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# EUROPEAN AGRICULTURE AT THE CROSS-ROADS: COMPETITION AND SUSTAINABILITY

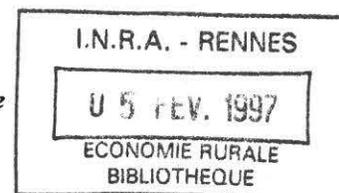
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Consistency between environmental and competitiveness objectives of agricultural policies: economics of price support, set-aside, direct payments and other Common Agricultural Policy instruments

(very preliminary draft)

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## 1. Introduction

For a long time, the basic Common Agricultural Policy (CAP) instrument has been market price support, which encourages production but penalises consumers, and has resulted in European Union (EU) self-sufficiency or surpluses in most temperate farm products. The use of this instrument has over time become increasingly costly in terms of budget costs, complicated administration, distortion of resource use, detrimental environmental effects and international trade tensions (European Economy, EC Agricultural Policy for the 21st Century, 1994). The 1992 CAP reform clearly changed the direction of the CAP in shifting, but only partially, the burden of support from the consumers to the taxpayers with the objective of reducing the negative effects mentioned above. Furthermore, the CAP reform was undoubtedly essential in paving the way for a GATT (General Agreement on Tariffs and Trade) settlement on agriculture (see, for example, Guyomard et al., 1994 ; Sumner, 1994).

On May 21, 1992, the EU Union's Council of Ministers thus agreed, more rapidly than expected, to the most fundamental changes to the CAP in its 30-year history. The final decisions of the Ministers appear clearly milder than the initial proposals of the European Commission (EC) for the current farmers, but also far less ambitious as regards the reorientation of European agriculture toward meeting the long-run objectives of competitiveness, resource conservation and sustainable development. The reform is there, however, and although it does not cover all sectors, it directly affects about 50 % of total EU agricultural output, particularly grains, the commodity at the core of European agriculture.

The emphasis of the CAP reform on grains makes sense in light of their importance in land use, animal-vegetal interactions via the feed sector and international agricultural trade, particularly in the context of United States - European Union relationships and the Uruguay Round of GATT negotiations. The reform clearly changed the direction of the CAP in shifting the burden of support from the consumers (via the

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market price support system) to the taxpayers (via the mechanism of targeted compensatory payments). This new instrumentation of support in the arable crop sector should improve the economic incentives from price signals. Both the set-aside programme and the move away from price support toward direct payments to producers should result in some decline in production, at least relative to what would otherwise have been the case. Compensatory payments based on historical area and yields are, at least theoretically, decoupled from yields, and the farmer allocating variable inputs would only increase yields if it were profitable at the new market price. Nevertheless, as noted by, for example, Moschini and Sckokai (1994) or Harvey (1995), they cannot be considered fully decoupled. Even if the Uruguay Round Agricultural Agreement considers direct aids as decoupled transfer that can be included in the so-called green box, the aid remains tied to the obligation of producing certain crops, it requires set aside of some land and it is based on current acreage declaration. In addition, compensatory payments may influence production decisions via acreage allocation (Guyomard et al., 1995 ; Oude Lansink and Peerlings, 1995).

Even if farm programmes are not the only factors affecting agricultural management decisions, it is now well recognised that they have significant impacts on agricultural land uses, output supply and input demand levels, good prices, producer incomes and fixed or quasi-fixed netput rents, ... The effects of farm programmes on the agricultural sector and on the economy as a whole are continually being analysed. There is, in particular, a recent and growing literature on the effects of farm programmes, and more generally of agricultural activities, on environment. This surge in interest stems from the recognition that agriculture is, in some cases, a primary source of environmental pollution and degradation.

As noted by Kuch and Reichelderfer (1992), agricultural policies can affect environmental quality by influencing management decisions which result in two sorts of fundamental processes, i.e., changes at the extensive margin of production (the amount of land used in agricultural production) and changes in the intensity of land use (the amount of nonland inputs used per hectare). In the EU, it is in particular widely recognised that pre-reform CAP instruments have resulted in "excessive" use of fertilisers and pesticides detrimental to the environment, these inputs being often applied at rates that could not be justified economically without considerations of present and future farm support programmes. The pre-reform CAP has thus probably contributed to socially inefficient chemical input use not only by an excess use to achieve higher yields and maximise government programme payments on agricultural lands, but also by an use to expand production onto marginal lands or to support production in regions poorly suited to a particular crop.

In the absence of specific government intervention, farmers have no incentives to take into account the potential negative environmental externalities arising from excessive chemical input use. The potential costs of this excessive chemical input use are completely ignored, farmers' decisions being solely based on private interests. As explained above, these decisions are greatly influenced by farm programmes. In the context of the pre-reform CAP, Mahé and Rainelli (1987) showed how the scarcity of the land factor

resulted in an increase in both the price of land and the intensification level, here simply defined as the ratio of chemical inputs on land quantity. They also showed that the price support mechanism increased these two movements and that it was only a second best policy for supporting farm labour income since a major part of the support was dissipated in the land rent. Furthermore, this policy also led to environmental negative effects at the extensive margin since production moved onto marginal lands and ecologically sensitive and/or vulnerable zones were converted to agricultural production.

The purpose of this paper is threefold. We first propose a simplified analytical framework of producer behaviour allowing us to analyse the effects of changes in key agricultural policy instruments and/or exogenous variables at both the intensive and extensive margin of production. The model is mono-product and considers land as a fixed, but allocatable production factor. The fixed amount of land can be allocated between two enterprises, the first one corresponding to an "intensive" technology which implies high levels of chemical input use and the second one corresponding to an "extensive" technology which uses low levels of fertilisers and pesticides per hectare. Following Lichtenberg (1985, 1989) and Just et al. (1991), we explicitly consider land quality as an argument of production and behavioural functions and analyse the producer problem on a quality class by class basis<sup>1</sup>. Comparative statics are used to examine the potential effects of changes in key policy parameters and exogenous variables. The second objective of the paper is then to analyse to what extent the 1992 CAP reform may be viewed as a first response to the problem of chemical input inefficiency in the crop sector and induced non-point source pollution. In that context, we first analyse the potential impact of the new CAP arrangements in the crop sector, i.e., lower support prices, per hectare compensatory payments and set aside, on the intensity of land use. We show that yields and farming intensity are likely to decrease due to support price cuts, but that the set-aside programme may counterbalance a large part of this effect. In the same way, comparative static results are used to analyse the various parameters which may influence conversion of land from the intensive technology toward the extensive technology, i.e., to analyse changes at the extensive margin of production. We show that output support price cuts are likely to favour land conversion from the intensive technology toward the extensive one, but again that the set-aside programme and "induced" input price decreases may offset conversion incentives due to output price decreases. Finally, we extend the analysis by including negative social costs arising from "excessive" chemical input use. In that context, we first analyse the effects of environmental policies (emission, input or output taxes) on producer behaviour at the intensive margin of production, i.e., for a given land quality. We then show that an uniform input or output tax, undifferentiated according to land quality, may be too detrimental for the highest land quality (i.e, in other words, for "competitive" land quality) with respect to their own contribution to the total level of pollution emission. In contrast, an uniform output or input tax may be not detrimental enough for the

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<sup>1</sup> The alternative to considering the problem on a quality class by class basis is to allow decreasing marginal returns to land (see, for example, Chambers and Just, 1989 ; Coyle, 1993).

lowest land quality cultivated with intensive techniques. This result relates directly to the relationship between land quality and pollution emission.

The paper is organised as follows. The analytical framework is presented in section two. Comparative static results and implications for policy design are discussed in section three. Section four extends the analysis by considering negative social costs resulting from intensive production techniques and focuses on the relationship between land quality and pollution emission. Section five concludes.

## 2. Analytical framework

### 2.1. Notations and assumptions

Consider a mono-product farm with a fixed land stock sufficiently large so that the acreage  $L$  is heterogeneous in quality. Following Lichtenberg, let  $q$  be a scalar measure of land quality, normalised to lie between zero and one, and  $G(q)$  represent total acreage of quality no less than  $q$ . 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 which exhibits constant returns to scale in land. Denote the per hectare production function  $y = f(x,q,u)$  where  $x$  is a vector of 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. Let assume that each per hectare production functions satisfies the following assumptions:

a1)  $f'_x(.) > 0$

a2)  $f''_{xx} < 0$

a3)  $f'_q(.) > 0$

a4)  $f''_{ux} > 0$

a5)  $f''_{uq} > 0$

a6)  $f'_{qx} > 0$

Assumptions a1, a2 and a3 are standard. 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*. Here, land quality  $q$  is simply defined as an indicator characterising the properties of land input with respect to agricultural production. Assumptions a4, a5 and a6 are less obvious and require some explanations. They closely rely on technical ground.

Let first consider assumption a6 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

not true

ability to provide water and nutrients (and pesticides) to the plant in sufficient quantities, assumption a6 follows immediately. In that context, the quality of a soil mostly depends on its slope, its composition and its structure. The relationship between land quality and input use largely determines the "environmental" properties of a soil with respect to input use. In fact, assumption a6 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.

Let now consider assumption a4 which indicates that technology intensity is assumed to increase the marginal productivity of variable inputs such as fertilisers 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 a4. Let consider fertilisers 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 fact, plants that are highly productive use most of their energy to grow which results in detrimental effects on their resistance 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).

Let now consider assumption a5 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 have not to 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. 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*<sup>2</sup>. 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 a6 which state that variables  $x$ ,  $q$  and  $u$  "cooperate" in output production (Rader, 1968). Third, it may be noted that assumptions a4 to a6 imply that the production function  $f(x,q,u)$  is "supermodular" in  $(x,u,q)$ . This supermodularity property is both necessary and sufficient for  $x^*(u,q)$  defined as the maximand of any function  $f(x,q,u)+k(x)$  to be non-decreasing in  $u$  or  $q$  (Milgrom and Shannon, 1994). The usefulness of this quite strong theoretical result is illustrated below.

## 2.2. Characterisation of optima and land allocation patterns

For simplicity, consider the problem of allocating land between two technology combinations only corresponding to intensification levels  $u^-$  and  $u^+$ , respectively. Let  $l_{u^-}(q)$  be the proportion of land of quality  $q$  used with the extensive technology. Following Lichtenberg, the decision problem of the profit-maximising producer is then to choose  $l_{u^-}(q)$  for every land quality  $q$  so that he maximises the following programme:

$$\text{Max}_{l_{u^-}} \int_0^1 [\pi(p, w, q, u^-)l_{u^-}(q) + \pi(p, w, q, u^+)(1-l_{u^-}(q))]g(q)dq \quad (1)$$

where the per-hectare profit function is defined by:

$$\begin{aligned} \pi(p, w, q, u) &= \text{Max}_{y,x} (pf(x, q, u) - wx) \\ &= py^*(p, w, q, u) - wx(p, w, q, u); u = u^-, u^+ \end{aligned} \quad (2)$$

Programme (1) shows that the optimal land allocation is to devote all land of quality  $q$  to the extensive technology  $u^-$  if  $\pi(p, w, q, u^+) > \pi(p, w, q, u^-)$  and, inversely, to devote all land of quality  $q$  to the intensive technology  $u^+$  if  $\pi(p, w, q, u^+) < \pi(p, w, q, u^-)$ .

Before characterising the various patterns of land allocation, we first show the two following propositions.

**Proposition 1:**  $x^*(p, w, q, u^-) \leq x^*(p, w, q, u^+)$

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<sup>2</sup> In other words, it is not assumed that  $f'_u(\cdot) \geq 0$ .

**Proof :** Let consider programme (2) and assume an interior solution for  $x^*(p,w,q,u^-)$  and  $x^*(p,w,q,u^+)$ . First-order conditions for programme (2) imply then that the following equality is verified at the optimum:

$$f'_x(x^*(p, w, q, u^-), q, u^-) = f'_x(x^*(p, w, q, u^+), q, u^+) = w / p$$

By using assumption a4, we have:

$$f'_x(x^*(p, w, q, u^-), q, u^+) > f'_x(x^*(p, w, q, u^-), q, u^-) = w / p$$

By using assumption a2, we have:

$$f'_x(x^*(p, w, q, u^-), q, u^+) > f'_x(x^*(p, w, q, u^+), q, u^+) = w / p$$

Hence,

$$x^*(p, w, q, u^+) > x^*(p, w, q, u^-)$$

**Proposition 2:** 
$$\frac{dH(q, p, w, u^+, u^-)}{dq} = \frac{d[\pi(q, p, w, u^-) - \pi(q, p, w, u^+)]}{dq} < 0$$

**Proof:** We define the implicit function  $H(p,w,q,u^+,u^-)$  by the difference  $\pi(p, w, q, u^-) - \pi(p, w, q, u^+)$ .

Differentiating this function  $H(q,.)$  with respect to land quality  $q$  yields:

$$\begin{aligned} \frac{dH(q, w, p, u^-, u^+)}{dq} &= \frac{dH(q, w, p, u^-)}{dq} - \frac{dH(q, w, p, u^+)}{dq} \\ &= p[f'_q(x^*(p, w, q, u^-), q, u^-) - f'_q(x^*(p, w, q, u^+), q, u^+)] \end{aligned}$$

By using assumption a5, we have:

$$f'_q(x^*(p, w, q, u^-), q, u^-) < f'_q(x^*(p, w, q, u^-), q, u^+)$$

By using assumption a6 and proposition 1, we then obtain:

$$f'_q(x^*(p, w, q, u^-), q, u^+) < f'_q(x^*(p, w, q, u^+), q, u^+)$$

Hence,

$$\frac{dH(p, w, q, u^+, u^-)}{dq} < p[f'_q(x^*(p, w, q, u^+), q, u^+) - f'_q(x^*(p, w, q, u^+), q, u^+)] = 0$$

Proposition 1 shows that the per hectare variable input demand function is an increasing function of the intensification parameter  $u$ . Proposition 2 shows that the unit profit function defined for the extensive technology intersects the unit profit function obtained with the intensive technology from above.

Let  $\tilde{q}$  be the critical land quality defined by:

$$H(p, w, \tilde{q}, u^-, u^+) = \pi(p, w, \tilde{q}, u^-) - \pi(p, w, \tilde{q}, u^+) = 0$$

This definition and propositions 1 and 2 presented above now allow us to characterise the patterns of land allocation as follows:

i) When the critical land quality  $\tilde{q}$  is greater than one,  $\pi(p, w, 1, u^-) > \pi(p, w, 1, u^+)$  and all the land stock  $L$  will be allocated to the extensive technology which is the most profitable crop on all land qualities in that case.

ii) When the critical land quality  $\tilde{q}$  is lower than zero, then  $\pi(p, w, 0, u^-) < \pi(p, w, 0, u^+)$  and all the land stock  $L$  will be allocated to the intensive technology which is the most profitable crop on all land qualities in that case.

iii) When the critical land quality  $\tilde{q}$  lies between zero and one, then all land of quality less than  $\tilde{q}$  will be allocated to the extensive technology and all land of quality greater than  $\tilde{q}$  will be allocated to the intensive technology. In other words, extensive techniques are used on lower quality land and intensive techniques are employed on higher quality land. Acreages allocated to the extensive and intensive technologies are, respectively:

$$L_{u^-} = \int_0^{\tilde{q}} g(q) dq = G(\tilde{q}) \quad (3a)$$

$$L_{u^+} = L - L_{u^-} = \int_{\tilde{q}}^1 g(q) dq = G(1) - G(\tilde{q}) \quad (3b)$$

This land allocation mechanism on a class by class basis is depicted graphically in Figure 1 in the case of an interior solution. The critical land quality  $\tilde{q}$  corresponds to point E where the extensive per hectare profit function  $\pi(p, w, q, u^-)$  intersects the intensive unit profit function  $\pi(p, w, q, u^+)$  from above. Therefore, all land of quality lower (respectively higher) than  $\tilde{q}$  is allocated to the extensive (respectively intensive) technology.

*(Insert Figure 1. Land allocation mechanism on a class by class basis: case of an interior solution.)*

### 3. Comparative static results and implications for policy design

Comparative statics may now be used to examine the potential influence of changes in key policy instruments of the CAP, i.e., output support price, set aside and per hectare compensatory payments, and/or exogenous variables, i.e., input prices. Results are summarised in Table 1. They are used to analyse the potential impact of the 1992 CAP reform on both the intensity of land use and the land allocation decision.

*(Insert Table 1. Comparative static results on the intensive margin and on the extensive margin.)*

### **3.1. Comparative static results**

#### ***i) Policy changes and adjustments at the intensive margin***

Adjustments on the intensive margin are first addressed. The first row of Table 1 gives the impact of changes in policy instruments on per hectare variable input use and the second row of Table 1 gives the corresponding impact on yields. These results are obvious and directly linked to unit production and profit function properties. The per hectare demand for a variable input is an increasing function of output price  $p$  and a decreasing function of its own price  $w$ . It does not depend on the set aside rate  $\theta$  and on per hectare compensatory payments  $a$ . The per hectare output supply is an increasing function of output price and a decreasing function of variable input prices. It does not depend on the set aside rate and on per hectare compensatory payments.

Comparative static results show, in particular, that compensatory payments of the CAP reform which are based on historical area and yields are decoupled at the intensive margin of production and hence, do not influence per hectare input use and yields for a given technology choice. They also show that the CAP reform should result in some decline in per hectare input use and in yields, at least relative to what would otherwise have been the case. They finally show that the output-input price ratio is the main variable which influences input use and yields at the intensive margin.

#### ***ii) Policy changes and adjustments at the extensive margin***

The discussion now focuses on impacts at the extensive margin. We first consider the case of a producer who uses simultaneously the extensive technology  $u^-$  on lower quality land and the intensive technology  $u^+$  on higher quality land. In other words, we assume an interior solution for the land allocation programme. Consider then the impact of changes in input prices. Differentiating the acreage equation (3a) with respect to variable input prices yields:

$$\frac{dL_{u^-}}{dw} = \frac{dG(\tilde{q})}{dq} \frac{d\tilde{q}}{dw} \quad (4)$$

Since  $dG(\tilde{q})/dq$  is positive, the sign of  $dL_{u^-}/dw$  is the same as the sign of  $d\tilde{q}/dw$ . Let then consider the implicit function  $H(\cdot)$  evaluated at the critical land quality  $\tilde{q}$ . By definition,  $H(p, w, \tilde{q}, u^-, u^+) = 0$ . Differentiating this function with respect to variable input prices yields:

$$\begin{aligned}
\frac{dH(p, w, \tilde{q}, u^-, u^+)}{dw} &= \frac{d\pi(p, w, \tilde{q}, u^-)}{dw} \Big|_{\tilde{q}=\text{cst}} + \frac{d\pi(p, w, \tilde{q}, u^-)}{dq} \frac{d\tilde{q}}{dw} - \frac{d\pi(p, w, \tilde{q}, u^+)}{dw} \Big|_{\tilde{q}=\text{cst}} - \frac{d\pi(p, w, \tilde{q}, u^+)}{dq} \frac{d\tilde{q}}{dw} \\
&= -[x^*(p, w, \tilde{q}, u^-) - x^*(p, w, \tilde{q}, u^+)] + \left[ \frac{d\pi(p, w, \tilde{q}, u^-)}{dq} - \frac{d\pi(p, w, \tilde{q}, u^+)}{dq} \right] \frac{d\tilde{q}}{dw} \\
&= 0
\end{aligned}$$

Hence,

$$\frac{d\tilde{q}}{dw} = [x^*(p, w, \tilde{q}, u^-) - x^*(p, w, \tilde{q}, u^+)] / \left[ \frac{d\pi(p, w, \tilde{q}, u^-)}{dq} - \frac{d\pi(p, w, \tilde{q}, u^+)}{dq} \right] \quad (5)$$

Proposition (1) implies that the numerator of (5) is negative while proposition (2) implies that the denominator is strictly negative. Hence,

$$d\tilde{q} / dw > 0 \text{ and } dL_{u^-} / dw > 0 \quad (6)$$

By a similar reasoning, one obtains:

$$\frac{d\tilde{q}}{dp} = [y^*(p, w, \tilde{q}, u^-) - y^*(p, w, \tilde{q}, u^+)] / \left[ \frac{d\pi(p, w, \tilde{q}, u^-)}{dq} - \frac{d\pi(p, w, \tilde{q}, u^+)}{dq} \right] \quad (7)$$

Hence,

$$d\tilde{q} / dp < 0 \text{ and } dL_{u^-} / dp < 0 \quad (8)$$

An intuitive interpretation of the two previous results is the following. An increase in the price of a variable input will give an incentive to cut back on its use and to substitute other less costly factors. One mechanism for doing so is to convert more land to the extensive technology  $u^-$  which, by definition, uses this input less intensively. The critical land quality increases from, say,  $\tilde{q}_0$  to  $\tilde{q}_1$ , and all land of quality between  $\tilde{q}_0$  and  $\tilde{q}_1$  is now allocated to the extensive technology. At this stage, it is important to note that the producer's response to policy variable changes is generally indeterminate in sign at the extensive margin when both  $\pi(p, w, q, u^-)$  and  $\pi(p, w, q, u^+)$  are simultaneously affected, as they are when inputs are common to both technologies (on this point, see Parks, 1995). In our case, it is possible to determine the impact of input price changes on land allocation thanks to proposition (1) and (2) which mean that each factor is used more intensively with the intensive technology  $u^+$  than with the extensive technology  $u^-$  and that unit profit functions are increasing in land quality, other things being equal. Similarly, an increase in the price of the output will lead the producer to allocate more land to the intensive technology. The critical land quality decreases from, say,  $\tilde{q}_0$  and  $\tilde{q}_{-1}$ , and all land of quality lying between  $\tilde{q}_{-1}$  and

$\tilde{q}_0$  is devoted to the intensive technology which is now more profitable than the extensive technology on these land quality classes. It thus can be concluded that an output-input ratio cut decreases input use both by an adjustment at the intensive margin and an adjustment at the extensive margin, i.e., by the (potential) conversion of lower quality land from the intensive technology toward the extensive technology.

Consider next the impact of a (fixed, i.e., non rotational) set-aside policy. Assumptions about the production technologies in both the intensive and extensive cases imply that the producer will optimally choose to first set aside the lowest land qualities<sup>3</sup>. The lower bound of the land quality interval is no more zero, but  $q_{inf}$  strictly greater than zero and implicitly defined by:

$$\int_{q_{inf}}^1 g(q) dq = (1-\theta) \int_0^1 g(q) dq = (1-\theta)G(q) \quad (9)$$

where  $\theta$  is the land set-aside rate.

If  $q_{inf}$  is lower than  $\tilde{q}$ , the producer will set aside low quality land (i.e., extensively used land) only. If  $q_{inf}$  is greater than  $\tilde{q}$ , the set aside of all land of quality lower than  $\tilde{q}$ , i.e., all extensively used land, is not sufficient to satisfy the set aside requirement and a part of intensively used land, of quality lying between  $\tilde{q}$  and  $q_{inf}$ , will also be set aside. The new optimal land allocation corresponds to a corner solution where all cultivated land which is now of quality lying between  $q_{inf} > \tilde{q}$  and one is devoted to the intensive technology.

Consider finally the impact of CAP reform compensatory payments. Since they do not influence neither land quality bounds (i.e., zero and one) nor the critical land quality (i.e.,  $\tilde{q}$ ), they have no impact on land allocation at least in our mono-product simplified framework. In other words, compensatory payments of the CAP reform are not only decoupled at the intensive margin (see point i) above), but also at the extensive margin. At this stage, the following remarks are in order. The analytical framework developed in this section considers only one product and assumes that total area  $L$  allocated to this product is constant. In the context of the CAP, one may consider that the product is an aggregate of grains and oilseeds crops (hereafter CO crops) and that  $L$  is the fixed eligible base area. The fact that compensatory payments are found to be decoupled applies only if area  $L$  is assumed to be constant, i.e., if it is always profitable to devote the predetermined area  $L$  to CO crops in the new CAP regime<sup>4</sup>. But without compensatory payments, it is likely that the area in CO crops would decrease compared to the area of

<sup>3</sup> This result is simply due to the fact that  $\pi(p, w, q, u)$  is an increasing function of land quality.

<sup>4</sup> On this point, see Roberts et al. (1996) who showed that participation in the programme should be very high (nearly 100 %) in England if CAP reform parameters (i.e., output price levels, set aside rate and per hectare compensatory payments) remain at current levels.

sugarbeets, potatoes and/or fodder crops (Oude Lansink and Peerlings, 1995). Accordingly, even in the framework of a mono-product technology, compensatory payments cannot be considered fully decoupled since they remain tied to the obligation of producing CO crops. In addition, compensatory payments would also influence production decisions for the various CO crops (wheat, maize, barley, other coarse grains, sunflower, rapeseed, soya and protein crops) via CO crop-specific acreage allocation demands under the binding constraint of a fixed base area. Cahill (1993) and Guyomard et al. (1995) clearly showed that, because the compensatory payments are very different for the various CO crops<sup>5</sup>, they do influence land allocation decisions and hence, output supplies and variable input use. Nevertheless, it is interesting to note that Guyomard et al. showed that the compensatory payments package is, to a large extent, neutral in so far as its effects on CO yields and supplies, and variable input use, would be only very small. The neutrality is due to the fact that effects of own compensatory payments are nearly offset by the cross effects of compensatory payments on substitutable CO crops.

We now consider the case of a corner solution for the land allocation problem, i.e., more precisely, the case where  $\tilde{q}$  is initially lower than zero. At the initial equilibrium, all the available area is thus allocated to the intensive technology  $u^+$ . Comparative static results on critical land quality  $\tilde{q}$  are the same as those derived in the case of an interior solution, i.e.,  $d\tilde{q}/dw > 0$ ,  $d\tilde{q}/dp < 0$ ,  $d\tilde{q}/dL = 0$  and  $d\tilde{q}/da = 0$ . Consider first a variable input price increase. It leads to a higher critical land quality  $\tilde{q}$ , say,  $\tilde{q}_0 < \tilde{q}_1$ . If the new threshold  $\tilde{q}_1$  remains lower than zero, the input price change has no impact at the extensive margin. But if the new threshold becomes greater than zero, some land of low quality, between 0 and  $\tilde{q}_1 > 0$ , will be used with extensive techniques. Consider now an output price increase which decreases the critical land quality from, say,  $\tilde{q}_0$  to  $\tilde{q}_1 < \tilde{q}_0 < 0$  and hence has no impact at the extensive margin. But in the case of an output price cut, the critical land quality increases and some land of low quality may be converted to the extensive technology, as in the case of a variable input price increase. Consider finally a set aside programme. The setting aside of a fixed proportion of available area has no impact at the extensive margin in the case of a corner solution since it enlarges the gap between the critical land quality which remains unchanged at  $\tilde{q}_0 < 0$  and the lowest land quality class  $q_{in} > 0$ .

### *iii) Policy changes and total impact on input use, output supply and yields*

Total impacts of policy variable changes on input use, output supply and yields may now be addressed by simultaneously considering changes at the intensive margin and changes at the extensive margin. Results are reported at the end of Table 1. For simplicity, we consider an interior solution only<sup>6</sup>.

<sup>5</sup> Compensatory payments are much higher for oilseeds than for grains.

<sup>6</sup> Extending the results to corner solutions is straightforward.

By definition, the total variable input demand function is:

$$X^* = \int_0^1 x^*(p, w, q, u^*(q))g(q)dq \quad (10)$$

$$= \int_0^{\tilde{q}} x^*(p, w, q, u^-)g(q)dq + \int_{\tilde{q}}^1 x^*(p, w, q, u^+)g(q)dq$$

Differentiating equation (10) with respect to a variable input price yields:

$$\frac{dX^*}{dw} = \int_0^{\tilde{q}} \frac{dx^*(p, w, q, u^-)}{dw} \Big|_{\tilde{q}=\text{cst}} g(q)dq + \int_{\tilde{q}}^1 \frac{dx^*(p, w, q, u^+)}{dw} \Big|_{\tilde{q}=\text{cst}} g(q)dq \quad (11)$$

$$+ \frac{d\tilde{q}}{dw} g(\tilde{q}) [x^*(p, w, \tilde{q}, u^-) - x^*(p, w, \tilde{q}, u^+)]$$

The first and second right-hand side terms of (11) capture the impact of input price change at the intensive margin : they are negative by convexity of unit profit functions  $\pi(p, w, q, u^-)$  and  $\pi(p, w, q, u^+)$  in  $w$ . The third right-hand side term of (11) measures the impact at the extensive margin: it is negative because  $d\tilde{q}/dw$  is positive and  $x^*(., u^-)$  is lower than  $x^*(., u^+)$ . Hence,  $dX^*/dw < 0$ . By a similar reasoning, one easily shows that  $dX^*/dp > 0$ .

The output supply function on all land qualities is defined by:

$$Y^* = \int_0^{\tilde{q}} y^*(p, w, q, u^-)g(q)dq + \int_{\tilde{q}}^1 y^*(p, w, q, u^+)g(q)dq \quad (12)$$

Differentiating equation (12) with respect to  $w$  and  $p$  yields, respectively,  $dY^*/dw < 0$  and  $dX^*/dp > 0$ .

### 3.2. Implications for policy design: the 1992 CAP reform and the extensification issue

It is now widely recognised that the pre-reform CAP, and in particular high and stable output-input price ratios, provided strong incentives for European producers to both increase the intensity of land use and expand intensive production techniques onto marginal lands. According to the theoretical framework presented in section 2 and according to comparative static results shown above, one can then reasonably assume that the pre-reform CAP corresponds to a corner solution where the critical land quality  $q\sim$  is "sufficiently" low for most producers so that they decided to allocate all available land to the intensive technology only. By reducing output-input price ratios, the 1992 CAP reform should therefore likely induce these producers to reduce variable input use at the intensive margin. Nevertheless, three factors may, at least partially, offset the positive effect of the reform on land use intensity. First, the institutional price cut does not necessarily translate into an equivalent decrease in market price, as it can be observed from the first three years of CAP reform application. Second, a downward adjustment of chemical input prices may offset a part of output price cut, as again it can be observed from the first years of CAP reform

application. Third, and perhaps more importantly for the long term, price elasticities of yields and input use may be low around the pre-reform "equilibrium" point so that the effects of an output-input price ratio decrease are small only. Many empirical studies suggest that these price elasticities are rather low in the short run when primary factors (i.e., labour, land and capital) are fixed. These price elasticities are much higher, in absolute value, in the long run when primary factors, labour and land in particular, may adjust to new economic conditions. CAP reform per hectare compensatory payments cannot be considered fully decoupled, in particular because they remain tied to the obligation of producing certain crops, i.e., CO crops. As explained above, and shown by Oude Lansink and Peerlings, it is likely that the area in CO crops would decrease without these compensatory payments. In other words, the definition of a fixed eligible base area for CO crops and the obligation of producing these CO crops to receive direct aids imply that land and labour would not substantially adjust in response to policy instrument changes introduced in May 1992. Price elasticities relevant to consider are thus short-run or restricted elasticities. These elasticities are probably low. Accordingly, the effects of support price cuts on yields and variable input use at the intensive margin should be limited, even in the long run.

According to comparative static results presented above, a support price cut should increase the critical land quality  $q^*$  and hence, induce producers to convert some low quality land, previously cultivated with intensive techniques, to the extensive technology. Again, the three factors mentioned above, i.e., the imperfect transmission of institutional price changes to market prices, the downward adjustment of market prices of chemical inputs, and the quasi-fixity of primary factors and the subsequent low values of price elasticities, may in practise offset the positive effect of the reform on critical land quality  $\tilde{q}$ . Furthermore, even if the land quality threshold increases sufficiently so that the farmer decides to allocate part of his low quality land to the extensive technology, he also will decide to set aside this low quality land first.

The previous discussion suggests that the most important policy parameter which could affect the level of demand for fertilisers and crop protection chemicals in the EU is the reduction in the area of arable cropping as a result of the set-aside requirement. At this stage, it is thus particularly important to highlight the rationale of the set-aside programme and, more generally, the rationale of the new instrumentation of the CAP. The logic of the reform is clear and may be described as follows. Support prices for grains were substantially cut down, from a current average buying-in price of 155 green ecus per tonne in 1992-93 to align on a target price of 110 green ecus per tonne and an intervention price of 100 green ecus per tonne in the 1995-96 marketing year. The objective of this support price cut was to induce an increase in the domestic demand and especially in its feed component thanks to an improved price competitiveness of interior cereals with respect to imported feed ingredients (i.e., protein cakes and substitutes of grains). The support price cut, which is compensated by "fixed" direct payments per hectare, should induce producers to both reduce variable input use at the intensive margin and adopt less intensive production techniques which should reduce rates of growth in yields in the medium term. In the short

term, an improved balance for grains is obtained by a set-aside programme, compulsory to be eligible to the direct payments.

The decision to decrease EU support prices of grains toward world prices has thus provided substantial gains, essentially in terms of lower user prices for both final consumption and derived demand. These gains are greater the closer the EU prices are to world prices. It appears thus clearly that one of the main limits of the 1992 CAP reform (for grains) is to fix the minimum institutional price at a level greater than the world price which alters the price competitiveness of European grains with respect to third countries and implies the continuous use of subsidies to export on foreign markets. Furthermore, the first years of CAP reform application have clearly showed that market prices may be substantially higher than these minimum institutional prices. If the EU does not fulfil its GATT commitment in terms of subsidised export volume reduction, the easiest way to operate would obviously be to increase the set-aside rate which means that the negative effects of this regulatory instrument would be aggravated, i.e., increased costs, decreased competitiveness on the international scene, and less incentives toward more extensive farming. An alternative way to operate would be to set the domestic price to the world price level which would allow the EU to export without restitutions (GATT commitments would no longer apply in that case), to increase its competitiveness not only on world markets but also on the domestic scene with respect to substitutes, and to abandon the requirement for land to be set aside. Removing this requirement would allow farmers to operate at minimum total cost and would induce them to use less intensive farming. In the context of the current instrumentation of the CAP, a first step in that direction would be to introduce a double market for grains in which land actually set aside would be cultivated with more extensive techniques (i.e., with low per hectare chemical input levels) and would be remunerated at world price levels.

It is clear that the new CAP reform mechanisms were primarily designed to solve the problems of surplus production for grains, not the ill-defined environmental problems that modern farming may potentially create. One weak feature of the reform is the lack of integration between the natural conservation mission of agriculture on the one hand, and the food production and trade roles of agricultural activity on the other hand. The analysis developed above implicitly assumes that agricultural pollution problems in the EU, such as nitrate contamination of groundwater supplies, eutrophication of surface water supplies and marine waters and smell, are directly arisen from the increased use of chemical inputs (and also problems of waste disposal from large livestock units). Given the link between agricultural pollution and the growing intensity of agricultural production, the solution advocated by economists, and also by CAP reform promoters, to reducing agricultural pollution is to return to lower-intensity farming by reducing the use of agricultural chemicals and/or by shifting to less intensive land uses. The CAP reform should, at least theoretically, induce a movement toward lower-intensity farming at both the intensive and extensive margin of production. Nevertheless, this movement should be limited as many factors may offset this

positive trend: the imperfect transmission of institutional price changes to market prices, the downward adjustment of market prices of chemical inputs, the quasi-fixity of primary factors and the subsequent low values of price elasticities, the current set-aside programme which implies that it is more profitable to set aside low land quality first, .... With few exceptions, the use of chemical inputs at high levels will remain profitable in the EU. Our current system of agriculture has developed because of these chemicals and is likely to remain very dependent upon them. Because the majority of the costs from the pollution are external to agricultural production, society cannot expect the agricultural problem to be drastically reduced without direct intervention, even if the CAP reform is, but only indirectly, a first step in the good direction. The following section of the paper shows how tax instruments on pollution emission, output or input may be used to reduce variable input use. The first sub section compares the (producer) profit efficiency of these three tax instruments in achieving a given reduction in input use per hectare. The second sub section extends the analysis by including the land quality heterogeneity issue. For a given land quality, it is now generally recognised that pollution emissions increase with chemical input use. But it is also generally accepted that pollution emissions decrease with land quality, for a given variable input use level. It seems thus particularly important to analyse under which conditions the land quality effect may offset the negative effect of high levels of chemical inputs on good quality hectares.

#### 4. Environmental and agricultural policy interactions

The model of Section 2 can easily be extended to incorporate production of a "bad" output such as pollution by introduction of a pollution generation function  $z=z(x,q,u)$ . Such a pollution generation function allows for pollution to be generated by inputs  $x$  and influenced by land quality  $q$  and technology choice  $u$ , directly and indirectly via the use of input  $x$ . Note that this notation does not allow the bad output to be influenced directly by product  $y$ , but only indirectly via input  $x$  use.

Let consider the producer problem on a given land quality  $q$ . Without any environmental regulation, each producer solves programme (2) and hence, does not take into account the negative environmental externalities arising from input use. The private optimal solutions are denoted by  $x^*(p,w,q,u)$  and  $y^*(p,w,q,u)$ , and let  $z^*(x^*(p,w,q,u),q,u)=z^*(p,w,q,u)$  denote the emission level resulting from solving the first-order conditions of programme (2). It is clear that this emission level  $z^*(.)$  differs from the social optimal emission level which is obtained by solving the first-order conditions of the following programme:

$$\text{Max}_{x,y} (pf(x, q, u) - wx - vz(x, q, u)) \quad (13)$$

If we let the social optimal solution to programme (13) be denoted by  $\hat{x}(p, w, v, q, u)$  and  $\hat{y}(p, w, v, q, u)$ , the social optimal amount of pollution generated is then obtained by substituting these choice functions into the pollution generation function, i.e.,  $z(\hat{x}(p, w, v, q, u), q, u) = \hat{z}(p, w, v, q, u)$ .

To see how private and social emission levels ( $z^*$  and  $\hat{z}$ , respectively) differ, for a given land quality  $q$  and a given production technology  $u$ , let consider Figure 2. The private optimum corresponds to point P where private marginal cost (i.e.,  $w$ ) and private marginal revenue (i.e.,  $pf'_x(\cdot)$ ) curves intersect. At point P, the marginal product of  $x$  is equal to its private real price, i.e.,  $pf'_x(x^*)=w/p$ , and the producer profit is equal to area abc. The social optimum corresponds to point S where social marginal cost (i.e.,  $w+vz'_x$ ) and private marginal revenue intersect. At point S, the marginal product of  $x$  is equal to its social real price, i.e.,  $f'_x(\hat{x}) = [w + vz'_x(\hat{x})] / p$ , and the producer profit is equal to area aa'b'c. One easily verifies that  $\hat{x}$  is lower than  $x^*$  and hence, that  $\hat{z}$  also is lower than  $z^*$ , if the pollution generation function is an increasing function of input use. The social welfare loss on land quality  $q$  corresponds to area a'bd and is given by:

$$wsl(q) = \int_{\hat{x}}^{x^*} [w + vz'_x(x, q, u) - pf'_x(x, q, u)] dx = \int_{\hat{x}}^{x^*} [SCM(x, q, u) - RM(x, q, u)] dx \quad (14)$$

where  $SCM(\cdot)$  denotes the social marginal cost function and  $RM(\cdot)$  is the private marginal revenue.

*(Insert Figure 2. Characterisation of social and private optima on a given land quality q.*

Government intervention is thus required to internalise the negative social costs resulting from excessive variable input use. The government may directly regulate input use by an appropriate quota or indirectly by levying a tax on emission  $z$ , on input  $x$  or/and on output  $y$ .

#### 4.1. Impact of environmental policies at the intensive margin

Socially optimal input use at the intensive margin could be induced through a pollution tax. With a pollution tax  $v$ , the profit-maximising level of input use on land quality  $q$  cultivated with the technology  $u$  is defined by (Antle and Just, 1991):

$$pf'_x(x^*(p, w, v, q, u), q, u) - w - vz'_x(p, w, v, q, u) = 0 \quad (15)$$

The appropriate tax  $\hat{t}$  which would induce producers to equate the value of the marginal product with the marginal social cost of production, i.e., which would induce the social welfare-maximising input use at the intensive margin, is simply equal to the unit value  $v$  of emissions.

A pollution tax is generally not practical. Because emissions are difficult to observe and costly to monitor, input taxes may be a useful alternative to an effluent charge in the case of non-point source pollutants. Imposing a per-unit tax  $t$  on inputs that cause pollution should also reduce emissions. In that case, the profit-maximising level of input use at the intensive margin is defined by  $pf'_x(x^*)-w-t = 0$  and the social welfare-maximising input level is obtained by fixing  $t$  to its optimal value  $\hat{t} = vz'_x(p, w, v, q, u)$ . In a similar way, the social welfare-maximising output tax  $\hat{s}$  is equal to  $vz'_x(p, w, v, q, u) / f'_x(p, w, v, q, u)$ .

The previous analysis shows that optimal taxes,  $\hat{v}$  on pollution emission,  $\hat{t}$  on polluting inputs and  $\hat{s}$  on output, all makes the producer to choose the social welfare-maximising input use level  $\hat{x}$ , for a given land quality  $q$ . But these three taxes do not have the same impact on producer unit profit. It is clear that the tax on pollution emission has the lowest negative effect on unit profit. It is more interesting to compare the profit efficiency of input and output optimal taxes. Let consider unit profit functions when input (respectively output) is optimally taxed. These functions may be written as:

$$\pi(p, w + \hat{t}, q, u) = pf(\hat{x}, q, u) - w\hat{x} - \hat{t}\hat{x} \quad (16a)$$

$$\pi(p - \hat{s}, w, q, u) = pf(\hat{x}, q, u) - w\hat{x} - \hat{s}f(\hat{x}, q, u) \quad (16b)$$

By subtracting (16b) from (16a), one yields:

$$D(.) = \pi(p, w + \hat{t}, q, u) - \pi(p - \hat{s}, w, q, u) = -\hat{t}\hat{x} + \hat{s}f(\hat{x}) \quad (17)$$

This implicit function  $D(.)$  equals zero if  $\hat{s}/\hat{t} = \hat{x}/f(\hat{x})$ . Substituting optimal taxes by their respective expressions, this condition may finally be written as:

$$D(.) = 0 \Leftrightarrow f(\hat{x}) = \hat{x} \cdot f'_x(\hat{x}) \Leftrightarrow \hat{y}/\hat{x} = f'_x(\hat{x}) \quad (18)$$

Equation (17) shows that input and output optimal taxes will have the same negative effect on producer unit profit if the input use optimal level  $\hat{x}$  corresponds to the point where the average productivity of input equals the marginal productivity of input. Accordingly, if the average productivity of input is greater (respectively lower) than the marginal productivity, then  $D(.) > 0$  (respectively  $D(.) < 0$ ) and the unit profit evaluated with an input tax at optimal level  $\hat{t}$  will be greater (respectively lower) than the unit profit evaluated with an output tax at optimal level  $\hat{s}$ . It is likely that we are rather in the first case which corresponds to a situation of decreasing average yields and hence that an optimal tax on input is better, from a producer profit point of view, than an optimal output tax, for a given land quality  $q$ .

All the results detailed above relate to a given land quality  $q$ . It is now interesting to consider in more detail the quality issue, and more particularly the relationship between land quality  $q$  and pollution emission  $z$ . A first step in that direction is to analyse how the welfare social loss function  $wsl(q)$  changes with land quality. Differentiating equation (14) with respect to  $q$  yields:

$$\frac{dwsl(q)}{dq} = v \frac{dz^*}{dx} \frac{dx^*}{dq} - p \left[ f'_q(x^*) - f'_q(\hat{x}) \right] + v \cdot \left[ z'_q(x^*) - z'_q(\hat{x}) \right] \quad (19)$$

In general, the sign of (19) is indeterminate. Assumption a6 implies that  $dx/dq$  is positive and hence that the first right-hand side term of (19) is positive if the pollution generation function  $z$  is an increasing function of input level, i.e., if  $dz/dx \geq 0$ . Since  $x^*$  is greater than  $\hat{x}$ , assumptions a3 and a6 imply that

the second right-hand side term of (19) is negative. If we assume that the pollution generation function does not depend on land quality, i.e., if we assume that  $z'_q = 0$ , the third right-hand side term of (19) equals zero. In the more general case where the pollution generation function depends on land quality, the sign of this third term depends on the sign of the second partial derivative  $z''_{xq}$ .

The previous discussion shows that the dependence of the welfare social loss function  $wsl(q)$  with respect to land quality is indeterminate. The following sub-section addresses then the issue of the relationship between pollution emission and land quality in detail in order to define some conditions allowing the pollution generation function to decrease with land quality.

#### **4.2. Input use intensity, land quality and damage to the environment**

The aim of this sub-section is to show that the link between the level of chemical input use and the level of the damage to the environment they are responsible to may be far less obvious than usually assumed. It is clear that an increase in chemical input use on a given land quality leads to an increase in their negative effect on the environment. However, does it necessarily mean that farmers using high input loads on high quality areas generate more damage to the environment than farmers using lower input loads on lower quality areas? Our objective here is to show that the answer to this question may be no, under reasonable assumptions.

##### *i) The model*

In order to analyse this question, we modify the model used in the previous sections. We now assume that the producer production function has the following structure  $f(x,q,u) \equiv F(x_a(x,q),u)$ , where  $x_a(x,q) = x - l(x,q)$  and  $l(x,q) \in [0, x]$ , and that farmers may choose the technology  $u$  which is comprised between  $u^-$  and  $u^+$ , i.e., technology intensity choices are not discrete anymore. The  $l(\cdot)$  function represents the amount of input  $x$  lost by the farmer, i.e., the amount of input that does not reach the plant. Accordingly, we implicitly assume that the main impact of an increased land quality is to provide increasing quantities of inputs to the plant.

We may assume that  $l(x,q)$  represents the amount of input harmful to the environment when the amount of input used by the producer is  $x$ . In the case of fertilisers, the amount of input that does not enter in the production process very likely becomes harmful for the environment due to its transfer to water resources. In the case of pesticides, the existing link between the  $l(x,q)$  function and the potential environmental damage of the input is more questionable because the success of a pesticide application does not imply an assimilation of this input by the plant. In other words, an active ingredient displaying low biodegradation may be harmful to the water resources even if it reaches its target pest population, i.e., even if it enters in the agricultural production process. However, given that the new referenced pesticides have quick biodegradation, it is reasonable to assume that the lower is the pesticide transfer away from its target, the

less the effects of this input to the environment are likely to be important and the more its productivity is likely to be high. This is especially true in the case of herbicides or nematicides.

Let assume that the loss function  $l(x,q)$  satisfy the following properties:

p1)  $l'_x > 0$  with  $l'_x \in ]0,1[$ ,

p2)  $l''_{xx} > 0$ ,

p3)  $l'_q < 0$ , and

p4)  $l''_{xq} < 0$ .

These assumptions imply, in particular, that a land quality increase results in a decrease in the input quantity which is lost and in a decrease in the marginal input quantity which is lost.

The previous interpretation of the  $l(x,q)$  function means that the  $x_a(x,q)$  function represents the quantity of input  $x$  that actually enters in the production process. We assume that the  $F(x_a(x,q),u)$  production function satisfies the following properties with respect to  $x_a$  and  $u$ :

p5)  $F'_{x_a} > 0$ ,

p6)  $F''_{x_a x_a} < 0$ ,

p7)  $F''_{ux_a} > 0$ , and

p8) concavity of  $F(.)$  in  $(u, x_a)$  with  $F''_{uu} < 0$ .

Properties p5, p6 and p7 correspond to assumptions a1, a2 and a5 defined on  $f(.)$  with respect to  $x$  and  $u$ . Property p8 indicates that the marginal productivity of intensification is decreasing, *ceteris paribus*. These properties on the  $F(.)$  production function imply that assumptions a1 to a5 defined for the  $f(.)$  function in section two are satisfied. Assumption a6 deserves further attention as the sign of the expression

$$f''_{xq}(x, q, u) = \frac{\partial^2 F(x - l(x, q), u)}{\partial x \partial q} = -l''_{xq} F'_{x_a} - (1 - l'_x) l'_q F''_{x_a x_a}$$

is indeterminate. The first right-hand side term, i.e.,  $-l''_{xq} F'_{x_a}$ , is positive. It indicates that the decrease in the marginal loss implied by an increase in  $q$  leads to an increase in the marginal productivity of  $x$ . The second right-hand side term, i.e.,  $(1 - l'_x) l'_q F''_{x_a x_a}$ , is negative. It indicates that the positive effect of  $q$  on  $x_a$  leads to a decrease in the marginal productivity of  $x$ . The more the input quantity is available to the plant, the lower its marginal productivity due to the decreasing marginal productivity of available input quantity. It is important to remember that  $f''_{xq}(x, q, u) > 0$  is a necessary and sufficient condition for  $x^*$  to be increasing in  $q$ . Since  $q$  leads to an increase in the (marginal) available input quantity,  $f''_{xq}(x, q, u) < 0$

indicates would indicate that the increasing soil quality increases sufficiently the availability of the input to almost saturate the plant with. Such a situation may only occur where  $q$  is very high when compared to  $u$ . We show below that this situation should occur only very rarely. This comes from the fact that the optimal intensification level  $u^*$  is an increasing function of land quality  $q$ .

## ii) Optimal choice of technology $u$ and cooperation of $q$ and $x$ in production process

Let consider first and second order conditions of the profit maximisation programme defined on the basis of the  $F(\cdot)$  production function. These conditions may be written as:

$$pF'_{x_u}(u, x^* - l(x^*, q))(1 - l'_x(x^*, q)) - w = pF'_{x_u}(u, x^* - l(x^*, q)) \frac{\partial x_u(u, x^*)}{\partial x} - w = 0 \quad (20a)$$

$$pF''_{x_u x_u}(u, x^* - l(x^*, q))(1 - l'_x(x^*, q))^2 - F''_{x_u}(u, x^* - l(x^*, q))l''_{xx}(x^*, q) \leq 0 \quad (20b)$$

It is important to note that the loss function  $l(\cdot)$  provides an incentive for farmers to take into account the effect of their input use on the environment. Obviously, this is not originated from altruism since the value producers give to the marginal pollution simply corresponds to the loss in gross product value due to the marginal input loss, i.e.,  $pF'_{x_u}(u, x^* - l(x^*, q))l'_x(x^*, q)$ .

Using the implicit function theorem allows us to show that the partial derivative  $dx^*/du$  is positive since it has the same sign as the expression  $pF''_{x_u u}(u, x^* - l(x^*, q))(1 - l'_x(x^*, q)) = pF''_{x_u u}(1 - l'_x)$  which is positive.

The marginal profit due to intensification is defined by:

$$pF'_u(u, x^* - l(x^*, q)) + \left[ pF'_{x_u}(u, x^* - l(x^*, q))(1 - l'_x(x^*, q)) - w \right] \frac{dx^*}{du} = pF'_u(u, x^* - l(x^*, q)) \quad (21)$$

We then show that the marginal profit intensification is non decreasing in  $q$ .

Proof. The marginal profit of intensification is non decreasing in  $q$  if :

$$\frac{\partial}{\partial q} \left\{ F'_u + \left[ (1 - l'_x)F'_{x_u} - w \right] \frac{dx^*}{du} \right\} = \frac{F''_{ux_u}}{(1 - l'_x)} \left[ \frac{dx^*}{dq} \Big|_u - \frac{dx^*}{dq} \Big|_{x_u} \right] \geq 0$$

This condition is equivalent to:

$$\frac{dx^*}{dq} \Big|_u \geq \frac{dx^*}{dq} \Big|_{x_u}$$

The second right-hand term of this inequality is negative since it may also be written as:

$$\frac{l'_q}{(1-l'_x)} = \frac{dx}{dq} \Big|_{x_a} < 0$$

Accordingly, two cases may occur:

i) first case :  $\frac{dx^*}{dq} \Big|_u \geq 0$

ii) second case:  $0 > \frac{dx^*}{dq} \Big|_u \geq \frac{l'_q}{(1-l'_x)} = \frac{dx}{dq} \Big|_{x_a}$

These two cases may equivalently be defined by:

i) first case:  $f''_{xq}(x^*, q, u) \geq 0$

ii) second case:  $f''_{xq}(x^*, q, u) \leq 0$  with  $\frac{dx^*}{dq} \Big|_u \geq \frac{dx}{dq} \Big|_{x_a}$

These two conditions may be equivalently be summarised by one inequality, i.e.,

$$\frac{dx_a(x^*, q)}{dq} \Big|_u \geq 0 \quad (22)$$

which shows that  $x_a(x^*, q)$  increases in  $q$ .

In the first case i), the following inequality is satisfied:

$$\frac{dx^*}{dq} \Big|_u \geq 0 \Rightarrow \frac{dx_a(x^*, q)}{dq} \Big|_u = \frac{dx^*}{dq} \Big|_u (1-l'_x(x^*, q)) - l'_q(x^*, q) \geq 0 \quad (23a)$$

In the second case ii), the following inequality is satisfied:

$$0 \geq \frac{dx^*}{dq} \Big|_u \geq \frac{l'_q}{(1-l'_x)} = \frac{dx}{dq} \Big|_{x_a = \text{cst}} \Rightarrow \frac{dx_a(x^*, q)}{dq} \Big|_u = \frac{dx^*}{dq} \Big|_u (1-l'_x(x^*, q)) - l'_q(x^*, q) \geq 0 \quad \text{and}$$

$$\frac{dl(x^*, q)}{dq} \Big|_u = \frac{dx^*}{dq} \Big|_u l'_x(x^*, q) + l'_q(x^*, q) \leq 0$$

(23b)

Condition (23a) occurs when input use and land quality are cooperant in the Rader sense while condition (22b) occurs when an increase in land quality allows farmers to save input quantities. The intuition behind these conditions is that under i) the "land quality constraint" is binding while under ii) the "intensification level constraint" is binding. When neither condition i) nor condition ii) holds, we have:

$$\left. \frac{dx_a(x^*, q)}{dq} \right|_u \leq 0$$

We show in appendix A that this is impossible, i.e., that either condition i) or condition ii) holds.

The previous analysis shows that an increase in land quality leads producers to increase their technology intensification level because an higher land quality increases available input quantities to the plant, as is required by property p7, i.e.,  $F''_{ux_a} > 0$  (Milgrom and Shannon, 1994). Thus we have:

$$\frac{du^*}{dq} \geq 0 \quad (24)$$

If the producer chooses an optimal intensification level  $u^*$  strictly comprised between  $u^-$  and  $u^+$  on land quality  $q$ , we have:

$$pF'_u(u^*, x^* - l(x^*, q)) = 0$$

and condition i) holds. An intensification level strictly lower than  $u^+$  is chosen if and only if the "land quality constraint" is binding.

If the producer chooses an optimal intensification level  $u^*(q)$  equal to  $u^+$  on land quality greater than  $\underline{q}$ , we have:

$$pF'_u(u^+, x^* - l(x^*, \underline{q})) = 0 \text{ and condition i) holds at } \underline{q}$$

and

$$pF'_u(u^+, x^* - l(x^*, q)) > 0 \text{ and condition ii) holds at } q > \underline{q}.$$

The maximum intensification level is chosen for two reasons: either  $u^+$  corresponds to the optimal intensification level (for land quality  $\underline{q}$ ) or land quality is very good and the farmer is only constrained by  $u^+$  (for land quality  $q > \underline{q}$ ).

Within this context, we have:

$$f'_{xq}(x^*(q), q, u^*(q)) >, =, < 0 \Leftrightarrow q <, =, > \underline{q}$$

At this stage, it can be argued that the threshold  $\underline{q}$  is probably close to 1. In the case of fertilisers, this can be illustrated by using the results shown by Berck and Helfand (1990). The intensification level of the cropping technology  $u$  can be used as an indicator of variable input needs of the considered crop. Following Berck and Helfand, we can consider that a plant response to input uses corresponds to a linear response and plateau (LRP) function. accordingly, the higher is  $u$ , the more important is the input quantity  $x_a$  necessary to reach the plateau. Berck and Helfand argue the deterministic LRP model is valid at the plant level only. At the field level, micro-nonuniformities in soil quality, water supply or input

applications imply that one cannot reasonably assume that the plateau is reached for each plant. Similar considerations hold in the case of pesticide use and irrigation. Within this context, the assumption that  $q$  is close to 1 appears reasonable. Furthermore, it should be noted that farmers' technical skills may also appear very important here.

### iii) Land quality and pollution emission

The model developed in points i) and ii) above allows now us to show that farmers using high input loads on high quality land do not necessarily generate more damage to the environment than farmers using lower input loads on lower quality land. Furthermore, we also show that it is possible to find some (reasonable) conditions which allow us to claim the contrary.

The pollution level generated by farmers on land quality  $q$  is given by  $l(x^*, q)$ .

Let first consider the case where  $q > \underline{q}$ . In that case, we have:

$$\left. \frac{dx^*}{dq} \right|_{u=u^+} \leq 0 \quad (25a)$$

and

$$\left. \frac{dl(x^*, q)}{dq} \right|_{u=u^+} = \left. \frac{dx^*}{dq} \right|_{u=u^+} l'_x(x^*, q) + l'_q(x^*, q) \leq 0 \quad (25b)$$

Conditions (25a) and (25b) show that input use and pollution level are positively correlated for very good land quality when they are observed across fields of different qualities. However, as argued above, such a situation is likely to occur only very rarely.

Let now consider the case when  $q \leq \underline{q}$ . In that case, we have:

$$\frac{dx^*}{dq} = \left. \frac{dx^*}{dq} \right|_u + \frac{du^*}{dq} \frac{dx^*}{du} \geq 0 \quad (26a)$$

and

$$\frac{dl(x^*, q)}{dq} = \left( \left. \frac{dx^*}{dq} \right|_u + \frac{du^*}{dq} \frac{dx^*}{du} \right) l'_x(x^*, q) + l'_q(x^*, q) = \frac{dx^*}{dq} l'_x(x^*, q) + l'_q(x^*, q) \quad (26b)$$

In the case where  $l'_q < 0$ , it is impossible to say *a priori* that pollution increases or decreases with  $q$  although input use  $x^*$  increases with  $q$ . The sign of the effect of  $q$  on  $l$  is given by:

$$\frac{dl(x^*, q)}{dq} >, =, < 0 \Leftrightarrow \left( \frac{dx^*}{dq} \Big|_{u=cst} + \frac{du^*}{dq} \frac{dx^*}{du} \right) = \frac{dx^*}{dq} >, =, < - \frac{l'_q(x^*, q)}{l'_x(x^*, q)} = \frac{dx}{dq} \Big|_{l=l(x^*, q)=cst}$$

(27)

Condition (27) states that the pollution level does not increase with  $q$  if and only if an increase in  $q$  does not lead farmers to use more inputs than the amount that is affordable for the soil. However, further investigation is needed in order to give more intuitive contents to this condition.

Stacking first-order conditions of the profit maximisation programme and totally differentiating them with respect to  $x$ ,  $u$  and  $q$ , one obtains:

$$\begin{bmatrix} F'_{x_a x_a} (1-l'_x)^2 - F'_{x_a} l''_{xx} & F'_{x_a u} (1-l'_x) \\ F'_{x_a u} (1-l'_x) & F''_{uu} \end{bmatrix} \begin{bmatrix} \frac{dx^*}{dq} \\ \frac{du^*}{dq} \end{bmatrix} = \begin{bmatrix} F'_{x_a x_a} (1-l'_x) l'_q + F'_{x_a} l''_{qx} \\ F'_{u x_a} l'_q \end{bmatrix} \quad (28)$$

The solution in  $dx^*/dq$  of system (28) is:

$$\frac{dx^*}{dq} = \frac{(F'_{x_a x_a} (1-l'_x) l'_q + F'_{x_a} l''_{qx}) F''_{uu} - (F'_{x_a u})^2 (1-l'_x) l'_q}{(F'_{x_a x_a} (1-l'_x)^2 - F'_{x_a} l''_{xx}) F''_{uu} - (F'_{x_a u})^2 (1-l'_x)^2} \quad (29)$$

If we assume that optimal solution  $u^*$  and  $x^*$  correspond to an interior solution, the denominator of (29) is positive.

On the basis of (29), one easily shows that the marginal input loss. Using this equation, the marginal input loss in  $q$ , i.e.,  $dl(x^*, q) / dq$  may be written as:

$$\frac{dl(x^*, q)}{dq} = \frac{[F''_{uu} F'_{x_a x_a} - (F'_{x_a u})^2] (1-l'_x) l'_q + F'_{x_a} (l'_x l''_{qx} - l'_q l''_{xx}) F''_{uu}}{(F'_{x_a x_a} (1-l'_x)^2 - F'_{x_a} l''_{xx}) F''_{uu} - (F'_{x_a u})^2 (1-l'_x)^2} \quad (30)$$

Equation (30) has the same sign as the numerator:

$$[F''_{uu} F'_{x_a x_a} - (F'_{x_a u})^2] (1-l'_x) l'_q + F'_{x_a} (l'_x l''_{qx} - l'_q l''_{xx}) F''_{uu} \quad (31)$$

The first right-hand side term of (31) is negative by concavity of the production function  $F(\cdot)$  in  $(u, x_a)$ . By using the following identity,

$$(l'_x l''_{qx} - l'_q l''_{xx}) = - \frac{\partial}{\partial x} \left( \frac{l'_x}{l'_q} \right) (l'_q)^2 = \frac{\partial}{\partial x} \left( \frac{dq}{dx} \Big|_{l=cst} \right) (l'_q)^2$$

one verifies the second right-hand side term of (31) has the opposite sign of expression

$$\frac{\partial}{\partial x} \left( \frac{dq}{dx} \Big|_{l=cst} \right)$$

Expression  $\frac{dq}{dx} \Big|_{l=cst}$  defines the marginal rate of substitution of x for q along a loss isoquant. It is positive since an increase in q implies an increase in x in order to keep l constant. This marginal rate of substitution is increasing in x if the increase in q needed to compensate an increase in x on a given loss isoquant is increasing in x. This situation does seem too unrealistic. This can be verified by noting that:

$$(l'_x l''_{qx} - l'_q l''_{xx}) = l'_x l''_{xx} \left( \frac{l''_{qx}}{l''_{xx}} - \frac{l'_q}{l'_x} \right) = l'_x l''_{xx} \left( \frac{dx}{dq} \Big|_{l=cst} - \frac{dx}{dq} \Big|_{l'_x=cst} \right),$$

and hence that the second right-hand side term of (31) has the same sign as:

$$-\left( \frac{l''_{qx}}{l''_{xx}} - \frac{l'_q}{l'_x} \right) = -\left( -\frac{dx}{dq} \Big|_{l'_x=cst} \right) - \left( -\frac{dx}{dq} \Big|_{l=cst} \right) \quad (32)$$

The first right-hand side term of (32) corresponds to the marginal rate of substitution of q for x along the (optimal) marginal loss isoquant while the second right-hand side term of (32) corresponds to the marginal rate of substitution of q for x along the (optimal) loss isoquant. This expression (32) is negative if:

$$(x', q') \text{ and } (x'', q'') \text{ satisfy } x' < x'', q' < q'', \text{ and } l(x', q') = l(x'', q'')$$

implies that

$$(x', q') \text{ and } (x'', q'') \text{ also satisfy } l'_x(x', q') \leq l'_x(x'', q'').$$

This property means that an good quality area that generates the same amount of pollution than does an area of low quality will marginally generate more pollution than will do the area of low quality when input use x is increasing. This condition indicates that a good quality area that generates the same amount of pollution than an area of low quality is closer to its saturation threshold with respect to x than is the area of lower quality. This property is sufficient to ensure that input loss is decreasing in q although input use is increasing in q (for  $q \leq \underline{q}$ ). Of course, further investigations are needed in order to empirically check the validity of this property.

However, given that this property appears not unreasonable, some useful policy implications can be drawn from the analysis. If we consider that the quality of a given land is its ability to provide inputs to the plant, we must recognize that land quality drives i) the profitability of the intensification of the cropping technology as well as ii) the amount of pollution generated by using inputs such as fertilisers, pesticides or irrigation water. Thus it appears necessary to consider land quality in order to draw optimal

environmental policies. Given this definition of land quality, using high loads of inputs on high quality land generates less damages to the environment than using the same amount of inputs on lower quality land. We argue here that this property of high quality land also lies at the root of the positive link that is observed between land quality and farmers' cropping technology intensity choice. Agronomic studies clearly state that the cropping technology intensification level and input use are cooperant in the Rader sense (Meynard, 1991). As a result, very intensive cropping technologies can only be used on high quality land, i.e., on land that easily transforms applied input quantities into input quantities that are available to the plant. This comes from the fact that the higher the cropping technology intensity is, the more input losses are damageable for farmers' profit. Formally, this is illustrated by the the fact that the expression  $pF'_{x_a}(u, x - l(x, q))l'_x(x, q)$  is increasing in  $u$ . Accordingly, a technically efficient farmer who increases the intensity of his cropping technology also increases the cost valuation that are associated with input losses. Within this context, the cooperation of  $x_a$  and  $u$  in the production process provides an incentive for farmers to i) increase their input use as well as ii) reduce their input losses. Because of this unavoidable trade-off, farmers only intensify their cropping techniques on high quality land and consequently do not necessarily generate more damages to the environment where they use higher loads of intensification variable inputs such as fertilisers and pesticides.

Futhermore, we found conditions on the effect of land quality on input losses that are both reasonable and sufficient to ensure that the more farmers intensify their cropping patterns the less they generate input losses harmful to the environment. As long as land quality constitutes a binding constraint for intensification (i.e., where  $q < \underline{q}$ ), input uses and yields increase in  $q$  while input losses decrease. In this case, input uses clearly are not pertinent indicators of environmental damages. If it was validated, this result would have an important implication on agricultural and environmental policy design. It would provide arguments to strenghten environmental policy instruments on low quality land rather than on high quality land. Given that the higher quality land provides more competitive products, an environmental policy taking into account land quality would not necessarily imply a sharp decrease in the agricultural production sector competitiveness. Moreover, this result could have strong implications with respect to the design of farmers' income support policies and/or redistribution policies. An efficient environmental policy would allow to orient public depenses toward less competitive regions, i.e., toward regions where agriculture is weaker from an economic point of view.

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## Appendix A

$$\frac{\partial(pF'_{x_a}(1-l'_x) - w)}{\partial q} = -p(F''_{x_a x_a}(1-l'_x)l'_q + F'_{x_a} l''_{qx})$$

The following implication:

$$\left. \frac{dx^*}{dq} \right|_u \leq \frac{l'_q}{(1-l'_x)} = \left. \frac{dx}{dq} \right|_{x_a = \text{cst}} \leq 0 \Rightarrow \left. \frac{dx_a(x^*, q)}{dq} \right|_u = \left. \frac{dx^*}{dq} \right|_u (1-l'_x(x^*, q)) - l'_q(x^*, q) \leq 0$$

is thus verified when:

$$\left. \frac{dx^*}{dq} \right|_u = \frac{F''_{x_a x_a}(1-l'_x)l'_q + F'_{x_a} l''_{qx}}{F''_{x_a x_a}(1-l'_x)^2 - F'_{x_a} l''_{xx}} \leq \frac{l'_q}{1-l'_x}$$

This condition is equivalent to:

$$F''_{x_a x_a}(1-l'_x)^2 l'_q + F'_{x_a}(1-l'_x)l''_{qx} \geq l'_q F''_{x_a x_a}(1-l'_x)^2 - F'_{x_a} l'_q l''_{xx} \Leftrightarrow (1-l'_x)l''_{qx} \geq -l'_q l''_{xx}$$

By noting that  $(1-l'_x)l''_{qx} \leq 0$  and  $-l'_q l''_{xx} \geq 0$ , one shows that:

$$\left. \frac{dx^*}{dq} \right|_u \leq \frac{l'_q}{(1-l'_x)} = \left. \frac{dx}{dq} \right|_{x_a = \text{cst}} \leq 0 \Rightarrow \left. \frac{dx_a(x^*, q)}{dq} \right|_u = \left. \frac{dx^*}{dq} \right|_u (1-l'_x(x^*, q)) - l'_q(x^*, q) \leq 0$$

is impossible.

**Table 1. Comparative static results on the intensive margin and on the extensive margin**

Panel a. Results at the intensive margin

$\alpha$	w	p	L	a	q	u
$dx^*(p,w,q,u)/d\alpha$	-	+	0	0	+	+
$dy^*(p,w,q,u)/d\alpha$	-	+	0	0	+	+

Panel b. Results at the extensive margin (interior solution, i.e.,  $\tilde{q} \in [0,1]$ )

$\alpha$	w	p	L	a
$d\tilde{q}/d\alpha$	+	-	0	0
$dL_{\tilde{q}}/d\alpha$	+	-	-	0

Figure 1. Land allocation mechanism on a class by class basis: case of an interior solution

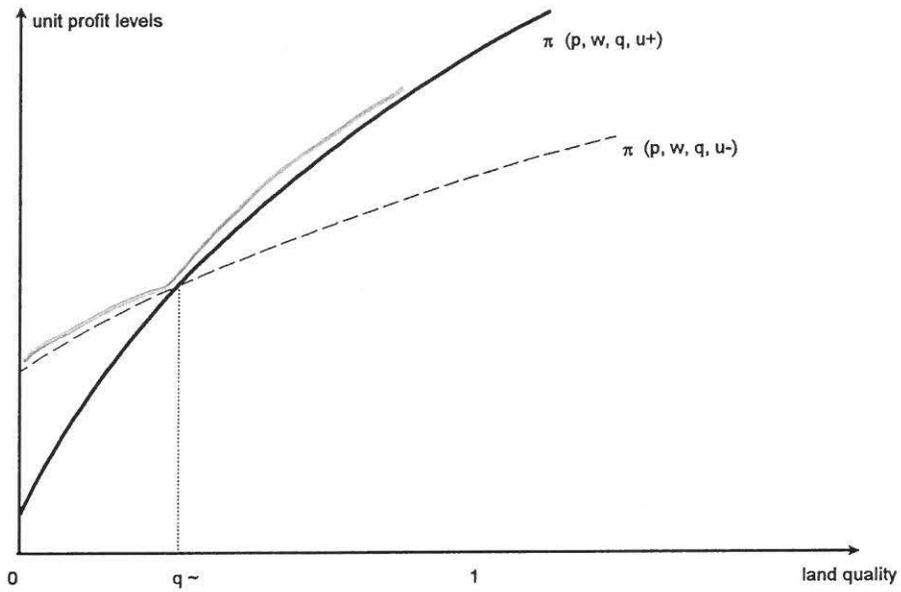


Figure 2. Characterisation of social and private optima on a given land quality q

