (A4) to (A7) which state that variables $\mathbf{x}$, q and u "cooperate" in output production (Rader, 1968). In fact, these assumptions simply reflect the fact that the relatively ininsive cropping technologies used in France are consistent. They have been stemmed, developped and implemented to increase yields because of the French arable land quantity constraint (Mahé and rainelli, 1987), under land quality constraint and given the fact that industrial input prices were and still are relatively low. Third, assumptions (A4) to (A7) imply that the production function *f*(**x**,*q*,*u*) is "supermodular" in (**x**,*u*,*q*). The usefulness of this supermodularity property is illustrated below along the lines of Milgrom and Roberts (1990), Milgrom and Shannon (1994) and Topkis (1995a).

3. Intensification, input uses and land quality

In this section, we derive the first comparative statics results under the assumptions developed above and under the assumption that farmers are economically efficient in maximizing their profit. This results heavily relies on Rader's (1968) and Milgrom and Shannon's (1994) previous work. To illustrate the relancy of our representation of the French agricultural production sector, we analyze, within our framework, the most salient facts that have been originated by the implementation of the Common Agricultural Policy.

3.1. Farmers' objectives

Given an output price $p > 0$ and an input price vector $\mathbf{w} > 0$, farmers' objective having land of quality q is given by:

$$\text{(1a)} \qquad \underset{\mathbf{x},u}{Max}\,\Pi(\mathbf{x},u,q) \quad \text{s.t.} \quad \mathbf{x} \geq 0 \ \text{ and } u \in [u^{-}\,;\,u^{+}]$$

where:

$$\text{(1b)} \qquad \Pi(\mathbf{x},u,q) \equiv py - \mathbf{w}'\mathbf{x} = pf(\mathbf{x},u,q) - \mathbf{w}'\mathbf{x}\,.$$

3.2. Input choices

Consider first the program of maximization with u held constant. Given (A1) to (A3), the solution of this program is unique. Assuming that the considered parameter values lead to an interior solution (this assumption is maintained throughout the paper), it is defined by:

$$\text{(2)} \qquad \Pi_{\mathbf{x}}(\mathbf{x}^{*}(p,\mathbf{w};u,q),u,q) = 0 \quad \Leftrightarrow \quad pf_{\mathbf{x}}(\mathbf{x}^{*}(p,\mathbf{w};u,q),u,q) - \mathbf{w} = 0\,.$$

Differentiating (2) by $\mathbf{w}'$ gives:

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[4] In other words, it is not assumed that $f'u(.) \geq 0$.

(3) $$\frac{d\mathbf{x}^*(p,\mathbf{w};u,q)}{d\mathbf{w}'}=\frac{1}{p}\left[f_{\mathbf{xx}}(\mathbf{x}^*(p,\mathbf{w};u,q),u,q)\right]^{-1}$$

Given that $f_{\mathbf{xx}}$ is a negative definite matrix (by (A2)) with non-negative off-diagonal elements (by (A4)), $[f_{\mathbf{xx}}]^{-1}$ is non-positive, i.e. the demand of an input decreases with an increase in its own price and inputs are never gross substitutes (Rader, 1968)[5]:

(4a) $$\frac{dx_k^*(p,\mathbf{w};u,q)}{dw_h}\leq 0 \quad \forall h,k\,.$$

A simple corollary of this result is that an increase in output price leads to an increase in the demand of each input:

(4b) $$\frac{dx_k^*(p,\mathbf{w};u,q)}{dp}\geq 0 \quad \forall k\,.$$

The interpretation of this result is that factors are used in conjunction with each other rather than as subsitutes. In fact, even though there is a substitution effect in favor of those factors whose price has not increased, this is more than offset by the decrease in output, and, hence in all inputs, due to increased marginal cost.

3.2. Input and intensification level choices

It is assumed here that only induced costs (related to adjustments of choices of **x**) occur when *u* is chosen. This mainly relies on the assumptions that different seed varieties can, at least approximately, be bought at the same unit price and that the choice *u* does not affect the level of required fixed factors. This approximation seems acceptable since the processus of intensification mainly affects the timing of the different operations in the fields and the levels of variable input uses (fertilizer applications, pesticide applications and seed density.

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[5] Note that this also follows from the fact that, $f(.)$ being supermodular in $\mathbf{x}$, $pf(\mathbf{x})-\mathbf{w}'\mathbf{x}$ is supermodular in $(\mathbf{x}, -\mathbf{w})$.

Let first consider the effect of the level of intensification *u* on input choices. Under assumptions (A0), (A1), (A4) and (A5), it is possible to show that $\mathbf{x}^*(p,\mathbf{w};u,q)$ is increasing in *u*:

$$\text{(5a)} \qquad \frac{dx_k^*(p,\mathbf{w};u,q)}{du} \geq 0 \quad \forall k$$

This result follows application of Milgrom and Shannon's (1994) theorem 10. Moreover, it is shown by Milgrom and Shannon (1994) that under assumptions (A0) and (A1) (and assuming the existence of a solution for the considered maximisation program), assumptions (A4) and (A5) are necessary and sufficient to obtain these comparative statics results. In other words, the supermodularity of *f(.)* in $(\mathbf{x},u)$ is a necessary and sufficient condition for this model to represent the fact that an increase in the used intensification level leads to an increase (does not decrease) in the use of (variable) inputs. Since the properties of *q* in *f(.)* are symetric to those of *u*, it is also easily demonstrated that:

$$\text{(5b)} \qquad \frac{dx_k^*(p,\mathbf{w};u,q)}{dq} \geq 0 \quad \forall k$$

This simply means that with the technologies used in France, industrial inputs are used in conjunction with land properties and not to compensate land deficiencies. It should be noted that this requirement is equivalent to the the supermodularity of *f(.)* in $(\mathbf{x},q)$. This requirement may be seen as severe for inputs such irrigation set-ups and water, drainage set-ups or soil structure improvement inputs. These inputs are used to compensate lack of rainfall or deficient soil structure. To overcome theses problems, either one considers that fixed inputs such as irrigation set-ups and input uses such as irrigation water uses or soil stucture improvement input uses are included in *q* or one only considers farms in similar situations with respect to these questions. The main inconvenient of the later solution is that it considerably limits the applicability domain of the presented framework. The inconvenient of the former solution is that it consists in the inclusion of endogenous factors in q which is considered as an exogenous parameter throughout the analysis. However it should be noted that farmers' choices are often limited with respect to these problems in the sense that profitability of farms' operation heavily depends on these decisions. In other words, either the concerned farmers accept these costs or they do not operate their farm (or eventually move to other productions). This could be integrated in the present analysis by the inclusion in farmers' costs a fixed cost of operation decreasing in q.

The program leading to farmers' intensification level choices is given by (1a) or:

$$\underset{u}{Max}\,\Pi(\mathbf{x}^*(p,\mathbf{w};u,q),u,q). \tag{6}$$

The possible solutions for this program are given by:

$$\underset{u}{Arg\,max}\,\Pi(\mathbf{x}^*,u,q)=u^- \quad \text{if} \quad \Pi_u\,(\mathbf{x}^*(p,\text{w}\ ;u^-,q),\ u^-,q) \leq 0. \tag{7a}$$

$$\underset{u}{Arg\,max}\,\Pi(\mathbf{x}^*,u,q)=u^*(p,w;q)\in]u^-;u^+[\quad \text{if} \quad \Pi_u\,(\mathbf{x}^*(p,\text{w}\ ;u^*,q),\ u^*,q) = 0 \tag{7b}$$

$$\underset{u}{Arg\,max}\,\Pi(\mathbf{x}^*,u,q)=u^+ \quad \text{if} \quad \Pi_u\,(\mathbf{x}^*(p,\text{w}\ ;u^+,q),\ u^+,q) \geq 0. \tag{7c}$$

Considering interior solutions, the first order conditions characterizing the optimal choice of $(\mathbf{x}, u)$ can be summarised as:

$$\begin{bmatrix}\Pi^*_{\mathbf{x}}\\ \Pi^*_u\end{bmatrix}=\begin{bmatrix}pf^*_{\mathbf{x}}-\mathbf{w}\\ pf^*_u\end{bmatrix}=0 \;\Leftrightarrow\; p\begin{bmatrix}f^*_{\mathbf{x}}\\ f^*_u\end{bmatrix}=\begin{bmatrix}\mathbf{w}\\ 0\end{bmatrix} \tag{8}$$

By the implicit function theorem, the effects of changes in input prices $\mathbf{w}$ on $(\mathbf{x}^*, u^*)$ is given by:

$$\begin{bmatrix}d\mathbf{x}^*/d\mathbf{w}'\\ du^*/d\mathbf{w}'\end{bmatrix}=\frac{1}{p}\begin{bmatrix}f^*_{\mathbf{xx}} & f^*_{\mathbf{x}u}\\ f^{*\,\prime}_{\mathbf{x}u} & f^*_{uu}\end{bmatrix}^{-1}\begin{bmatrix}I_K\\ 0\end{bmatrix} \tag{9}$$

Given that the Hessian matrix of the function f in $(\mathbf{x}, u)$ is a negative definite matrix (by (A2)) with non-negative off-diagonal elements (by (A4) and (A5)), the last term of (9) has only non-positive entries, i.e. the demand of an input decreases with an increase in its own price, inputs are never gross substitutes and the optimal level of intensification decreases as the input prices increase:

$$\text{(10a)} \qquad \frac{dx_k^*(p,\mathbf{w};q)}{dw_h} \leq 0 \quad \forall h,k$$

$$\text{(10b)} \qquad \frac{du^*(p,\mathbf{w};q)}{dw_h} \leq 0 \quad \forall h$$

A simple corollary of this result is that an increase in output price leads to an increase in the demand of each input and in the level of intensification:

$$\text{(10c)} \qquad \frac{dx_k^*(p,\mathbf{w};q)}{dp} \geq 0 \quad \forall k$$

$$\text{(10d)} \qquad \frac{du^*(p,\mathbf{w};q)}{dp} \geq 0$$

These results highlight the dependence of the implementation of intensive cropping technology on the availability of industrial inputs at relatively low prices. This dependence has been pointed out by Mahé and Rainelli (1987), in the context of the European Union agriculture and Mundlak (1992), in the context of the Green Revolution in India. They also show how the implementation of the early Common Agriculture Policy, which gave high output price supports to the European farmers, has led to the adoption of intensive cropping technology in the European Union. It can be noted that these results are obtained without the assumption of decreasing returns in scale to land while this was a central assumption in the Mahé and Rainelli's (1987) paper. We return to this point in what follows. These results also suggest that there may be no need in using taxes on several inputs to achieve a given level of input use by farmers since the interdependence of the different input uses implies that a tax on one input price leads to a decrease in the uses of the others. The implementation of several taxes could permit to achieve the same goals at higher costs for farmers. Moreover, in the long run, i.e. with adjustment of the intensification level, the effects of such taxes may be substantial according to the LeChâtelier-Samuelson principle.

3.3. Land quality and input and intensification level choices

So far we have only considered the effects of economic parameters on the input and intensification level decisions of the farmers. Since in developped countries like France the economic context is relatively homogenous across regions, we must associate the heterogeneity in farmers' observed behavior to other factors. Our aim in this sub-section is to shown that differences in natural resources endowment across farms such as the land quality index q may explain this heterogeneity.

Using the framework developed above and Milgrom and Shannon's (1994) results it is possible to give comparative statics results with respect to the effects of q on the level of intensification and on input choices. Indeed, under assumptions (A0), (A1), and (A4) to (A7), it is possible to show that $\mathbf{x}^*(p,\mathbf{w};q)$ and $u^*(p,\mathbf{w};q)$ are increasing in q:

$$\text{(11a)} \qquad \frac{dx_k^*(p,\mathbf{w};q)}{dq} \geq 0 \quad \forall k$$

$$\text{(11b)} \qquad \frac{du^*(p,\mathbf{w};q)}{dq} \geq 0$$

As in our analysis of the effect of u on $\mathbf{x}^*(p,\mathbf{w};u,q)$, this result follows application of Milgrom and Shannon's (1994) theorem 10. Moreover, it is shown by Milgrom and Shannon (1994) that under assumptions (A0) and (A1), (and assuming the existence of a solution for the considered maximisation program), assumptions (A4) to (A7) are necessary and sufficient to obtain these comparative statics results. In other words, the supermodularity of $f(.)$ in $(\mathbf{x},u,q)$ is a necessary and sufficient condition for this model to represent the fact that farms with better natural resource endowments use higher intensification levels and more (variable) inputs. In fact, this result can also be used to reinterprete q as an index of the suitability of the considered farm's site for intensive agricultural production. When the French crop sector is analyzed, it can be observed that farms located in the large Paris basin use more intensive cropping technologies than farms located outside of this Region. Moreover, the nearer those farms are to the center of the Paris Basin, the more intensive are their cropping technologies. Given that the climatic conditions prevailing in this region are rather homogeneous, this heterogeneity in cropping patterns may be attributed to differences in soil quality. It is well-know that soils have better agronomic properties near the center of the Paris basin.

3.4. Land quality and, input and intensification level choices at the extensive margins

It is interesting to investigate corner solutions with respect to the adoption of intensive cropping technologies because it allows a study of the cases where production is constrained either by the level of technology currently available or by land quality. In particular, it is intended to show that as long as the maximal level of intensification u^+ is not implemented by the farmer, land quality is constraining. This means that the farmer can chose in the available set of technologies the technology that exploits the natural resources of the farm at a maximum level. It should be noted that this maximum level is not absolute, since it depends on the economic context in which the farmer operates. It is also intended to show that the nature of the technical change that has occured so far in the European Union, in conjunction with the implementation of the Common Agricultural Policy, has considerable effects on farming patterns and farmers' profits in regions where land quality is relatively low. This can be related to path dependence technical change issues and endogenous technical change (Mahé and Rainelli, 1987; Meynard, 1991; Just and Hueth, 1993; Cowan and Gunby, 1996). As, will be shown in the next section these results are crucial when the impacts of farming patterns are considered.

In order to investigate the corner solutions in u, it is useful give some comparative static results on the effects of q, u and $\mathbf{x}$ on farmers' profit. Firstly it can be shown that in increase in q leads to an increase in the optimal profit:

$$\text{(12)} \qquad \frac{d\Pi^*(p,\mathbf{w};q)}{dq} = \sum_k \frac{dx_k^*}{dq}\frac{\partial \Pi^*}{\partial x_k} + \frac{du^*}{dq}\frac{\partial \Pi^*}{\partial u} + \frac{\partial \Pi^*}{\partial q} = \frac{\partial \Pi^*}{\partial q} = pf_q(\mathbf{x}^*,u^*,q) > 0.$$

This comes from the fact that higher quality lands provides higher economic rents. As shown by (11b), the optimum intensification level increases in q.

Thus, the minimal intensification level u^- is only chosen where q is inferior or equal to a certain threshold $q^-(p,\mathbf{w},u^-)$. We note here these threshold q^- as a function of p, $\mathbf{w}$ and u^- to emphasize its dependence on these parameters. By definition, this threshold is determined by the equation:

$$\text{(13)} \qquad \Pi_u\,(\mathbf{x}^*(p,\mathrm{w}\,;\,u^-,q^-),\,u^-,q^-) = pf_u\,(\mathbf{x}^*(p,\mathrm{w}\,;\,u^-,q^-),\,u^-,q^-) = 0.$$

We assume here that a solution to (13) exists. Indeed, in order to simplify the analysis we now adopt the convention here that if $\Pi_u\,(\mathbf{x}^*(p,\mathrm{w}\,;\,u^-,q),\,u^-,q) < 0$, i.e., the minimum intensification level does not correspond to an optimal "interior" solution, production does not occur. In other words, we assume that production is not profitable in the considered economic context if the marginal profit associated with the minimum intensification level is strictly negative. Using the implicit function theorem, we have:

$$\text{(14a)} \qquad \frac{dq^-}{dw_k} = -\frac{\dfrac{d^2\Pi\left[\mathbf{x}^*(u^-,q^-)\right]}{du\,dw_k}}{\dfrac{d^2\Pi\left[\mathbf{x}^*(u^-,q^-)\right]}{du\,dq}} = -\frac{f_{u\mathbf{x}'}^*\,\dfrac{d\mathbf{x}^*(u^-,q^-)}{dw_k}}{f_{uq}^* + f_{u\mathbf{x}'}^*\,\dfrac{d\mathbf{x}^*(u^-,q^-)}{dq}} \geq 0$$

and:

(14b)
$$\frac{dq^-}{dp} = -\frac{\dfrac{d^2\Pi\left[\mathbf{x}^*(u^-,q^-)\right]}{dudp}}{\dfrac{d^2\Pi\left[\mathbf{x}^*(u^-,q^-)\right]}{dudq}} \leq 0.$$

These results show that an evolution of the economic context where the prices of inputs tend to decrease relatively to the output price tends to increase the level of intensification at the extensive margin. That is, if u^- remains fixed; the share of land used with intensification u^-: $G(q^-)$ decreases in p and increases in **w**. Within this context, the effects of the Common Agricultural Policy has been the increasing use of lands of low quality for agricultural productions, and more specifically cereals and oilseeds. As we shall see below, this suggests that the implementation of the Common Agricultural Policy has had significant impacts on the degradation of the environment through its effects at the extensive margin (see also Mahé and Rainelli., 1987).

To investigate the corner solution in u^+, the threshold q^+ , if it exists, is defined by:

(15)
$$\Pi_u\,(\mathbf{x}^*(p,\mathrm{w}\,;\,u^+,q^+),\,u^+,q^+) = pf_u\,(\mathbf{x}^*(p,\mathrm{w}\,;\,u^+,q^+),\,u^+,q^+)\;=0.$$

A solution to equation (16) exists if maximum land quality can support intensification levels higher than u^+. In this case, technology is a constraint for yield increase through the intensification process. Using the implicit function theorem, we have:

(16a)
$$\frac{dq^+}{dw_k} = -\frac{\dfrac{d^2\Pi\left[\mathbf{x}^*(u^+,q^+)\right]}{dudw_k}}{\dfrac{d^2\Pi\left[\mathbf{x}^*(u^+,q^+)\right]}{dudq}} = -\frac{f^*_{ux'}\dfrac{d\mathbf{x}^*(u^+,q^+)}{dw_k}}{f^*_{uq} + f^*_{ux'}\dfrac{d\mathbf{x}^*(u^+,q^+)}{dq}} \geq 0$$

and:

(16b)
$$\frac{dq^+}{dp} = -\frac{\dfrac{d^2\Pi\left[\mathbf{x}^*(u^+,q^+)\right]}{dudp}}{\dfrac{d^2\Pi\left[\mathbf{x}^*(u^+,q^+)\right]}{dudq}} \leq 0.$$

That is, if u^+ remains fixed; the share of land used with maximum intensification level u^+: $1-G(q^+)$ decreases in $\mathbf{w}$ and increases in p. Within this context, the effects of the Common Agricultural Policy has been the increasing use of lands for maximum level of intensification.

3.5. Land quality and, input and intensification level choices and technical change in the European union

As demonstrated by Meynard (1991) and Cowan and Gunby (1996) and suggested by Just and Hueth (1993), the implementation of the Common Agricultural Policy has also had significant impacts on agronomic research. Due to high output price support, agronomic research has mainly focused on the most intensive cropping technologies. These technologies were supposed to be adopted by farmers in the context of high output prices. Similarly, the agricultural input industry has also focused its supply on intensification inputs[6]. This suggests that an indicator t of technical change for the European agricultural production would have the following properties (see also Milgrom, Qian and Roberts, 1991 and Evenson, ????):

(17a) $f_t(.) > 0,$

(17b) $f_{ut}(.) > 0$

and:

(17c) $f_{xt}(.) \geq 0$ with a strict inequality for at least one input.

Assumption (17a) implies that technical progress may have benefited to agricultural production in general while assumptions (17b) and (17c) imply that technical progress has more benifited to the most intensive production technologies, by technical improvement in intensification techniques (17b) and by technical improvement in intensification inputs (17c).

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[6] It can be noted that this technical change has certainly affected supported productions but also non-supported productions. This is due to the fact that all agriultural production processes rely on common biological principles. This is specifically true for biochemical researches. Morevover; this also may come from research methods. For example, pesticide innovations are based on screening methods. If a chamical family is expected to possess interesting phytosanitary properties, several molecules of this family are randomly produced and tested against different pests. Even if the testing priorities are determined by tke size of the expected market of the

Highly productive seed varieties and pesticides, the key intensification inputs, may be the best examples of this technical change biased in favor of the intensification of cropping patterns (see, e.g., Byé, Descoins and Deshayes, 1991). We could also add the following assumption:

$$(17d) \qquad u^+ = u^+(t) \quad \text{with} \quad u_t^+ \geq 0.$$

Assumption (17d) represents the effects of technical change on the maximum level of intensification. Using Milgrom and Shannon's (1994) theorem 10, it is possible to show that under (17b), (17c) (and (17d)):

$$(18a) \qquad \frac{dx_k^*(p,\mathbf{w};q,t)}{dt} \geq 0 \quad \forall k$$

and:

$$(18b) \qquad \frac{du^*(p,\mathbf{w};q,t)}{dt} \geq 0.$$

That is, if we consider technical progress as endogenous and specifically driven by price effects, one of the most important indirect effects of the inplementation of the Common Agricultural Policy has been carried by technical progress. This technical progress has been biased toward the intensification of the cropping patterns and the use of intensification inputs, both effects being closely interdependent by complementarity.

It can be noted that this induced effect of the Common Agricultural Policy price support program reinforces its direct effects with respect to subvention distribution. The higher were farmers' yields the more these farmers received public money through the price support program. High yields corresponds to high intensification levels and, as a result, to high benefits from biased technical change. Formally, we have:

$$(19) \qquad \frac{d^2\Pi^*}{dtdq} = pf_{\mathbf{x}'t}^* \frac{d\mathbf{x}^*}{dq} + pf_{qt}^* = p\frac{d\mathbf{x}^{*\prime}}{dt} f_{\mathbf{x}t}^* + pf_{qt}^* \geq 0$$

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tested molecules, it may be profitable for a firm to test the considered molecule against pests that would generate only small expected markets because the marginal costs associated with additional tests may be rather small.

considering that $f_{qt} = 0$. Equation (19) simply means that farmers with natural resource endowments that are favorable to intensification benefit more from the considered technical change than others.

Moreover, this result also suggests that the implementation of the price support created irreversibility effects with respect to industrial input uses, at least for farmers using highly intensive cropping patterns. Let assume for simplicity that the disembodied effects of the technical change are neglectible, i.e. that $f_t(.) = 0$, and that:

(20a) $f_{ut}(u^+) > 0,\ f_{ut}(u^-) = 0$ with $f_{ut}(.)$ continuous,

(20b) $f_{xt}(.) \geq 0$

and:

(20c) $u^+ = u^+(t)$ with $u_t^+ > 0$.

Assumption (20a) asserts that the considered technical change has had neglectible effects on extensive production techniques while it has had significant effects on highly intensive production technologies. In this case and considering the induced effects of the Common Agricultural Policy price support program, a come back to the price system prevailing before the implementation Common Agricultural Policy would lead to a come back of the farms with low land quality (i.e., farms where $q \leq q^-$) to a situation close to their initial situation only if the technical change embodied in inputs is neglectible due to their low input uses (i.e. $f_{xt} \cong 0$ due to (18a)). In the same context, farms with higher land quality would use higher levels of intensification as well as amounts of industrial inputs higher than the ones they used before the implementation of the Common Agricultural Policy price support system.