Modelling of Agricultural Behavior under the CAP Regime: Assessment of Environmental Impacts and Policy Effectiveness[1]

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Abstract

The structure of farming activity under the provisions of the generalized regime of the Common Agricultural Policy involving both the first and second pillar elements is modelled. Independently of whether regulated agents exhibit unbounded or bounded rationality, the impact of the different type of CAP measures, as prescribed by Agenda 2000, in the decision making - and thus on the environmental performance of a homogeneous population of farmers - are discussed. The problem of a representative farmer is used for this purpose. After assessing the environmental effectiveness of the various CAP regimes, the mechanism that provides the type of CAP instruments that safeguard the collective attainment of a social environmental target, along with the type of interdependence characterizing them, is defined under the analytical framework of unboundedly and boundedly rational agents respectively. The problem of the optimal regulation of an unboundedly rational population of farmers is discussed in both a static and a dynamic context. The long-run viability of the Agenda 2000 CAP reform is also examined under the assumption of bounded rationality by employing the evolutionary framework of replicator dynamics.

Keywords: Environmental impacts, coupling, decoupling, production subsidy, direct payment, cross-compliance principle, rural development subsidy.

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1 European Environment under the CAP Regime

Despite their beneficial environmental services, European agriculture is associated with a series of adverse environmental effects.[2] Among the factors creating the unbalance between agriculture and environment, CAP measures are considered of primary importance.[3] Supports linked with output levels (coupled payments) increased production to levels that would not have occurred otherwise, resulting into intensification, specialization, expansion of cultivated areas and rise in livestock numbers (Baldock et al., 2002). Even though coupled payments have not yet been cancelled by EU market policy (Pillar I), the Commission circularly admitted in 1988 that such a price policy is liable for environmental damages (Fennel, 1997) and decided to reorganize CAP as a response to the wider demand for an environmentally oriented CAP.

The major element of the 1992 or McSharry CAP reform was the gradual reduction or even elimination of production subsidies and the introduction of direct aid payments, provided per hectare (decoupling) to compensate farmers for support price cuts (EC, 2003). The substitution of price support measures by decoupled payments was continued by the 1999 or *Agenda 2000 reform*, which makes direct aid payments conditional to environmental aims (i.e. horizontal regulation). A long-term set-aside mechanism[4] was proposed and a package of *rural development measures* (Pillar II)[5] was promoted to complement reforms of common market organizations (CMOs) and internalize major environmental considerations. To maximize environmental benefits, both direct and pillar II payments are subject to the *cross-compliance principle*, a sanctioning approach incorporated in horizontal regulation that involves proportionate penalties for environmental infringements entailing, where appropriate, partial or full removal of aid in the event of deviation from certain farming standards (EC, 1999). Finally, *dynamic modulation* involves the transfer of funds released

[2] Among the beneficial services are classified the decline of greenhouse emissions and the gains to biodiversity, while among the adverse services are the loss of landscape diversity and quality, as well as the deterioration of important habitats. For further details about the beneficial and adverse environmental services of agriculture, see Baldock et al. (2002).

[3] The driving forces of such an unbalance are: (i) changes in market conditions (i.e. input prices), (ii) commercial considerations (i.e. profit maximization), (iii) institutional changes, (iv) technology development, (v) economic and social changes in rural areas (i.e. cost of labour, population mobility), (vi) independent and partly endogenous environmental changes (i.e. global warming), as well as (vii) public policy measures of CAP or in different policy realms (i.e. land ownership, food safety) (Baldock et al., 2002). Furthermore, among the factors that contribute to agricultural pollution are also classified the imperfect knowledge about the (i) land attributes (i.e. soil moisture and fertility level) (Johnson et al., 1991), (ii) location physical attributes (Wu and Babcock, 2001), as well as (iii) the operating characteristics of the activity (i.e. farming experience, education) (Wu and Babcock, 2001).

[4] Farmers setting-aside their arable land for ten years are eligible for direct payments dependent on this requirement. Non-food crops (i.e. energy crops) can be cultivated on this land (EC, 2004a).

[5] Under Pillar II, aid is provided for (i) early retirement, (ii) set-up of young farmers, (iii) reafforestation of agricultural land, (iv) compensatory payments for mountainous and other less-favoured areas, (v) agri-environmental programs, (vi) vocational training, (vii) improving processing and marketing of agricultural products, and (viii) investment in agricultural holdings (EC, 2004a).

from the compulsory reduction of market policy payments to rural development measures contributing to environmentally benign practices. The reforms were strengthened by the 2003 or Mid-term review CAP reform, which introduced a single payment scheme based on direct payments received during the period 2000-2002 and the hectares entitled for those payments, as well as redefining the cross-compliance principle to make it dependent on the detected noncompliance type (EC, 2004b).[6]

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Agenda 2000 is known as the "*Green CAP*" because of the belief that it brings greater quality to environmental integration. However, the theoretical analysis of this regime has been rather limited and its environmental impacts have not yet been fully assessed to justify such a characterization. Hence, the intention of this section is to assess the impact of the various pillar I and pillar

[6] Particularly, if a farmer fails to comply with standards due to negligence, then the reduction of payments varies between 5% and 15%, while payments are reduced by at least 20% and may also be completely withdrawn in the event of deliberate noncompliance.

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II policy instruments, as foreseen by the 1999 CAP reform, on the environmental performance of a homogeneous population of farmers defined in terms of equilibrium production choices of a representative farmer. Moreover, it aims at evaluating the effectiveness of the given CAP reform to stimulate compliance of an entire population of either unboundedly or boundedly rational farmers with a socially desirable environmental target. This is achieved by considering the mechanism that provides the type of the CAP instruments, along with the type of interdependence characterizing them which guarantees the achievement of such a target.[10]

To do so a conceptual, theoretical framework describing farming behaviour under the Agenda 2000 provisions is developed, by considering a homogeneous population of farmers where each farmer is eligible for a production subsidy and two types of direct payments provided for alternative land treatments: (i) cultivation and (ii) set-aside. The given financial provisions are granted to each European farmer through a public voluntary program,[11] in the form of a formal contract between the entitled farmer and the Commission. Given the attainment costs of environmental requirements incorporated in direct payments, two strategies are considered: compliance with and deviation from farming standards. A deviating strategy can be detected via random inspections,[12] given the non-point-source characteristics of agricultural pollution, and deterred via the enforcement of the cross-compliance principle.

Given the generalized nature of the provided farm model, the different CAP regimes associated with common market organizations are reproduced under the proper simplifying assumptions, allowing comparisons between regimes in terms of farmers' equilibrium production choices, independent of the rationality assumptions. The examined CAP regimes associated with CMOs are: (i) *full coupling regime* that involves only production subsidies independent of environmental requirements, (ii) *partial decoupling regime*, involving coupled and decoupled payments, and (iii) *full decoupling regime*, that provides only direct payments. The unregulated regime, providing neither coupled nor decoupled payments, is employed as a benchmark regime. To assess whether and how production choices are altered by the introduction of farming standards and the cross-compliance principle, the partially and fully decoupled regimes are examined under the absence and presence of such considerations. Likewise the compliant and deviating strategy is compared in terms of equilibrium input and land usage values.

To examine the Commission's perception that rural development measures

[10] Under unbounded rationality agents adopt an optimizing behavioural rule and behave as if they had all the necessary data and skills to calculate the optimum response (Binmore, 1992), while under bounded rationality agents have imperfect information about payoffs, they are unable to compute the optimal strategy and choose between predetermined strategies (Noailly et al., 2003).

[11] For further details about the elements of the particular voluntary programs, see EC (2004b; 2007) or visit the official site of the European Commission: www.europa.eu/pol/agr/index_en.htm

[12] The simultaneous inspection of the entire population of farmers within a given geographical region is a technically very demanding task and potentially prohibitively costly.

enhance further the "green" character of Agenda 2000, it is considered that the land quality target is attained either by restricting main production choices (inputs, land and labour) or by treating them in an environmentally benign way through secondary production choices (treatments on input usage etc.). Such treatments can either be self-financed fully or partially through an RD program - that is actually a public voluntary program - providing a set of subsidies per unit of established treatments subject to farming standards and the cross-compliance principle. The extended farm model is employed to examine the environmental performance of farmers' population when CAP regimes are extended with Pillar II payments (i.e. extended full coupling, partial and full decoupling regime).

The perception that CAP, as shaped by Agenda 2000, achieves the integration of environmental considerations into individual and thus collective farming behaviour is not supported strongly by the results of our analysis. Comparative static analysis shows that even though the reduction of coupled payments and the incorporation of environmental constraints induce the population of potentially deviating farmers to restrict production choices, the final impact of direct payments and the compliance enforcement mechanism on these choices is ambiguous. The comparison of strategies also indicated that direct payments and the compliance enforcement mechanism may not be sufficient to induce deviating farmers to alter their production choices and adopt a strategy approaching (or even matching with) the compliant strategy.

Nonintervention is preferable on environmental grounds to intervention via production subsidies, justifying the wide criticism of coupled payments. However, the environmental performance of the regulated farmers under the Agenda 2000 regimes (partial or full decoupling) can not be clearly shown to be superior to the performance resulting under the unregulated and full coupling regime both under the compliant and non-compliant strategy. Even though both the partial and full decoupling regimes involve less input usage, there is uncertainty about their relative impact on the set-aside decision of farmers' population given that direct payments are provided on conflicting land usages. The fully decoupled regime is environmentally superior in terms of both production choices (i.e. input and land usage) to the regime involving both coupled and decoupled payments, justifying the Commission's decision to proceed with the full cancellation of coupled payments. However, the relative environmental performance of the regulated population under these intervention regimes becomes ambiguous when examined in terms of both main and secondary production choices. The prospect that the transition from the partial and full decoupling regime to the rural development regime may forestall the further deterioration of the agricultural environment and proceed further in the reconstruction of the quality of the agricultural landscape, as indicated by the Mid-term review, is not verifiable by our theoretical model. Finally, the environmental performance of the population of farmers under the partially and fully decoupled regimes can be further enhanced by the incorporation of environmental considerations and rural development payments, justifying the Commission's decision to embody pillar II in CAP.

2 Model

Consider a farmer i producing a single crop and possessing $\bar{L}_i$ gross land that is decomposed into:

$$\bar{L}_i = \left(1 - b_i^F\right) \bar{L}_i + b_i^F \bar{L}_i$$

where $\left(1 - b_i^F\right)$ is the fraction of gross land used for cultivation and b_i^F the remaining fraction voluntarily set aside (non-production case). For simplicity $\left(1 - b_i^F\right) \bar{L}_i = L_i^c$.

Crop yields are given by:

$$y_i = f(\mathbf{x}_{ij}, L_i^c) \tag{1}$$

where $\mathbf{x}_{ij}$ is the vector of input choices among a set of $j = 1, ..., m$ inputs.[13]

Farming activity i is associated with unintended generation of emission flows (e.g. nitrates leaching):

$$e_i = e(\mathbf{x}_{ij}, L_i^c) \tag{2}$$

that is positively correlated to production.[14]

In the absence of regulatory intervention the payoff function is:

$$\pi_i = Pf(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j \mathbf{x}_{ij}$$

where P is the output price and $\mathbf{w}_j$ the vector of input prices in the competitive market respectively.[15]

Under Agenda 2000 the given crop is eligible both for a production subsidy (s) and two types of direct aid payments (DPs) coupled with the alternative and conflicting land usages, distinguished into:

- A direct payment DP_1 granted on the basis of cultivated land

  $$L_i^c : DP_1 = \sigma_1 L_i^c = \sigma_1 \left(1 - b_i^F\right) \bar{L}_i$$

  where σ_1 is the premium provided per hectare of cultivated land.

- A direct payment DP_2 granted on the basis of set-aside land

  $$\left(\bar{L}_i - L_i^c\right) : DP_2 = \sigma_2 \left(\bar{L}_i - L_i^c\right) = \sigma_2 b^R \bar{L}_i$$

  where σ_2 is the premium granted per hectare of set-aside land and $\left(\bar{L}_i - L_i^c\right)$ the size of the voluntarily set-aside land. The Commission has defined a

[13] It holds $f_x, f_{L^c} > 0$ and $f_{xx}, f_{L^c L^c} < 0$, indicating that crop yields are increasing both in input and land usage, whilst display diminishing returns in both x and L^c. It is considered that $\mathbf{x}_{ij}$ and L^c are complements, in the sense that $f_{\mathbf{x}L^c} > 0$, a fact that involves that the marginal product of x is increasing to increases of L^c. Alternatively $f_{b^F} < 0$ and $f_{b^F b^F} < 0$.

[14] It holds $e_x, e_{L^c} > 0$ and $e_{xx}, e_{L^c L^c} > 0$, with $e_{xL^c} > 0$ given that $\mathbf{x}_{ij}$ and L^c are treated as complements. Alternatively $e_{b^F} < 0$ and $e_{b^F} > 0$.

[15] Land is not included in the vector since it is owned by the farmer.

certain fraction of land to be compulsory set-aside $\left(b^R\right)$. Hence, farmers setting-aside more land are not eligible for a premium for the additional range $\left(b_i^F - b^R\right)$.[16]

Based on the horizontal regulation, direct payments are conditional on environmental requirements:

- DP_1 is subject to an individual land quality standard, assumed to be expressed by the following constraint:

$$Q_i(e_1, e_2, ..., e_n) \geq \bar{Q}_i \tag{3}$$

  where Q_i is a decreasing function of emissions' flows[17] indicating the possibility of strategic interactions among farmers within a geographical area. A typical example of such interaction is the upstream and downstream farmer.[18]

- DP_2 is conditional to a land usage constraint:

$$b^F \geq b^R \text{ or } L_i^c \leq \tilde{L}^c \tag{4}$$

  where the constraint constant $\tilde{L}^c = (1 - b^R)\bar{L}_i$ represents the maximum permissible size of cultivated land.

Incentives not to attain environmental requirements arise from the non-point-source character of agricultural pollution. The fact that individual production choices are not directly observed by a third party (i.e. regulator) allows individual farmers to retain production choices unchanged and thus avert profit losses that compliance with (3) and (4) entails.[19] Such a deviation from given performance standards cannot always be attributed to deliberate actions but rather sometimes to farmers' negligence to comply. In any case deliberate and negligent deviating behaviour can be detected via the realization of a number of random inspections, given the regulator's inability to inspect simultaneously the entire population of farmers receiving direct payments.

Such a deviating behaviour can be detected under a certain probability and further deterred via the principle of cross-compliance, which involves reduction or even cancellation of provided direct payments by the amounts:

$$DP_1\gamma(\bar{Q}_i - Q_i) \text{ and } DP_2\gamma(L_i^c - \tilde{L}^c)$$

[16] The additional range can be eligible for a DP through an RD program, providing compensation for the afforestation of agricultural land (EC, 2004a).

[17] Given that $Q_{e_i}, Q_{e_ie_i} < 0$ it holds that $Q_x, Q_{L^c} < 0$ and $Q_{xx}, Q_{L^cL^c} < 0$, with $Q_{xL^c} > 0$. Alternatively, $Q_{b^F} > 0$ and $Q_{b^Fb^F} < 0$.

[18] Note that in an area characterised by a steep slope the land quality valuation of a farmer located on the top of a hill cannot be adversely affected by the emission flows of a farmer located at the bottom.

[19] The attainment of the land quality target requires the restricted use of inputs $\mathbf{x}_{ij}$ and / or of cultivated land L^c, resulting into a reduction in crop yields. Similarly, the attainnment of the land usage target imposes restrictions on the size of cultivated land, also involving reduction in crop yields.

where $\gamma \in [0,1]$ denotes the reduction rate. The final reduction of DPs is proportional to deviations from the constraint constant. Hence the higher the deviation is, the more evident deliberate noncompliance, justifying the higher reduction of DPs as foreseen by the 2003 CAP reform.

3 Alternative Behavioral Strategies under the CMOs CAP Regime

Under a CAP regime involving performance standards and a compliance enforcement mechanism, two behavioural rules can be distinguished, depending on farmers' attitude towards environmental constraints. If constraints (3) and (4) enter farmer i's profit maximization problem, then the compliant strategy is considered, while if the constraints do not enter the problem, the possibility of noncompliance with environmental standards is considered and the deviating strategy occurs. The two maximization problems are:[20]

1. **Compliant Strategy.**

$$\max_{\mathbf{x},b^F} \pi_i^C = P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j\mathbf{x}_{ij} + \sigma_1 L_i^c + \sigma_2\left(\bar{L}_i - L_i^c\right) \quad (5)$$

$$\text{subject to}$$
$$L_i^c \leq \tilde{L}^c$$
$$Q_i(e_1, e_2, ..., e_n) \geq \bar{Q}_i$$

2. **Deviating Strategy**.

$$\begin{aligned}\max_{\mathbf{x},b^F} \pi_i^{NC} &= P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j\mathbf{x}_{ij} + \sigma_1 L_i^c\left\{1 - p\gamma\left(\bar{Q}_i - Q_i\right)\right\} \quad (6)\\ &+\sigma_2\left(\bar{L}_i - L_i^c\right)\left\{1 - p\gamma(\tilde{L}^c - L_i^c)\right\}\end{aligned}$$

where $\left\{1 - p\gamma\left(\bar{Q}_i - Q_i\right)\right\}$ and $\left\{1 - p\gamma(L_i^c - \tilde{L}^c)\right\}$ represent the net percentage of direct payments provided after the detection of deviation from the imposed constraints and the enforcement of cross-compliance principle.

The generalized nature of the described CAP regime[21] allows the definition of the different CAP regimes via the proper simplifying assumptions. Hence, the environmental performance of the homogeneous population of farmers can

[20] In the absence of farming standards there is no distinction between compliant and deviating farmer. The maximization problem reduces into: $\max_{\mathbf{x},b^F} \pi_i = P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j\mathbf{x}_{ij} + DP_1 + DP_2$, where Pillar I payments (s, σ_1, σ_2), environmental considerations $\left(\bar{Q}_i, \tilde{L}^c\right)$ and the compliance enforcement mechanism (p, γ) are considered to be uniform for every farmer.

[21] It is the regime of partial decoupling denoted below by the indication (3b).

be examined in terms of set-aside decision $\left(b_i^F\right)$ and inputs usage $(\mathbf{x}_{ij})$ through the problem of a representative farmer i. The analyzed CAP regimes are:

1. *Unregulated competitive regime*: $s = 0$ and $\sigma_1, \sigma_2 = 0$. It is the *prior-CAP regime* or a CAP regime characterized by nonprovision of Pillar I payments.

2. *Full coupling regime*: $s > 0$ and $\sigma_1, \sigma_2 = 0$. It is the *old regime* providing production subsidies independent of farming standards.

3. *Partial decoupled regime*: $s > 0$ and $\sigma_1, \sigma_2 > 0$. It is the *current regime* involving both coupled and decoupled payments, the performance of which is examined under:[22]

   (a) Absence of land quality and land usage constraints.[23]

   (b) Existence of land quality and land usage constraints.

   to verify the perception that the link of decoupled payments with environmental constraints restrains farmers' production choices.

4. *Full decoupled regime*: $s = 0$ and $\sigma_1, \sigma_2 > 0$. It can be viewed as the *forthcoming regime*, involving complete cancellation of coupled payments and provision only of direct payments.[24] Its performance is examined both under the (a) absence and (b) existence of farming standards.[25]

3.1 The Maximization Problem under the Compliant Strategy

Given the production choices of the other farmers, farmer i considers, given the choices of the rest farmers, the problem (5) and maximizes the Langrangean function:

$$\begin{aligned}\mathcal{L}(\mathbf{x}_{ij}, b^F, \lambda_1, \lambda_2) &= P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j\mathbf{x}_{ij} + \sigma_1 L_i^c + \sigma_2\left(\bar{L}_i - L_i^c\right) \\ &\quad +\lambda_1\left[Q_i(e_1, e_2, ..., e_n) - \bar{Q}_i\right] + \lambda_2\left[\tilde{L}^c - L_i^c\right]\end{aligned}$$

The Kuhn-Tucker necessary conditions of the problem are given by:

[22] Limited production aid and a supplementary per hectare aid is foreseen for some crop types such as rice, nuts and some protein crops (EC, 2004a).

[23] When examing the performance of the given CAP regime under the deviating rule, the subcase a) is analogous to examining the case of nonenforcement of environmental standards in the sense either that no farmer is inspected (*i.e.* $p = 0$), or if inspected and found to be deviating from given standards, then no reduction of DP_s occurs (*i.e.* $\gamma = 0$).

[24] This regime already applies for cereals, oilseeds, protein crops, grain legumes, potatoes for starch production, beef, veal and sheepmeat (EC, 2004a).

[25] The Mid-term CAP regime is identical to the full decoupling regime since it involves the provision of DP_s and a single farm payment that is a fixed amount given that it depends on direct payments received during the period 2000-2002 and the number of hectares eligible for those payments, leaving thus the analysis unaffected.

$$
\begin{aligned}
FOC_{x_j} &: P(1+s)\frac{\partial f(\mathbf{x}^*_{ij}, L^c_{i*})}{\partial x_{ij}} - w + \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i\left(\mathbf{x}^*_{ij}, L^c_{i*}\right)}{\partial x_{ij}} = 0 \text{ if } x^*_{ij} > 0 \quad (7)\\
&\quad \text{or } \frac{\partial \mathcal{L}\left(\mathbf{x}^*_{ij}, b^F_{i*}, \lambda_1, \lambda_2\right)}{\partial x_{ij}} < 0 \qquad \text{if } x^*_{ij} = 0\\
FOC_{b^f_i} &: \lambda_2 - \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\cdot)}{\partial L^c_i} - P(1+s)\frac{\partial f(\cdot)}{\partial L^c_i} - \sigma_1 + \sigma_2 = 0 \text{ if } b^F_{i*} > 0 \quad (8)\\
&\quad \text{or } \frac{\partial \mathcal{L}\left(\mathbf{x}^*_{ij}, b^F_{i*}, \lambda_1, \lambda_2\right)}{\partial b^F_i} < 0 \qquad \text{if } b^F_{i*} = 0\\
FOC_{\lambda_1} &: Q_i(e_1, e_2, ..., e_n) - \bar{Q}_i = 0 \qquad \text{if } \lambda_1 > 0\\
&\quad \text{or } Q_i(e_1, e_2, ..., e_n) - \bar{Q}_i > 0 \qquad \text{if } \lambda_1 = 0\\
FOC_{\lambda_2} &: \tilde{L}^c - L^c_{i*} = 0 \qquad \text{if } \lambda_2 > 0\\
&\quad \text{or } \tilde{L}^c - L^c_{i*} > 0 \qquad \text{if } \lambda_2 = 0
\end{aligned}
$$

By the Envelop Theorem the Langrangean multipliers λ_1 and λ_2 express the marginal cost and benefit resulting from a change in the land quality and usage constraint constant, $\bar{Q}_i$ and $\tilde{L}^c$ respectively.

Conditions (7) and (8) provide the Nash equilibrium input usage x^*_{ij} and set-aside b^F_{i*} values under the compliant behavioural rule, assuming that such a Nash equilibrium exists, as:[26]

$$x^*_{ij}(P, \mathbf{w}_j, s, \sigma_1, \sigma_2) \text{ and } b^F_*(P, \mathbf{w}_j, s, \sigma_1, \sigma_2)$$

According to condition (7) farmer i applies input x_{ij} up to the point where the marginal revenues from production equate with the marginal costs from the purchase of the j input and the nonattainment of the land quality constraint $\left(\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x}\lambda_1\right)$. In the same context condition (8) equates marginal revenues in terms of set-aside premium, shadow savings due to compliance with the land quality and the set-aside constraint constants, $\left(-\lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L^c_i} + \lambda_2\right)$, with marginal costs in terms of foregone market revenues and foregone land usage premium.

Comparative static analysis indicated that changes in the value of provided CAP payments leave unaffected the optimum production choices if constraints (3) and (4) are binding. On the other hand, if constraints are nonbinding then the optimum production choices of the population of compliant farmers are affected by marginal changes in the magnitude of coupled and decoupled direct premiums. Particularly:

Proposition 1 *The environmental performance of the population of compliant farmers is enhanced if the CAP regime is characterised by (i) a reduced production subsidy, (ii) reduced land-usage payments, and (iii) an increased land-aside*

[26] The sufficient conditions for maximum are considered to be satisfied.

direct premium, facts that restrict the optimum production choices under the compliant strategy.

Indeed the gradual reduction of both production subsidies and land usage direct payments is foreseen by the current structure of CAP via the principle of dynamic modulation. However, the same principle also involves gradual reduction of set-aside direct payments, introducing uncertainty about the final impact of the current structure of CAP on the environmental performance of the representative compliant farmer and thus on the performance of the associated population.

3.2 Profit Maximization under the Deviating Strategy

Under the deviating strategy the Kuhn-Tucker conditions are:

$$
\begin{aligned}
FOC_{x_{ij}} \quad &: \quad P(1+s)\frac{\partial f(\mathbf{x}_{ij}^{\#}, L_{i\#}^{c})}{\partial x_{ij}} - w_j + \sigma_1 L^c p\gamma \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\cdot)}{\partial x_{ij}} = 0 \text{ if } x_{ij}^{\#} > 0 \quad (9) \\
& \quad \text{or } \frac{\partial \pi_i^{NC}}{\partial x_{ij}} < 0 \qquad \text{if } x_{ij}^{\#} = 0 \\
FOC_{b^f} \quad &: \quad -P(1+s)\frac{\partial f(\mathbf{x}_{ij}^{\#}, L_{i\#}^{c})}{\partial L_i^c} - \sigma_1\left\{1 - p\gamma\left[\left(\bar{Q}_i - Q_i\right) - \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L_i^c}L_i^c\right]\right\} \quad (10) \\
& \quad +\sigma_2\left\{1 - p\gamma\left(\left(\bar{L}_i - \tilde{L}^c\right) - 2\left(\bar{L}_i - L_{\#}^c\right)\right)\right\} = 0 \qquad \text{if } b_{i\#}^F > 0 \\
& \quad \text{or } \frac{\partial \pi_i^{NC}}{\partial b_i^F} < 0 \qquad \text{if } b_{i\#}^F = 0
\end{aligned}
$$

Given the actions of the other farmers, the Nash equilibrium input usage $x_{ij}^{\#}$ and set-aside $b_{i\#}^F$ values under the deviating behavioural rule, as provided by conditions (9) and (10), are given by:[27]

$$x_{ij}^{\#}(P, \mathbf{w}_j, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p) \text{ and } b_{\#}^F(P, \mathbf{w}_j, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p)$$

According to condition (9) inputs are applied up to the point where marginal revenues from production equal the marginal costs from input purchase and the reduction of DP_1 due to both detection of deviation from the land quality constraint and enforcement of the cross-compliance principle. Similarly condition (10) defines the set-aside fraction that equates marginal revenues from nonproduction and enhanced land quality defined as the preserved amount of DP_1 payment $\left(\sigma_1 p\gamma\left[\left(\bar{Q}_i - Q_i\right) - \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L_i^c}L_i^c\right]\right)$, with marginal costs in terms of foregone market revenues and land usage premium. The last term can either reflect a marginal cost or revenue depending on the relative size of the voluntary $\left(\bar{L}_i - L_i^c\right)$ and compulsory set-aside land $\left(\bar{L}_i - \tilde{L}_i^c\right)$.

[27] It is assumed that the second-order sufficient conditions are satisfied.

Comparative statics analysis indicated that the final impact of the current structure of CAP on the environmental performance of the population of deviating farmers is ambiguous due to the opposing impact on production choices $\left(\mathbf{x}_{ij}^{\#}, L_{i\#}^{c}\right)$ of the various measures of the Agenda 2000 CAP reform. Even though a reduced production subsidy, along with increased constraint constants b^R and $\bar{Q}_i$, restricts the equilibrium production choices under the deviating strategy,[28] the impact of direct premiums (σ_1, σ_2) and the compliance enforcement mechanism (γ, p) is ambiguous. Hence:

Proposition 2 *The environmental behaviour of the population of deviating farmers is enhanced if the structure of CAP is characterised by:*

i) An increased land set-aside premium and a stringent compliance enforcement mechanism if the condition $\left(\bar{L}_i - L_{\#}^{c}\right) \geq \left(\left(\bar{L}_i - \tilde{L}^{c}\right)/2\right)$ *holds.*

ii) An invariant land set-aside premium and compliance enforcement mechanism if the condition $\left(\bar{L}_i - L_{\#}^{c}\right) < \left(\left(\bar{L}_i - \tilde{L}^{c}\right)/2\right)$ *holds.*

iii) An invariant land-usage premium independent of the relative magnitude of $\left(\bar{L}_i - L_i^{c}\right)$ *and* $\left(\bar{L}_i - \tilde{L}_i^{c}\right)$*.*

If the inspections to verify compliance with environmental standards b^R and $\bar{Q}_i$ are realized by independent regulatory bodies, then both the inspection probability p and the cross-compliance reduction rate γ may be differentiated across the direct payments of CAP, DP_1 and DP_2. In such a case a strict enforcement mechanism (p_1, γ_1) associated with the land quality direct payment (DP_1) stimulates reduced input and land usage, while in the case of the land usage direct payment (DP_2) the relative impact of (p_2, γ_2) remains dependent on the relative magnitude of the voluntarily and mandatorily set-aside land.

4 Assessment of CAP Regimes associated with CMOs and Behavioural Strategies

Consider two CAP regimes, given as g and h, that involve different type of payments. To compare the equilibrium production choices $\left(\mathbf{x}_{ig}, b_{ig}^{f}\right)$ of regime g with the profit maximizing choices $\left(\mathbf{x}_{ih}, b_{ih}^{f}\right)$ of regime h, the optimality

[28] Under the assumption that $F_{xb^f} < 0$ the results of comparative static analysis are summarized in:

	s	σ_1	σ_2	γ	b^R	$\bar{Q}_i$	p
$x_{ij}^{\#}$	+	?	− (?)	− (?)	−	−	− (?)
$b_{\#}^{F}$	−	?	+ (?)	+ (?)	+	+	+ (?)

where the impact of (σ_2, γ, p) on production choices is clearly assessed if $\left(\bar{L}_i - L_{\#}^{c}\right) \geq \left(\left(\bar{L}_i - \tilde{L}^{c}\right)/2\right)$, while if $\left(\bar{L}_i - L_{\#}^{c}\right) < \left(\left(\bar{L}_i - \tilde{L}^{c}\right)/2\right)$ then their impact is uncertain as indicated by the question marks (?) in the parentheses.

conditions π_x^g and $\pi_{b^f}^g$ of the initial regime are evaluated at the equilibrium choices of the latter. The expressions are:[29]

$$\pi_x^g(\mathbf{x}_{ih}, b_{ih}^f) \quad \text{and} \quad \pi_{b^f}^g(\mathbf{x}_{ih}, b_{ih}^f)$$

If both expressions are zero then the compared CAP regimes involve the same production choices and thus are identical in environmental terms, while if the expressions are nonzero then deviation in the equilibrium production choices, and thus in the environmental performance, of the regulated population occurs. The performance of the population of farmers under regime g is environmentally inferior to that of regime h, in the sense of higher input usage ($\mathbf{x}_{ig} > \mathbf{x}_{ih}$) and less land-set-aside $\left(b_{ig}^f < b_{ih}^f\right)$, if:

$$\pi_x^g(\mathbf{x}_{ih}, b_{ih}^f) > 0 \quad \text{and } \pi_{b^f}^g(\mathbf{x}_{ih}, b_{ih}^f) < 0$$

while in the opposite case its performance is environmentally superior.

The mechanism operates in the following way. Assume that under each CAP regime the optimality conditions yield a unique solution that is defined as:[30]

$$(\tilde{\mathbf{x}}_i, \tilde{b}_i^f) : \pi_x(\tilde{\mathbf{x}}_i, \tilde{b}_i^f) = 0 \text{ and } \pi_{b^f}(\tilde{\mathbf{x}}_i, \tilde{b}_i^f) = 0$$

implying that the farmer i uses both $\tilde{\mathbf{x}}_i$ and $\tilde{L}_i^c$ up to the point that marginal costs are equated with marginal revenues $\left(i.e.\ MC\left(\tilde{\mathbf{x}}_i, \tilde{b}_i^f\right) = MR\left(\tilde{\mathbf{x}}_i, \tilde{b}_i^f\right)\right)$.

When optimality conditions are evaluated at another pair of production choices, in the sense that $\left(\mathbf{x}_i, b_i^f\right) \neq \left(\tilde{\mathbf{x}}_i, \tilde{b}_i^f\right)$, then there is a divergence between marginal costs and revenues, a fact that involves nonattainment of maximum payoffs. Therefore, if the optimality condition with respect to input usage of regime g is evaluated at the production choices of regime h and yields $\pi_x^g(\mathbf{x}_{ih}, b_{ih}^f) > 0$, this implies that the profits are increasing at the production choices of regime h and therefore these values do not yield the maximum profits. Marginal revenues exceed marginal costs $\left(i.e.\ MC_i^g\left(\mathbf{x}_{ih}, b_{ih}^f\right) < MR_i^g\left(\mathbf{x}_{ih}, b_{ih}^f\right)\right)$, indicating that there is room for a further increase of input usage. The given production choice under regime h falls behind the profit maximizing production choice, in the sense that $\mathbf{x}_{ih} < \tilde{\mathbf{x}}_{ig}$. Hence, regime g is considered to be environmentally inferior for the given production choice. On the other hand, if $\pi_x^g(\mathbf{x}_{ih}, b_{ih}^f) < 0$ then profits are decreasing at the production choices of regime h and therefore this regime is characterized by excess input use.

Findings are summarized in the following table.[31]

---

[29] It holds $\pi_x^h(\mathbf{x}_{ih}, b_{ih}^f), \pi_{b^f}^h(\mathbf{x}_{ih}, b_{ih}^f) = 0$ due to the first-order conditions.

[30] This involves that both optimality conditions have a global maximum at $\tilde{\mathbf{x}}_i$ and $\tilde{b}_i^f$ respectively, and they can be both illustrated by an inverse "U" curve.

[31] Analysis is carried out both under the compliant and deviating strategy, providing the same results regarding input usage $\left(\Delta x_j^i\right)$. Only in two cases in the $\left(\Delta\left(b^f\right)_j^i\right)$ table is the indication modified under the deviating strategy denoted in parentheses.

$g \setminus h$	$\Delta x_h^g = (x_g - x_h)$: 2	3_a	3_b	4_a	4_b	$\Delta \left(b^f\right)_h^g = \left(b_g^f - b_h^f\right)$: 2	3_a	3_b	4_a	4_b
1	−	−	?	0	+	+	?	?	?	?
2		0	+	+	+		?	?	?	?
3_a			+	+	+			− (?)	−	−
3_b				?	+				?	−
4_a					+					− (?)

(1) unregulated competitive regime (UN), (2) full coupling regime (FC), (3) partial decoupled regime (PD) under the absence (3a) and presence (3b) of land quality and usage constraints, (4) full decoupled regime (FD) under the (4a) absence and (4b) existence of environmental considerations.[32]

Nonintervention (UN) is preferable on environmental grounds to intervention via coupled payments (FC), since it can be verified that the population of farmers is induced to employ both less inputs and land:[33]

$$\pi_x^1(\mathbf{x}_2^*, b_2^{*f}) = \left\{ P(1+s)\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial x} - w \right\} - Ps\frac{\partial f(\cdot)}{\partial x} = -Ps\frac{\partial f_2^*}{\partial x} < 0$$

$$\pi_{b^f}^1(\mathbf{x}_2^*, b_2^{*f}) = \left\{ -P(1+s)\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial L_i^c} \right\} + Ps\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial L_i^c} = Ps\frac{\partial f_2^*}{\partial L_i^c} > 0$$

Even though the FC regime is clearly environmentally inferior compared to the rest of the CAP regimes in terms of input usage, the relative performance of the population of both compliant and deviating farmers in set-aside terms is ambiguous. Hence:

Conclusion 3 *There is no clear evidence that the transition from the FC regime to the regime of partially or fully decoupled payments (i.e. Agenda 2000 regimes) can induce the population of regulated farmers to enhance their environmental performance compared to the old regime with respect to the land set-aside decision, whilst there is evidence that the transition has led to an environmentally superior performance of farmers with respect to the input usage.*

In the same context:

Conclusion 4 *Intervention via decoupled payments (FD) is environmentally preferable in terms of both inputs and set-aside to intervention via a combination*

[32] Indication (−) in the Δx_h^g table implies that regime h involves higher input usage, while the same indication in the $\Delta \left(b^f\right)_h^g$ table denotes that regime h sets aside more land. Indication (0) denotes that the examined regimes involve the same level of the given production choice, while (?) that their relative performance is uncertain.

[33] Where $\pi_x^2(\mathbf{x}_2^*, L_2^{*c}) = P(1+s)\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial x} - w = 0$ and $\pi_x^2(\mathbf{x}_2^*, L_2^{*c}) = -P(1+s)\frac{\partial f_2^*}{\partial L_i^c} = 0$.

of coupled and decoupled payments (PD), under both the absence and presence of farming standards, indicating the distorting role of production subsidies on farmers' production choices.

The incorporation of such standards within the direct payment regime has enhanced the environmental performance of the population of compliant farmers under both the PD and FD regimes, while there is uncertainty about their exact impact on the production choices of the population of deviating farmers. Undoubtedly the provision of DPs, as well as the introduction of farming constraints, restrain input usage compared to the UN and FC regimes, however their final impact on the set-aside decision is ambiguous given that DPs are associated with conflicting land usages.

The given procedure is further employed to compare the compliant and deviating strategy by evaluating the optimality conditions of the representative deviating farmer at the equilibrium values of the compliant strategy:

$$\pi^{\#}_{x_j}(\mathbf{x}^*_{ij}, b^f_{i*}) = \{\sigma_1 L^c_{i*} p\gamma - \lambda_1\} \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(\mathbf{x}^*_{ij}, L^c_{i*})}{\partial x_j} \tag{11}$$

$$\pi^{\#}_{b^f}(\mathbf{x}^*_{ij}, b^f_{i*}) = \sigma_1 p\gamma \left[\left(\bar{Q}_i - Q^*_i\right) - \frac{\partial Q_i}{\partial e_i} \frac{\partial e^*_i}{\partial L^c_i} L^c_{i*} \right] + \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e^*_i}{\partial L^c_i} \tag{12}$$
$$- \lambda_2 - \sigma_2 p\gamma \left[\left(\bar{L}_i - L^c_{i*}\right) - 2\left(\bar{L}_i - \tilde{L}^c\right) \right]$$

As it can be seen by conditions (11) and (12), if the partial or full decoupling CAP regime is characterized by non-enforcement of constraints, in the sense that either no inspection is realized to verify compliance (*i.e.* $p = 0$) or no detected deviating farmer is penalized (*i.e.* $\gamma = 0$), 0), then the deviating strategy is environmentally inferior. In particular, if p or $\gamma = 0$ it holds:

$$(11): \quad \pi^{\#}_{x_j}(\mathbf{x}^*_{ij}, b^f_{i*}) = \left\{ -\lambda_1 \tfrac{\partial Q_i}{\partial e_i} \tfrac{\partial e_i(\mathbf{x}^*_{ij}, L^c_{i*})}{\partial x_j} \right\} > 0 \qquad \rightarrow \mathbf{x}^*_{ij} < \mathbf{x}^{\#}_{ij}$$
$$(12): \quad \pi^{\#}_{b^f}(\mathbf{x}^*_{ij}, b^f_{i*}) = \left\{ \lambda_1 \tfrac{\partial Q_i}{\partial e_i} \tfrac{\partial e^*_i}{\partial L^c_i} - \lambda_2 \right\} < 0 \qquad \rightarrow b^f_{i*} > b^f_{i\#}$$

indicating that the deviating strategy involves higher usage of both inputs $\mathbf{x}_i$ and land L^c. Such an environmentally inferior behaviour may also be observed even under the existence of a compliance enforcement mechanism, indicating that the introduction of such an enforcement mechanism by Agenda 2000 may not sufficient to induce the adoption by the regulated population of a behaviour tending to the compliant rule. In particular, if p, γ are sufficiently small, in the sense that $p, \gamma \gg 0$, then the deviating strategy involves higher input and land usage if it simultaneously holds:

$$\pi^{\#}_{x_j}(\mathbf{x}^*_{ij}, b^f_{i*}) > 0 \quad \rightarrow \mathbf{x}^*_{ij} < \mathbf{x}^{\#}_{ij} \quad if \quad \{\sigma_1 L^c_{i*} p\gamma - \lambda_1\} < 0$$

and,

$$
\begin{array}{lll}
\pi^{\#}_{b^f}(\mathbf{x}^*_{ij}, b^f_{i*}) & < & 0 \quad \to b^f_{i*} > b^f_{i\#} \quad if \\
& & i) \quad \{\lambda_1 Q^*_i - \lambda_2\} > p\gamma \left\{\sigma_1 \left[(\bar{Q}_i - Q^*_i) - Q^*_i L^c_{i*}\right]\right\} - \sigma_2 \left[(\bar{L}_i - L^c_{i*}) - 2\left(\bar{L}_i - \tilde{L}^c\right)\right] \\
& & \quad\; and \;\; (\bar{L}_i - L^c_{i*}) < 2\left(\bar{L}_i - \tilde{L}^c\right), \text{ or} \\
& & ii) \quad \left\{\lambda_1 Q^*_i - \lambda_2 - \sigma_2 p\gamma \left[(\bar{L}_i - L^c_{i*}) - 2\left(\bar{L}_i - \tilde{L}^c\right)\right]\right\} > \sigma_1 p\gamma \left\{\left[(\bar{Q}_i - Q^*_i) - Q^*_i L^c_{i*}\right]\right\} \\
& & \quad\; and \;\; (\bar{L}_i - L^c_{i*}) \geq 2\left(\bar{L}_i - \tilde{L}^c\right)
\end{array}
$$

Hence, it can be concluded that:

Conclusion 5 *In the absence of the cross-compliance mechanism or even under the existence of a lax enforcement mechanism, the relationship between the production choices of the compliant and deviation farmer are characterized by:*

$$
\begin{array}{lll}
\pi^{\#}_{x}(\mathbf{x}^*_{ij}, b^f_{i*}) & > & 0 \quad \textit{with } \mathbf{x}^*_{ij} < \mathbf{x}^{\#}_{ij} \textit{ and} \\
\pi^{\#}_{b^f}(\mathbf{x}^*_{ij}, b^f_{i*}) & < & 0 \quad \textit{with } b^f_{i*} > b^f_{i\#} \quad \textit{if } p \textit{ or } \gamma \geq 0
\end{array}
$$

where ■*, p are sufficiently small if considered to be nonzero.*[34]

Under the generalized CAP regime the signs of (11) and (12) are uncertain, implying that in equilibrium the deviating strategy may involve less input and land usage to the compliant rule. In particular, the deviating farmer applies less inputs compared to a compliant farmer either if the land quality constraint (3) is nonbinding involving $\lambda_1 = 0$, or if the marginal costs resulting from a marginal increase of input usage defined in terms of forgone direct payment on land usage are higher than the associated marginal benefits resulting from the nonattainment of the land quality constraint $\left(i.e.\ \sigma_1 L^c_{i*} p\gamma \frac{\partial Q_i}{\partial e_i}\frac{\partial e^*_i}{\partial x_j} > -\lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e^*_i}{\partial L^c_i}\right)$. Similarly the deviating strategy involves higher set-aside fraction if the associated cost-benefit analysis indicates that a marginal decrease in the size of cultivated land stimulates higher marginal benefits than costs. Nevertheless, analysis considers that $\mathbf{x}^*_{ij} < \mathbf{x}^{\#}_{ij}$ and $L^c_{i*} > L^c_{i\#}$.

5 The Farm Model under the CAP Regime associated with Rural Development

The function of crop yields (1) and emission flows (2) is redefined as:

$$
\begin{array}{lll}
y_i & = & f(\mathbf{x}_{ij}, L^c_i, \ell_i) \\
e_i & = & e_i(\mathbf{x}_{ij}, L^c_i, \bar{L} - L^c_i, \ell_i)
\end{array}
$$

[34] Moreover, the same inequalities are expected to occur either under the absence of a regime of direct payment or under the existence of a lax regime of direct payments.

where ℓ represents either hired or family labor.

Given the environmental requirements incorporated in DP_1, the population of farmers complies with the land quality constraint $\bar{Q}_i$ by either restricting main production choices $(\mathbf{x}_{ij}, L_i^c, \ell_i)$ or by treating them in an environmentally benign way via secondary production choices that are disassociated by production but directly related with emission flows abatement. Let $\mathbf{t}_i = \left(\mathbf{t}_{ij}^x, t_i^c, t_i^{nc}, t^\ell\right)$ be the vector of the secondary production choices established by farmer i, which are distinguished into:

t_i^x *Treatments on input usage* (i.e. advanced irrigation) reduce the impact of inputs on emission flows *as if* the farmer has employed fewer inputs in production. Given that $\frac{\partial e_i}{\partial x_{ij}} > 0$, the vector of vector of effective input usage in emission generation is:

$$\mathbf{x}_{ij}^e = \left(1 - \mathbf{t}_{ij}^x\right) \mathbf{x}_{ij} \quad \text{with } \frac{\partial e_i}{\partial x_{ij}^e} > 0$$

where $\mathbf{t}_{ij}^x = (t_{i1}^x, t_{i2}^x, ..., t_{im}^x)$ is the vector of undertaken treatments per unit of input used.

t_i^c *Treatments of cultivated land* (i.e. contour farming, conservation tillage, terracing) reduce emission flows as if the farmer had set less land into production. Given that $\frac{\partial e_i}{\partial L^c} > 0$, the effective land usage in emission generation is:

$$L_c^e = (1 - t_i^c)\, L_i^c \quad \text{with } \frac{\partial e_i}{\partial L_c^e} > 0$$

t_i^{nc} *Treatments of set-asided land* (i.e. non-fertilised grass strips, hedges, trees, watercourses, ditches) make set-aside land more effective in emission abatement *as if* the farmer has set aside more land. Given that $\frac{\partial e_i}{\partial L^{nc}} < 0$, the effective set-aside land in emission generation is:

$$L_{nc}^e = (1 + t_i^{nc}) \left(\bar{L} - L_i^c\right) \quad \text{with } \frac{\partial e_i}{\partial L_{nc}^e} < 0$$

t_i^ℓ *Treatments of labour* (i.e. vocational training, advisory services) affect the impact of labour (ℓ) on both crop yields and emission flows. Let ℓ_y^e be the effective labour in crop yields generation and ℓ_e^e the effective labour in emission generation, involving:

$$\ell_y^e = (1 + t^\ell)\ell \quad \text{with } \frac{\partial y_i}{\partial \ell_y^e} > 0 \quad \text{and} \quad \ell_e^e = (1 - t^\ell)\ell \quad \text{with } \frac{\partial e_i}{\partial \ell_e^e} > 0$$

Even though t^ℓ is classified with secondary choices, it is a mixed production choice affecting both crop yields and emission flows.

The production and emission functions are modified into:

$$y_i = f(\mathbf{x}_{ij}, L_i^c, \ell_y^e) \quad (13)$$

$$e_i = e\left(\mathbf{x}_{ij}^e, L_c^e, L_{NC}^e, \ell_e^e\right) \quad (14)$$

Treatments involve costs that can either be self-financed fully (TC_i^o) or partially $\left(TC_i^{RD}\right)$ through a rural development (RD_i) – in the form of a public VA - involving the granting of subsidies per unit of undertaken treatment. The associated costs are respectively given:

$$TC^o = \mathbf{r}_j \mathbf{t}_{ij}^x + \kappa t_i^{nc} + ct^c + dt^\ell$$

$$TC^{RD} = TC_i^o - RD_i = \mathbf{r}_j (1 - s^x) \mathbf{t}_{ij}^x + \kappa (1 - s^{nc}) t_i^{nc} + c (1 - s^c) t_i^c + d \left(1 - s^\ell\right) t^\ell$$

where $\mathbf{r}_j$ is the vector of the per unit cost of the m input usage treatments and s^x the associated per unit subsidy characterized by $1 > s^x > 0$, κ and s^{nc} are the per unit cost and subsidy of t_i^{nc}, c and s^c the per unit cost and subsidy of t_i^c, while d and s^ℓ the per unit cost and subsidy of t^ℓ in the competitive market. Finally, $RD_i = \mathbf{r}_j s^x \mathbf{t}_{ij}^x + \kappa s^{nc} t_i^{nc} + cs^c t_i^c + ds^\ell t^\ell$ represents the amount of payments provided by Pillar II to the representative farmer i.

RD payments are subject to both performance standards and the cross-compliance principle, involving a probabilistic reduction (or even cancellation) of provided rural development payments by the amount:

$$\tilde{R}Dp\gamma\left(\bar{Q}_i - Q_i\right)$$

where $\tilde{R}D = \mathbf{r}_j s^x \mathbf{t}_{ij}^x + \kappa s^{nc} t_i^{nc} + cs^c t_i^c = RD - ds^\ell t^\ell$ given that the aid for vocational training is not conditional to the land quality constraint.

Under a RD program the alternative maximization problems are:[35]

- **Compliant Strategy.**

$$\max_{\left(\mathbf{x}_{ij}, L_i^c, \ell, \mathbf{t}_{ij}^x, t_i^c, t_i^{nc}, t_i^\ell\right)} \pi_i^C = P(1+s) f(x_i, L_i^c, (1+t^\ell)\ell) - wx - v\ell + \sigma_1 L^c \quad (15)$$

$$+\sigma_2\left(\bar{L} - L^c\right) - (TC^o - RD)$$

subject to

$$L^c \leq \tilde{L}^c$$

$$Q_i(e_1, e_2, ..., e_n) \geq \bar{Q}_i$$

Given that the amount of undertaken vocational training is predetermined by the Commission, training cannot be a choice variable. Thus t^ℓ represents advice and $s^\ell = 0$,.

[35] In the absence of farming standards in the provision of DPs and RD payments the maximization problems reduce to:
$\pi_i = P(1+s) f(x_i, L_i^c, (1+t^\ell)\ell) - \mathbf{w}_j \mathbf{x}_{ij} - v\ell + DP_1 + DP_2 - (TC^o - RD)$

- **Deviating Strategy.**

$$\begin{aligned}\max \pi_i^{NC} &= P(1+s)f(x_i, L_i^c, (1+t^\ell)\ell) - wx - v\ell - TC^o + ds^\ell t^\ell \\ &+ \left[\sigma_1 L^c + \tilde{R}D\right]\left\{1 - p\gamma\left(\bar{Q}_i - Q_i\right)\right\} + \sigma_2\left(\bar{L} - L^c\right)\left\{1 - p\gamma(\tilde{L}^c - L^c)\right\}\end{aligned} \quad (16)$$

Optimality conditions indicate that nonzero secondary production choices allow both for increased usage of $(\mathbf{x}_{ij}, L_i^c, \ell_i)$ along with attainment of the land quality constraint. Comparisons between the environmental performance of the regulated population under the various CAP regimes in terms of main and secondary production choices are conducted, where the set of examined regimes is enriched by: (i) *extended full coupling regime*, involving the granting of both coupled and Pillar II payments, (ii) *extended partial decoupling regime* characterised by coupled, decoupled and RD payments, (iii) *extended full decoupling regime* that provides decoupled and RD payments, and (v) *rural development regime* involving only rural development subsidies.[36]

In the extended case regime is environmentally inferior to regime , in the sense that it involves both higher usage of the main production choices $\left(i.e.\ \left(\mathbf{x}_{ij}^g, L_{ig}^c, \ell_i^g\right) > \left(\mathbf{x}_{ij}^h, L_{ih}^c, \ell_i^h\right)\right)$ and less usage of secondary production choices $\left(i.e.\ \left(\mathbf{t}_{ij}^{xg}, t_i^{cg}, t_{ig}^{nc}, t_{ig}^\ell\right) < \left(\mathbf{t}_{ij}^{xh}, t_i^{ch}, t_{ih}^{nc}, t_{ih}^\ell\right)\right)$, if the following inequalities are simultaneously satisfied:

$$\begin{aligned}&\pi_x^g\left(\mathbf{q}_{ih}, \mathbf{t}_{ih}\right), \pi_\ell^g\left(\mathbf{q}_{ih}, \mathbf{t}_{ih}\right) > 0 \quad and \quad \pi_{bf}^g\left(\mathbf{q}_{ih}, \mathbf{t}_{ih}\right) > 0 \\ &\pi_{t^x}^g\left(\mathbf{q}_{ih}, \mathbf{t}_{ih}\right), \pi_{t^c}^g\left(\mathbf{q}_{ih}, \mathbf{t}_{ih}\right), \pi_{t^{nc}}^g\left(\mathbf{q}_{ih}, \mathbf{t}_{ih}\right), \pi_{t^\ell}^g\left(\mathbf{q}_{ih}, \mathbf{t}_{ih}\right) < 0\end{aligned}$$

where for simplicity let $\mathbf{q}_{ih} = \left(\mathbf{x}_{ij}^h, L_{ih}^c, \ell_i^h\right)$ be the vector of main production choices under the regime h, while $\mathbf{t}_{ih} = \left(\mathbf{t}_{ij}^{xh}, t_i^{ch}, t_{ih}^{nc}, t_{ih}^\ell\right)$ is the vector of the associated secondary production choices.

Analysis indicated that if CAP regimes associated with CMOs are extended with RD payments, the environmental performance of the population of farmers is enhanced relative to the case where no RD payments are provided. On the other hand, regimes involving production subsidies involve higher labour usage treatment to regimes providing either decoupled and / or Pillar II payments, since higher allows farmers both to attain the land quality standard and increase the received amount of coupled payments.

Despite the environmental benefits arising from the second pillar of CAP, there is no clear evidence that the transition from the FC regime to the regime of partially or fully decoupled payments (i.e. Agenda 2000 regimes), and ultimately to the rural development CAP regime (i.e. 2003 CAP reform), enhances the environmental performance of farmers' population. In particular, when evaluating the optimality conditions of the initial CAP regime (i.e. full coupling) at the equilibrium production choices of the rural development regime, there is clear evidence that it involves higher usage of the main production choices, in the sense that $\mathbf{q}_2^{i*} > \mathbf{q}_{8b}^{i*}$, since it simultaneously holds:

[36] Findings are summarized in tables (1) - (4) available in Appendix.

$$\pi_x^2(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{ Ps\frac{\partial f_i^*}{\partial x} - \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^*}{\partial x}\left(1 - t_{8b}^{ix}\right) \right\} > 0$$

$$\pi_{b^f}^1(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{ -Ps\frac{\partial f_i^*}{\partial L_i^c} + \lambda_1 \frac{\partial Q_i}{\partial e_i}\left[\frac{\partial e_i^*}{\partial L_c^e}\left(1 - t_{8b}^c\right) - \frac{\partial e_i^*}{\partial L_{nc}^e}\left(1 + t_{8b}^{nc}\right)\right] \right\} < 0$$

$$\pi_\ell^1(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{ -\lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^*}{\partial \ell}\left(1 - t_{8b}^\ell\right) \right\} < 0$$

On the other hand, their relative environmental performance in terms of secondary production choices is ambiguous. Even though the RD regime involves higher usage of the secondary production choices $\left(\mathbf{t}_{ij}^{xh}, t_i^{ch}, t_{ih}^{nc}\right)$, its relative performance in terms of t_i^ℓ is uncertain. It can be easily verified:

$$\pi_{t^x}^2(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{ -rs^x + \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^*}{\partial x_i^e}x \right\} < 0$$

$$\pi_{t^c}^2(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{ cs^c - \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^*}{\partial L_c^e}L^c \right\} < 0$$

$$\pi_{t^{nc}}^2(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{ ks^{nc} - \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^*}{\partial L_{nc}^e}\left(\bar{L} - L^c\right) \right\} < 0$$

$$\pi_{t^e}^2(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{ Ps\frac{\partial f_i^*}{\partial \ell_y^e}\ell + \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^*}{\partial \ell_e^e}\ell \right\} < 0 \quad if \quad Ps\frac{\partial f_i^*}{\partial \ell_y^e}\ell < \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^*}{\partial \ell_e^e}\ell$$

Hence, on the whole the environmental performance under the RD regime cannot be clearly inferred as superior to the relative environmental performance under the FC regime. In a similar way is assessed the relative environmental performance of the full coupling regime compared to the partially and fully decoupled CAP regime, providing identical results. Finally, even in the absence of an enforcement mechanism or the presence of a lax mechanism, the environmental performance of the deviating to the compliant strategy is uncertain.[37]

6 Conclusions

Common Agricultural Policy measures are classified among the factors responsible for the imbalance in the agricultural-environment relation. Following widespread criticism, CAP reformers introduced the Agenda 2000 CAP reform that is considered to be pioneering from an environmental aspect. Given that limited theoretical analysis regarding the environment impacts and the long term viability of this regime has been undertaken, a conceptual theoretical model of farming behaviour was developed to embody the basic reforms for the common market organizations and rural development. The generalized nature of

[37] The deviating rule involves less t^e, higher usage $\left(\mathbf{x}_{ij}^h, L_{ih}^c, \ell_i^h\right)$, while its performance in $\left(\mathbf{t}_{ij}^{xh}, t_i^{ch}, t_{ih}^{nc}\right)$ terms is uncertain.

the provided model allowed the assessment of the impacts of the various CAP regimes characterised either by CMOs payments (i.e. full coupling, partial and full decoupling regime), RD payments (i.e. rural development regime) or a combination of CMOs and RD payments (i.e. extended full coupling, partial and full decoupling regime), on the environmental performance of a representative farmer, and thus of a homogeneous population, in terms of primary and / or secondary production choices. The policy effectiveness of Agenda 2000 was evaluated by analysing the problem of optimal regulation of a population of unboundedly rational agents both in a static and dynamic context, allowing the assessment of the type of socially optimal Pillar I and Pillar II measures, along with type of interdependence characterizing them. Finally, the long-run viability of the 1999 CAP reform was assessed under the assumption of boundedly rational agents through the framework of replicator dynamics.

Intervention via decoupled payments under both the absence and presence of farming standards is environmentally preferable in terms of main production choices to intervention via a combination of coupled and decoupled payments. However, when the set of production choices is extended with secondary production choices, then the relative environmental performance of the population under the given CAP regimes of payments cannot be clearly inferred. There is no clear evidence that the transition initially from the full coupling regime to the intervention regime involving partial or full decoupling of Pillar I payments both in the absence and provision of rural development payments (i.e. Agenda 2000 regimes), and ultimately to the intervention regime involving solely the provision of second pillar payments (i.e. Mid-term review), induces the population of farmers to restrict main production choices and increase secondary choices. Nevertheless, it is evident that the incorporation of farming constraints and rural development measures enhances the environmental performance of the regulated population.

Appendix

Table 1: The relative environmental performance of the CAP regimes g and h in terms of input usage (x_i) and labor usage (ℓ)

$\Delta(x)_h^g = x_g - x_h$ and $\Delta(\ell)_h^g = \ell_g - \ell_h$													
$g \backslash^h$	2	$3a$	$3b$	$4a$	$4b$	$5a$	$5b$	$6a$	$6b$	$7a$	$7b$	$8a$	$8b$
1	−	−	?	0	+	−	?	−	?	0	+	0	+
2		0	+	+	+	0	+	0	+	+	+	+	+
$3a$			+	+	+	0	+	0	+	+	+	+	+
$3b$				?	+	−	0 (?)	−	0 (+)	?	+	?	+ (?)
$4a$					+	−	?	−	?	0	+	0	+
$4b$						−	− (?)	−	− (?)	−	0 (+)	−	0 (?)
$5a$							+	0	+	+	+	+	+
$5b$								−	0 (+)	?	+	?	+
$6a$									+	+	+	+	+
$6b$										?	+	?	+ (?)
$7a$											+	0	+
$7b$												−	0 (+)
$8a$													+

Table 2: The relative environmental performance of the CAP regimes in set-aside terms $\left(b^f\right)$.

$\Delta(b^f)_h^g = b_g^f - b_h^f$													
$g \backslash^h$	2	$3a$	$3b$	$4a$	$4b$	$5a$	$5b$	$6a$	$6b$	$7a$	$7b$	$8a$	$8b$
1	+	?	?	?	?	+	?	?	?	?	?	0	−
2		?	?	?	?	0	−	?	?	?	?	−	−
$3a$			− (?)	−	− (?)	?	?	0	− (?)	−	− (?)	?	?
$3b$				?	−	?	?	+ (?)	0 (−)	?	− (?)	?	?
$4a$					− (?)	?	?	+	?	0	− (?)	?	?
$4b$						?	?	+ (?)	+ (?)	+ (?)	0 (−)	?	?
$5a$							−	?	?	?	?	−	−
$5b$								?	?	?	?	?	−
$6a$									− (?)	−	− (?)	?	?
$6b$										?	−	?	?
$7a$											− (?)	?	?
$7b$												?	?
$8a$													−

Table 3: The relative environmental performance of the CAP regimes g and h in terms of input usage treatment (t^x), land usage treatment (t^c) and set-aside treatment (t^{nc}).

$\Delta(t^x)_h^g, \Delta(t^c)_h^g$ and $\Delta(t^{nc})_h^g$													
$g\backslash^h$	2	$3a$	$3b$	$4a$	$4b$	$5a$	$5b$	$6a$	$6b$	$7a$	$7b$	$8a$	$8b$
1	0	0	−	0	−	−	−	−	−	−	−	−	−
2		0	−	0	−	−	−	−	−	−	−	−	−
$3a$			−	0	−	−	−	−	−	−	−	−	−
$3b$				+	0	?	− (?)	?	−	?	−	?	− (?)
$4a$					−	−	− (?)	−	−	−	−	−	− (?)
$4b$						?	− (?)	?	−	?	−	?	− (?)
$5a$							−	0	−	0	−	0	−
$5b$								+	0 (−)	+	0 (?)	+	0
$6a$									−	0	−	0	−
$6b$										+	0	+	0 (+)
$7a$											−	0	−
$7b$												+	0
$8a$													−

Table 4: The relative environmental performance of the CAP regimes g and h in terms of labor usage treatment $\left(t^{\ell}\right)$.

$\Delta(t^{\ell})_h^g$													
$g\backslash^h$	2	$3a$	$3b$	$4a$	$4b$	$5a$	$5b$	$6a$	$6b$	$7a$	$7b$	$8a$	$8b$
1	−	−	−	0	−	−	−	−	−	0	−	0	−
2		0	−	+	?	0	−	0	−	+	?	+	?
$3a$			−	+	?	0	−	0	−	+	?	+	?
$3b$				+	+	+	0 (?)	+	0 (−)	+	+ (?)	+	+ (?)
$4a$					−	−	−	−	−	0	−	0	−
$4b$						?	− (?)	?	−	+	0 (−)	+	0 (?)
$5a$							−	0	−	+	?	+	?
$5b$								+	0 (−)	+	+ (?)	+	+
$6a$									−	+	?	+	?
$6b$										+	+	+	+
$7a$											−	0	−
$7b$												+	0 (+)
$8a$													−

where (1) unregulated regime (UN), (2) full coupling regime (FC), (3) partial decoupled regime (PD), (4) full decoupled regime (FD), (5) extended full coupling regime (EFC), (6) extended partial decoupled regime (EPD), (7) extended full decoupled regime (EFD), (8) rural development regime (RD). Let (a) denote the absence and (b) the presence of performance standards within the examined CAP regime.

The indication $(-)$ in $\Delta_h^g(x)$, $\Delta_h^g(\ell)$ and $\Delta(t^x)_h^g$, $\Delta(t^c)_h^g$, as well as $\Delta(t^{nc})_h^g$, $\Delta\left(t^{\ell}\right)_h^g$ tables, implies that regime h involves higher usage of the given main and secondary production choices, while the same indication in $\Delta_h^g\left(b^f\right)$ table denotes that regime h sets aside more land. If the indication is modified under the deviating strategy compared to the compliant strategy, then the altered indication is shown in parentheses.

A Bibliography

References

[1] Baldock D., J. Dwyer and J.M.S. Vinas, 2002, "Environmental Integration and the CAP", *Institute of European Environmental Policy*, in www.europa.eu.int/comm/agriculture/envir/report/ieep_en.pdf

[2] Binmore, K., 1992, "Fun and Games: A Text on Game Theory", Lexington-Toronto: D.C. Heath and Company.

[3] Department for Environment, Food and Rural Affairs, 2004, "Guidelines for Farmers in NVZs - England", in www.defra.gov.uk/ENVIRONMENT/water/quality/nitrate/directive.htm#3

[4] European Commision, 1991, Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, http://europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexplus!prod!

DocNumber&lg=en&type_doc=Directive&an_doc=1991&nu_doc=676

[5] European Commission, 1999, "Europe's Agenda 2000: Strengthening and Widening the European Union", Priority Publications Programme 1999, X/D/5

[6] European Commission, 2002, "Directive 91/676/EEC on nitrates from agricultural sources". Report COM(2002)407, in www.europa.eu.int/comm/environment/water/water-nitrates/index_en.html

[7] European Commission, 2003, "Agriculture and the Environment", in europa.eu.int/comm/agriculture/public/fact/envir/2003_en.pdf

[8] European Commission, 2004a, "Agenda 2000", in europa.eu.int/scadplus/leg/en/s04002.htm

[9] European Commission, 2004b, "The New Rural Development Policy and its Principles", in europa.eu.int/comm/agriculture/rur/back/index_en.htm

[10] European Commission, 2007, "The Common Agricultural Policy Explained", in ec.europa.eu/agriculture/publi/capexplained/cap_en.pdf

[11] Fennell R., 1997, "The Common Agricultural Policy: Continuity and Change", Oxford University Press.

[12] Gintis H., 2000, Game Theory Evolving, Princeton University Press, Princeton.

[13] Helfand G.E. and B.W. House, 1995, "Regulating Nonpoint Source Pollution under Heterogeneous Conditions", *American Journal of Agricultural Economics*, vol. 77, pages 1024-1032.

[14] Johnson, S.L., R.M. Adams and G.M. Perry, 1991, "The On-farm Costs of Reducing Groundwater Pollution", American Journal of Agricultural Economics, vol. 73, pages 1063-1073.

[15] Karagiannis G. and A. Xepapadeas, 2001, "Agricultural Policy, Environmental Impacts and Water Use under Production Uncertainty", in *Agricultural Use of Groundwater*, C.Dosi (ed), Kluwer Academic Publishers, pages 215-239.

[16] Noailly, J., J. van de Bergh and C. Withagen, 2003, "Evolution of Harvesting Strategies: Replicator and Resource Dynamics", *Journal of Evolutionary Economics*, vol. 13, no. 2, pages 183-200.

[17] Wu J. and B.A. Babcock, 2001, "Spatial Heterogeneity and the Choice of Instruments to Control Nonpoint Pollution", *Environmental and Resource Economics*, vol. 18, pages 173-192.

[18] Xepapadeas A., 1995, "Observability and choice of instrument Mix in the Control of Externalities", *Journal of Public Economics*, vol. 56, pages 485-498.

[19] Xepapadeas A., 1997, "Advanced Principals in Environmental Policy", Edward Elgar Publishers, Cheltenham UK.

[20] Xepapadeas A. and C. Passa, 2005, "Design of Public Voluntary Environmental Programs for Nitrate Pollution in Agriculture: An Evolutionary Approach", University of Crete, Department of Economics, Discussion paper, 05-12.