

Modelling of Agricultural Behavior under the CAP Regime: Policy Effectiveness and Design¹

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Abstract

The paper discusses the design of optimal regulatory policies under an alternative analytical framework of unbounded and bounded rationality, by considering the mechanism that provides the type of the optimal CAP instruments that ensure the collective attainment of a social environmental target, along with the type of interdependence characterizing them. 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. Analysis indicated that it may be socially desirable on environmental grounds not only to maintain coupled payments but also to impose on farmers a set of charges on the various aspects of farming activity.

Keywords: production subsidy, direct payment, cross-compliance principle, optimal regulation, unbounded rationality, bounded rationality, replicator dynamics.

JEL Classification: Q18, B52, L51.

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1 Introduction

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 mechanism⁴ 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

²Among 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).

³The 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).

⁴Farmers 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).

⁵Under Pillar II, aid is provided for (i) early retirement, (ii) set-up of young farmers, (iii) reforestation 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 paper is to evaluate the effectiveness of the given CAP re-

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form 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.

The socially optimum CAP measures under the common market organizations are obtained by a system comparing the solution of the optimal regulator with the solutions of the deviating, optimum farmer in a static context. Given that the number of instruments is higher than the number of externalities optimal CMOs CAP measures are defined for fixed values of the rest CAP measures. The type of interdependence between the various CAP measures and the optimal measure, as well as the conditions under which a particular CAP regime is optimal to occur are respectively provided. After defining the dynamic socially optimum CAP measures the effectiveness of Agenda 2000 is also assessed under an evolutionary context. The framework of replicator dynamics is employed to examine whether the reformed CAP can induce the majority, or even all the farmers to adopt a "greener" behavior relative to the previous CAP regimes, and define the type and the range of values of the various CAP instruments that render feasible the attainment of such a target. As previously, the problem of the optimal regulation is discussed both in a static and dynamic context to assess the type of socially optimal rural development (RD) CAP measures.

The assessment of the socially optimum CMOs and RD CAP regimes both in static and dynamic context indicated that it may be socially desirable not only to maintain coupled payments but also to extend the compliance enforcement mechanism with a set of charges on either crop yields, land-usage, set-aside-land

¹⁰Under 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).

¹¹For 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

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

and / or secondary production choices. Given the current structure of CAP such measures are not foreseen and hence both Agenda 2000 and Mid-term review are ex-ante suboptimal. The suboptimality assertion is further supported by the fact that the attainment of first-best solutions requires both nonuniform and time-flexible Pillar I and Pillar II CAP measures that however are practically infeasible given the high informational or / and administrative requirements they involve. Henceforth, the answer to the question <<whether Agenda 2000 CAP regime is indeed “greener” compared to the previous CAP regimes>> is uncertain and conditional to the characteristics of the given crop type. A further deepening and extension of the communal agricultural policy is rendered necessary so that given environmental targets are achieved in both static and dynamic context.

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2 Model

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

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

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

Crop yields are given by:

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

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

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

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

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

¹³It 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 $f_{b^F b^F} < 0$.

¹⁴It 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 $e_{b^F b^F} > 0$.

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

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

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

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

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

where σ_2 is the premium granted per hectare of set-aside land and $(\bar{L}_i - L_i^c)$ the size of the voluntarily set-aside land. The Commission has defined a certain fraction of land to be compulsory set-aside (b^R). Hence, farmers setting-aside more land are not eligible for a premium for the additional range $(b_i^F - b^R)$.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:

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

where Q_i is a decreasing function of emissions' flows¹⁷ 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:

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

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

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

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

¹⁸Note 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.

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:

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

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 The Farm Model under the CAP Regime associated with Rural Development

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

$$\begin{aligned} y_i &= f(\mathbf{x}_{ij}, L_i^c, \ell_i) \\ e_i &= e_i(\mathbf{x}_{ij}, L_i^c, \bar{L} - L_i^c, \ell_i) \end{aligned}$$

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 $\mathbf{t}_i = (\mathbf{t}_{ij}^x, t_i^c, t_i^{nc}, t_i^\ell)$ 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:

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

¹⁹The 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 attainment of the land usage target imposes restrictions on the size of cultivated land, also involving reduction in crop yields.

where $\mathbf{t}_{ij}^x = (t_{i1}^x, t_{i2}^x, \dots, t_{im}^x)$ 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:

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

t_i^{nc} *Treatments of set-aside 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:

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

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:

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

Even though t_i^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:

$$y_i = f(\mathbf{x}_{ij}, L_i^c, \ell_y^e) \tag{5}$$

$$e_i = e(\mathbf{x}_{ij}^e, L_c^e, L_{NC}^e, \ell_e^e) \tag{6}$$

Treatments involve costs that can either be self-financed fully (TC_i^o) or partially (TC_i^{RD}) 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:

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

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

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, $RD_i = \mathbf{r}_j s^x \mathbf{t}_{ij}^x + \kappa s^{nc} t_i^{nc} + c s^c t_i^c + d s^\ell t^\ell$ 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:

$$\tilde{RD} p \gamma (\bar{Q}_i - Q_i)$$

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

4 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.

$$\max_{\mathbf{x}, b^F} \pi_i^C = P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j \mathbf{x}_{ij} + \sigma_1 L_i^c + \sigma_2 (\bar{L}_i - L_i^c) \quad (7)$$

subject to

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

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

2. Deviating Strategy.

$$\begin{aligned} \max_{\mathbf{x}, b^F} \pi_i^{NC} = & P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j \mathbf{x}_{ij} + \sigma_1 L_i^c \{1 - p\gamma(\bar{Q}_i - Q_i)\} \quad (8) \\ & + \sigma_2 (\bar{L}_i - L_i^c) \{1 - p\gamma(\tilde{L}^c - L_i^c)\} \end{aligned}$$

²⁰In 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 (\bar{Q}_i, \tilde{L}^c) and the compliance enforcement mechanism (p, γ) are considered to be uniform for every farmer.

where $\{1 - p\gamma(\bar{Q}_i - Q_i)\}$ and $\{1 - p\gamma(L_i^c - \tilde{L}^c)\}$ 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 regime²¹ allows the definition of the different CAP regimes via the proper simplifying assumptions. In particular, the CAP regimes that can be considered are: 1) *unregulated competitive regime*: $s = 0$ and $\sigma_1, \sigma_2 = 0$, 2) *full coupling regime*: $s > 0$ and $\sigma_1, \sigma_2 = 0$, 3) *partial decoupled regime*: $s > 0$ and $\sigma_1, \sigma_2 > 0$, and 4) *full decoupled regime*: $s = 0$ and $\sigma_1, \sigma_2 > 0$.

4.1 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 (7) and maximizes the Langrangean function:

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

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

$$\begin{aligned} FOC_{x_j} &: P(1+s) \frac{\partial f(\mathbf{x}_{ij}^*, L_{i*}^c)}{\partial x_{ij}} - w + \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(\mathbf{x}_{ij}^*, L_{i*}^c)}{\partial x_{ij}} = 0 \text{ if } x_{ij}^* > 0 \quad (9) \\ &\text{or } \frac{\partial \mathcal{L}(\mathbf{x}_{ij}^*, b_{i*}^F, \lambda_1, \lambda_2)}{\partial x_{ij}} < 0 \quad \text{if } x_{ij}^* = 0 \\ FOC_{b_i^F} &: \lambda_2 - \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(\cdot)}{\partial L_i^c} - P(1+s) \frac{\partial f(\cdot)}{\partial L_i^c} - \sigma_1 + \sigma_2 = 0 \text{ if } b_{i*}^F > 0 \quad (10) \\ &\text{or } \frac{\partial \mathcal{L}(\mathbf{x}_{ij}^*, b_{i*}^F, \lambda_1, \lambda_2)}{\partial b_i^F} < 0 \quad \text{if } b_{i*}^F = 0 \\ FOC_{\lambda_1} &: Q_i(e_1, e_2, \dots, e_n) - \bar{Q}_i = 0 \quad \text{if } \lambda_1 > 0 \\ &\text{or } Q_i(e_1, e_2, \dots, e_n) - \bar{Q}_i > 0 \quad \text{if } \lambda_1 = 0 \\ FOC_{\lambda_2} &: \tilde{L}^c - L_{i*}^c = 0 \quad \text{if } \lambda_2 > 0 \\ &\text{or } \tilde{L}^c - L_{i*}^c > 0 \quad \text{if } \lambda_2 = 0 \end{aligned}$$

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.

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

Conditions (9) and (10) provide the Nash equilibrium input usage x_{ij}^* and set-aside b_{i*}^F values under the compliant behavioural rule, assuming that such a Nash equilibrium exists, as:²²

$$x_{ij}^*(P, \mathbf{w}_j, s, \sigma_1, \sigma_2) \text{ and } b_{i*}^F(P, \mathbf{w}_j, s, \sigma_1, \sigma_2)$$

4.2 Profit Maximization under the Deviating Strategy

Under the deviating strategy the Kuhn-Tucker conditions are:

$$\begin{aligned} FOC_{x_{ij}} &: P(1+s) \frac{\partial f(\mathbf{x}_{ij}^\#, L_{i\#}^c)}{\partial x_{ij}} - w_j + \sigma_1 L^c p \gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(\cdot)}{\partial x_{ij}} = 0 \text{ if } x_{ij}^\# > 0 \text{ (11)} \\ &\text{or } \frac{\partial \pi_i^{NC}}{\partial x_{ij}} < 0 \quad \text{if } x_{ij}^\# = 0 \\ FOC_{b_{i\#}^F} &: -P(1+s) \frac{\partial f(\mathbf{x}_{ij}^\#, L_{i\#}^c)}{\partial L_{i\#}^c} - \sigma_1 \left\{ 1 - p\gamma \left[(\bar{Q}_i - Q_i) - \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial L_{i\#}^c} L_{i\#}^c \right] \right\} \\ &+ \sigma_2 \left\{ 1 - p\gamma \left((\bar{L}_i - \tilde{L}^c) - 2(\bar{L}_i - L_{i\#}^c) \right) \right\} = 0 \quad \text{if } b_{i\#}^F > 0 \\ &\text{or } \frac{\partial \pi_i^{NC}}{\partial b_{i\#}^F} < 0 \quad \text{if } b_{i\#}^F = 0 \end{aligned}$$

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 (11) and (12), are given by:²³

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

5 The Problem of the Social Planner under the CMOs Regime

Individual emission flows affect aggregate land quality (Q^T) given as:

$$Q^T = H(Q_1, Q_2, \dots, Q_n)$$

where deviations from an aggregate land quality reference level \bar{Q}^T impose external costs on the society:

$$D(\bar{Q}^T - Q^T)$$

²²The sufficient conditions for maximum are considered to be satisfied.

²³It is assumed that the second-order sufficient conditions are satisfied.

The social planner or a regulator wishes to define the vectors of production choices $(\bar{\mathbf{x}}^{SP}, \bar{\mathbf{b}}_{SP}^f)$ that maximize the net social benefit (NSB) from agricultural activities:²⁴

$$\max_{x, b^f} NSB = \max_{x, b^f} \int_0^{\sum y} F(u) du - \mathbf{w}_j \bar{\mathbf{x}} - D(Z) \quad (13)$$

where $y = \sum_{i=1}^n f(\mathbf{x}_{ij}, L_i^c)$ is aggregate crop yields, $F(u)$ aggregate demand, while $\mathbf{w}_j \mathbf{x}$ is the aggregate purchase costs of the m inputs (*i.e.* $\sum_{i=1}^n \sum_{j=1}^m \mathbf{w}_{ij} \mathbf{x}_{ij}$). For simplicity let $Z = (\bar{Q}^T - Q^T)$.²⁵

The associated Kuhn-Tucker conditions are:²⁶

$$\begin{aligned} FOC_{x_i}^{SP} &: P \frac{\partial f(\mathbf{x}_{ij}, L_i^c)}{\partial x_i} - w + \frac{\partial D}{\partial Z} \frac{\partial Q^T}{\partial Q_i} \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(\mathbf{x}_{ij}, L_i^c)}{\partial x_i} = 0 \text{ if } x_i^{SP} > 0 \quad (14) \\ &\text{or } \frac{\partial SW}{\partial x} < 0 \quad \text{if } x_i^{SP} = 0 \\ FOC_{b_i^f}^{SP} &: -P \frac{\partial f(\mathbf{x}_{ij}, L_i^c)}{\partial L_i^c} - \frac{\partial D}{\partial Z} \frac{\partial Q^T}{\partial Q_i} \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(\mathbf{x}_{ij}, L_i^c)}{\partial L_i^c} \text{ if } b_{iSP}^f > 0 \quad (15) \\ &\text{or } \frac{\partial SW}{\partial b_i^f} < 0 \quad \text{if } b_{iSP}^f = 0 \end{aligned}$$

defining the socially optimal production choices for the representative farmer i , which when adopted by the entire population of farmers would result into the first-best aggregate land quality Q_{SP}^T . Condition (15) is assumed to have an interior solution for the socially optimum set-aside decision (*i.e.* $b_{iSP}^f > 0$). If the marginal productivity of land is too high or if its marginal social damage is too low, the socially optimum is on the boundaries (*i.e.* $\frac{\partial SW}{\partial Q^T} < 0$ and $b_{iSP}^f = 0$) and any increase in set-aside land reduces social welfare given the land usage constraint involved by Agenda 2000. To avoid, however, complexities it is assumed that b_{iSP}^f is nonzero, as well as that compliant farmers' production choices match with socially optimum choices.²⁷

5.1 Optimal Static CAP Measures associated with CMOs

Under unbounded rationality for the farmers the optimality conditions of the social planner and the representative deviating farmer define a system that provides both the type of CAP measures, as well as the type of correlation between

²⁴Let $\bar{\mathbf{x}}^{SP} = (\mathbf{x}_1^{SP}, \mathbf{x}_2^{SP}, \dots, \mathbf{x}_n^{SP})$ and $\bar{\mathbf{b}}_{SP}^f = (b_{SP}^{f1}, b_{SP}^{f2}, \dots, b_{SP}^{fn})$ be the vectors of the socially optimal input and set-aside choices respectively of each $i = 1, 2, \dots, n$ farmer.

²⁵It holds $D_Z, D_{ZZ} > 0$, or equivalently $D_{Q^T} < 0$ and $D_{Q^T Q^T} > 0$.

²⁶It is assumed that the second-order-conditions are satisfied.

²⁷It is assumed that $\pi_x^C(\mathbf{x}_i^{SP}, b_{iSP}^f), \pi_{b^f}^C(\mathbf{x}_i^{SP}, b_{iSP}^f) = 0$.

Agenda 2000 measures, which induce the population of deviating farmers to adopt the socially optimal choices $(\mathbf{x}_i^{SP}, b_{SP}^f)$. The system is given as:²⁸

$$P(1+s)\alpha_1^\# + \sigma_1 L_{\#}^c p\gamma\beta_1^\# = P\alpha_1^{SP} + \delta_1 \quad (16)$$

$$\alpha_2^{SP} [\sigma_2 \{1 - p\gamma B\} - \sigma_1 \{1 - p\gamma A\}] = -(1+s)\alpha_2^\# \delta_2 \quad (17)$$

where condition (16) is defined by setting equal the optimality condition (11) of the unbounded rational deviating farmer and regulator's optimality condition (14),²⁹ while condition (17) resulted from the equalization of the conditions (12) and (15).³⁰

To simplify the analysis production choices are restricted into a single input (x) and the set-aside decision. There is however an indeterminacy in the definition of optimal CAP measures. A unique determination of CAP instruments requires an equal number of production choices and measures. In this case CAP measures are more than externalities. For instance the optimum coupled payments and land usage premium are defined for fixed values of the rest of the CAP measures as:³¹

$$\bar{s} = \frac{1}{P\alpha_1^\#} \left[P \left(\alpha_1^{SP} - \alpha_1^\# \right) + \delta_1 - \bar{\sigma}_1 L_{\#}^c p\gamma\beta_1^\# \right] \quad (18)$$

$$\bar{\sigma}_1 = \left\{ \alpha_2^{SP} \sigma_2 \{1 - p\gamma B\} + \alpha_2^\# \left(1 + \frac{\delta_1}{P\alpha_1^\#} \right) \delta_2 + \delta_2 \left(\alpha_1^{SP} - \alpha_1^\# \right) \frac{\alpha_2^\#}{\alpha_1^\#} \right\} / \left\{ \alpha_2^{SP} \{1 - p\gamma A\} + \frac{\alpha_2^\#}{P\alpha_1^\#} \delta_2 L_{\#}^c p\gamma\beta_1^\# \right\} \quad (19)$$

The sign of both expressions is uncertain,³² implying that the simultaneous cancellation of coupled payments and DP_1 payment, which means $\bar{s} = \bar{\sigma}_1 = 0$, is socially optimal if both nominators are equal to zero. In particular:

²⁸Let $\alpha_1^{SP}, \alpha_2^{SP}, \beta_1^{SP}, \beta_2^{SP}$ and $\alpha_1^\#, \alpha_2^\#, \beta_1^\#, \beta_2^\#$ represent the impact of the social and individual optimum production choices on crop yields and individual land quality respectively, while δ_1, δ_2 denote the impact of social optimum choices on social damage. We define:

$$\alpha_1^{SP} = f_x^{SP}, \alpha_2^{SP} = f_{L^c}^{SP} \text{ and } \beta_1^{SP} = Q_x^{SP}, \beta_2^{SP} = Q_{L^c}^{SP}$$

$$\alpha_1^\# = f_x^\#, \alpha_2^\# = f_{L^c}^\# \text{ and } \beta_1^\# = Q_x^\#, \beta_2^\# = Q_{L^c}^\#$$

$$\delta_1 = D_x^{SP} \text{ and } \delta_2 = D_{L^c}^{SP}$$

which at the equilibrium are known and thus treated as parameters. Also, $A = \left[(\bar{Q}_i - Q_i^\#) - \beta_2 L_{i\#}^c \right]$ and $B = \left\{ 1 - p\gamma \left(2(\bar{L}_i - L_{i\#}^c) - (\bar{L}_i - \bar{L}^c) \right) \right\}$.

²⁹To do so, both conditions are restructured as, (11) : $w = P(1+s)\alpha_1^\# + \sigma_1 L_{\#}^c p\gamma\beta_1^\#$ and (14): $w = P\alpha_1^{SP} + \delta_1$.

³⁰To do so, both conditions are restructured as, (12) : $P = [\sigma_2 \{1 - p\gamma B\} - \sigma_1 \{1 - p\gamma A\}] / (1+s)\alpha_2^\#$ and (15): $P = (-\delta_2) / \alpha_2^{SP}$.

³¹Let $\alpha_1^{SP} = f_x(\mathbf{x}_i^{SP}, b_{SP}^f)$ and $\alpha_1^\# = f_x(\mathbf{x}_i^\#, b_{\#}^f)$ represent the impact of the social and individual optimum production choices on crop yields.

³²In both expressions the denominators are positive, while the sign of the nominators is uncertain.

Proposition 1 *The optimum CAP regime involves gradual cancellation of coupled payments:*

i) If under $(\alpha_1^{SP} \geq \alpha_1^\#)$ the marginal revenues $(P(\alpha_1^{SP} - \alpha_1^\#) - \bar{\sigma}_1 L_\#^c p \gamma \beta_1^\#)$ from the adoption of the social optimum input usage value defined in terms of additional market revenues and retained land usage direct payments equal the marginal costs of incurred social damage (δ_1) , or

ii) If under $(\alpha_1^{SP} < \alpha_1^\#)$ the marginal revenues $(-\bar{\sigma}_1 L_\#^c p \gamma \beta_1^\#)$ in terms of the retained land usage direct payment equal the marginal cost $(P(\alpha_1^{SP} - \alpha_1^\#) + \delta_1)$ in terms of foregone market revenues and incurred social damage.

Hence, if both (18) and (19) are zero, the optimum CAP regime is characterised by nonintervention if no set-aside premium is provided $(\sigma_2 = 0)$, while if $\sigma_2 \neq 0$ it involves only set-aside premiums. On the other hand, if both (18) and (19) are nonzero, then depending on the sign of the nominators:

Proposition 2 *The optimum CAP regime involves intervention via partially decoupled measures of the form either of:*

i) Premiums $(\bar{s}, \bar{\sigma}_1 > 0)$ both on crop yields and land usage if both nominators are positive, or

ii) Charges $(\bar{s}, \bar{\sigma}_1 = 0)$ both on crop yields and land usage if both nominators are nonpositive.

In the latter case such kinds of penalties are not included in the current structure of CAP, which implies the possibility of suboptimalities in the policy design relative to the social optimum aggregate land quality target \bar{Q}^T .

Farmers' production choices are affected by a marginal change of a given CAP instrument, requiring optimal CAP instruments $(\bar{s}, \bar{\sigma}_1)$ to be analogously modified. The type of interdependencies between the optimal CAP pair $(\bar{s}, \bar{\sigma}_1)$ and the rest of the instruments of the 1999 reform is assessed, by estimating the total derivatives of (18) and (19) with respect to the remaining instruments:³³

$$\begin{aligned} \frac{d\bar{\sigma}_1}{d\sigma_2} &= \frac{\alpha_2^{SP} \sigma_1 (1 - p\gamma B)}{G} \text{ and } \frac{d\bar{s}}{d\sigma_2} = \frac{1}{P\alpha_1^\#} \left[-p\gamma\beta_1^\# \frac{d\bar{\sigma}_1}{d\sigma_2} \right] \\ \frac{d\bar{\sigma}_1}{dp} &= \frac{-\gamma H}{G^2} \text{ and } \frac{d\bar{s}}{dp} = \frac{1}{P\alpha_1^\#} \left[P(\alpha_1^{SP} - \alpha_1^\#) + \delta_1 - \gamma\beta_1^\# \left(\bar{\sigma}_1 - \frac{d\bar{\sigma}_1}{dp} \right) \right] \\ \frac{d\bar{\sigma}_1}{db^R} &= \frac{-\alpha_2^{SP} p\gamma \bar{L}_i}{G} \text{ and } \frac{d\bar{s}}{db^R} = \frac{1}{P\alpha_1^\#} \left[P(\alpha_1^{SP} - \alpha_1^\#) + \delta_1 - p\gamma\beta_1^\# \frac{d\bar{\sigma}_1}{db^R} \right] \\ \frac{d\bar{\sigma}_1}{d\bar{Q}_i} &= \frac{-\alpha_2^{SP} p\gamma R}{G^2} \text{ and } \frac{d\bar{s}}{d\bar{Q}_i} = \frac{1}{P\alpha_1^\#} \left[P(\alpha_1^{SP} - \alpha_1^\#) + \delta_1 - p\gamma\beta_1^\# \frac{d\bar{\sigma}_1}{d\bar{Q}_i} \right] \end{aligned}$$

³³Where $G = \left(\alpha_2^{SP} \{1 - p\gamma A\} + \frac{\alpha_2^\#}{P\alpha_1^\#} \delta_2 L_\#^c p \gamma \beta_1^\# \right) > 0$, $H = \alpha_2^{SP} \sigma_2 B G + \left(\alpha_2^{SP} A - \frac{\alpha_2^\#}{\alpha_1^\#} \delta_2 L_\#^c \beta_1^\# \right)$, $R = \alpha_2^{SP} \sigma_2 \{1 - p\gamma B\} + \alpha_2^\# \left(1 + \frac{\delta_1}{P\alpha_1^\#} \right) \delta_2 + \delta_2 \left(\alpha_1^{SP} - \alpha_1^\# \right) \frac{\alpha_2^\#}{\alpha_1^\#}$

There is interdependence between the optimal coupled payment and land usage premium, since the impact of a given CAP measure on \bar{s} is affected by its prior impact on $\bar{\sigma}_1$. Optimal $\bar{\sigma}_1$ is negatively correlated to the land usage constraint constant, while there is complementarity between the optimal pair $(\bar{s}, \bar{\sigma}_1)$ and the set-aside premium if $(\bar{L}_i - L_i^c) \geq \left(\frac{(\bar{L}_i - \tilde{L}^c)}{2} \right)$.³⁴ However, the type of interdependence between the optimal pair of CAP instruments and the remaining CAP measures cannot be clearly inferred. This implies that the optimal CAP pair $(\bar{s}, \bar{\sigma}_1)$ may not always be modified properly following changes of CAP measures such as the enforcement mechanism (p, γ) , leading to production choices that deviate from the socially optimal choices (x_i^{SP}, b_{iSP}^f) .

Hence, to avoid having the regulated population of farmers adopt a sub-optimal environmental performance diverging from the aggregate land quality target \bar{Q}^T , the social planner needs to:

Proposition 3 *Precommit to the chosen structure of regulatory policy and offer assurances to regulated agents that he will not change both the optimal CAP pair $(\bar{s}, \bar{\sigma}_1)$ and the rest of the CAP elements for a given time period as long as there is no technological change.*

Such a CAP regime is characterised by “non-surprise” features in the sense that none of the CAP measures is modified for a given time period.

The socially optimal $(\bar{s}, \bar{\sigma}_2)$ and $(\bar{s}, \bar{\gamma})$ CAP pairs are respectively determined for given values of the remaining CAP measures. In particular, the optimum land set-aside premium $\bar{\sigma}_2$ is given by:

$$\bar{\sigma}_2 = \left\{ \alpha_2^{SP} \sigma_1 \{1 - p\gamma A\} + \alpha_2^\# \delta_2 (1 + \bar{s}) \right\} / \left\{ \alpha_2^{SP} (1 - p\gamma B) \right\}$$

The sign of the expression $\bar{\sigma}_2$ is uncertain,³⁵ implying that the provision of a set-aside premium may not always be the socially optimal type of intervention. In particular:

Proposition 4 *The optimum CAP regime involves intervention on the basis of set-aside land of the form of:*

- i) *A premium ($\bar{\sigma}_2 > 0$) either if the denominator is positive or if the enforcement mechanism of performance standards is insufficient or nonexistent ($p, \gamma \gg 0$ or $p, \gamma = 0$)*
- ii) *A charge ($\bar{\sigma}_2 < 0$) if the denominator is nonpositive.*

On the other hand, the optimal cross-compliance rate $\bar{\gamma}$ resulting from the optimal CAP pair $(\bar{s}, \bar{\gamma})$ is defined as:³⁶

³⁴The impact of b^R on \bar{s} is ambiguous. If $(\bar{L} - L^c) < \left(\frac{(\bar{L} - \tilde{L}^c)}{2} \right)$ the correlation between the optimal pair and σ_2 is uncertain. Such an uncertain context is also observed regarding the exact impact of σ_2 , \bar{Q}_i' and p (or γ) on both $(\bar{\sigma}_1, \bar{s})$.

³⁵The nominator is positive, while the sign of the denominator is ambiguous.

³⁶The socially optimal inspection probability \bar{p} can be equivalently assessed by replacing γ by the term p .

$$\bar{\gamma} = \frac{\left\{ \alpha_2^{SP} (\sigma_1 - \sigma_2) + \frac{\alpha_2^\#}{\alpha_1^\#} \left[\delta_2 (\alpha_1^{SP} - \alpha_1^\#) + \frac{1}{P} \delta_1 \delta_2 \right] \right\}}{\left\{ p \left[\alpha_2^{SP} (\sigma_2 B - \sigma_1 A) + \sigma_1 L_{\#}^c \beta_1^\# \delta_2 \frac{\alpha_2^\#}{P \alpha_1^\#} \right] \right\}}$$

where the sign of the expression $\bar{\gamma}$ is uncertain.³⁷ This implies that in the event of detected non-compliance a proportional reduction of provided *DPs* (*i.e.* $\bar{\gamma} > 0$) may not always be the socially optimal type of intervention. In particular, if the nominator is equal to zero then no action should be undertaken to enforce the performance standards since it is socially optimal to proceed in no reduction of provided direct payments (*i.e.* $\bar{\gamma} = 0$), while if both the nominator and denominator are nonzero then:

Proposition 5 *The optimum CAP regime involves intervention in the event of detected non-compliance of the form of:*

i) A proportional reduction of provided direct payments ($\bar{\gamma} > 0$) if both the nominator and denominator are positive (or negative).

ii) A proportional increase of provided direct payments ($\bar{\gamma} < 0$) if the nominator and denominator have reverse signs.

Given, however, that measures like a charge on land set-aside (*i.e.* $\bar{\sigma}_2 < 0$) and a nonpositive cross-compliance rate (*i.e.* $\bar{\gamma} < 0$), are not foreseen by Agenda 2000, the current structure of CAP may not be able to induce the population of deviating farmers to adopt the socially optimal choices (x_i^{SP}, b_{iSP}^f) and thus the attainment of the social optimum aggregate land quality target is infeasible.

6 Assessment of CAP regimes in a Dynamic Context

In a dynamic context the distinction between unbounded and bounded rationality is more evident in the employed analytical framework. Under unbounded rationality the dynamic problem of the social planner is considered to define the mechanism for the design of the dynamic socially optimal CAP instruments, while under the assumption of bounded rational farmers an evolutionary context is employed to assess the policy effectiveness of Agenda 2000 by defining the type and range of values of CAP measures inducing the majority or even all farmers to adopt the compliant strategy.

6.1 Optimal Dynamic CAP Measures associated with CMOs

Consider a social planner seeking to define the optimal path of production choices $(\mathbf{x}^{SP}, \mathbf{b}_{SP}^f)$ that maximize the current value of net social benefit from

³⁷The sign of both the nominator and denominator is uncertain.

farming activity subject to a transition equation describing the evolution of aggregate land quality. The maximization problem is:

$$\begin{aligned} \max_{x, b^f} \int_0^{\infty} e^{-rt} \left[\int_0^{\sum y} F(u) du - \mathbf{w}\mathbf{x} - D(Z) \right] dt \\ \text{st. } \dot{Q}^T = g(\mathbf{x}, \mathbf{L}^C) + h(Q^T) \end{aligned}$$

where $g(\mathbf{x}, \mathbf{L}^C)$ are the collective emissions generated each period t and $h(Q^T)$ is a concave “growth” function indicating nature’s ability to enhance land quality that attains an interior maximum.³⁸ Note that $Z = (\bar{Q}^T - Q^T)$

The current value Hamiltonian function is defined as:

$$\mathcal{H} = \int_0^{\sum y} F(u) du - \mathbf{w}\mathbf{x} - D(Z) + \mu [g(\mathbf{x}, \mathbf{L}^C) - h(Q^T)]$$

where $\mu(t)$ is the dynamic shadow value of the aggregate land quality Q^T that is nonnegative (*i.e.* $\mu > 0$).

The Pontryagin necessary conditions for optimality are:

$$\begin{aligned} FOC_x^{SP} &: P \frac{\partial f(x_i, L_i^c)}{\partial x} - w + \frac{\partial D}{\partial Z} \frac{\partial Q^T}{\partial Q_i} \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial x_i} + \mu \frac{\partial g}{\partial e_i} \frac{\partial e_i}{\partial x_i} = 0 \text{ if } x_i^{SP} > 0 \\ &\text{or } \frac{\partial \mathcal{H}}{\partial x} < 0 \quad \text{if } x_i^{SP} = 0 \\ FOC_{b^f}^{SP} &: -P \frac{\partial f(x_i, L_i^c)}{\partial L_i^c} - \frac{\partial D}{\partial Z} \frac{\partial Q^T}{\partial Q_i} \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial L_i^c} - \mu \frac{\partial g}{\partial e_i} \frac{\partial e_i}{\partial L_i^c} = 0 \text{ if } b_{SP}^f > 0 \\ &\text{or } \frac{\partial \mathcal{H}}{\partial b^f} < 0 \quad \text{if } b_{SP}^f = 0 \\ \dot{\mu} &= \mu(r + b) - \frac{\partial D}{\partial Z} \\ \dot{Q}^T &= g(\mathbf{x}, \mathbf{L}^C) + bQ^T \end{aligned}$$

and the Arrow type transversality condition at infinity is:

$$\lim_{t \rightarrow \infty} \exp(-rt) \mu(t) Q^T(t) = 0$$

Under the assumption that farmers systematically ignore the evolution of Q^T (*i.e.* myopic informational structure)³⁹ the system defining the dynamic

³⁸

Where $\mathbf{L}^C = (L_1^c, L_2^c, \dots, L_n^c)$ is the vector of individual choices regarding land usage. Aggregate emissions flows can also be given as: $g(\mathbf{x}, \mathbf{L}^C) = \sum_{i=1}^n e_i(x_i, L_i^c)$.

³⁹Farmers face a static problem, either (7) or (8), according to the behavioral rule.

social optimum CAP measures is:⁴⁰

$$P(1+s)\alpha_1^\# + \sigma_1 L_{\#}^c p \gamma \beta_1^\# = P\alpha_{1d}^{SP} + \delta_{1d} - \mu\varphi_{1d} \quad (20)$$

$$\alpha_{2d}^{SP} [\sigma_2 \{1 - p\gamma B\} - \sigma_1 \{1 - p\gamma A\}] = -(1+s)\alpha_2^\# \{\mu\varphi_{2d} + \delta_{2d}\} \quad (21)$$

which is similar to the static system (16) and (17). It is evident that the expressions of the dynamic and static optimum CAP measures that induce the population of unboundedly rational farmers to adopt the socially desired production choices and thus deliver the desired aggregate land quality level are identical. The only modification is the term containing the Hamiltonian multiplier (μ) that is zero in the static context.

6.2 Farmers' Compliance and Dynamic CAP Measures associated with CMOs

Assume that farmers are subject to dynamic socially optimum CAP measures. Under bounded rationality farmers have imperfect knowledge about the true structure of payoffs; they choose between the two predetermined strategies (i.e. compliant and non-compliant strategy) based on individual perceptions and information revealed via their interaction over time.

Thus, if individual farmers take CAP measures as given, then the socially optimum production choices (x_i^{SP}, L_{iSP}^c) are adopted and these farmers comply with the land-quality and land-usage constraints. However, if it is perceived that the announced enforcement mechanism (p, γ) is not effective and that the anticipated inspection probability (p^a) and reduction rate (γ^a) are either sufficiently small or even equal to zero, then a suboptimal pair of production choices ($x^\#, L_{\#}^c$) is adopted, stimulating deviation from farming standards. It implies that:

$$\text{if } (\bar{p}, \bar{\gamma}) > (p^a, \gamma^a) \geq 0 \text{ then } (x_i^*, L_{i*}^c) < (x_i^\#, L_{i\#}^c)$$

and the population of farmers is divided into two subgroups, where z is the proportion of farmers adopting the compliant strategy, while $(1-z)$ is the deviating proportion. Given that farmers learn the true structure of payoffs via their interactions, the proportion of farmers adopting the complying strategy evolves in time according to the rule of replicator dynamics. Hence, under the generalized CAP regime the evolution of the compliant strategy is given by:

⁴⁰Let $\alpha_{1d}^{SP}, \alpha_{2d}^{SP}, \delta_{1d}, \delta_{2d}, \phi_{1d}, \phi_{2d}$ represent the impact of the dynamic social optimum production choices on crop yields, social damage and aggregate emission flows. In particular, it holds:

$$\begin{aligned} \alpha_{1d}^{SP} &= f_x^{SP}, \alpha_{2d}^{SP} = f_{L^c}^{SP} \text{ and} \\ \delta_{1d} &= D_x^{SP}, \delta_{2d} = D_{L^c}^{SP} \text{ and} \\ \phi_{1d} &= g_x^{SP}, \phi_{2d} = g_{L^c}^{SP}. \end{aligned}$$

$$\dot{z} = z(1-z)(\pi_i^C - \pi_i^{NC}) \quad (22)$$

with

$$\begin{aligned} \pi_i^C - \pi_i^{NC} = & P(1+s)\Delta_{\#}^*(f(x, L_i^c)) - w\Delta_{\#}^*(x) + (\sigma_1 - \sigma_2)\Delta_{\#}^*(L_i^c) \\ & + p\gamma \left[\sigma_1 L_{\#}^c (\bar{Q}_i - Q_i(x, L_{\#}^c)) + \sigma_2 (\bar{L}_i - L_{\#}^c) (L_{\#}^c - \tilde{L}^c) \right] \end{aligned}$$

where $(\pi_i^C - \pi_i^{NC})$ is the payoff divergence of the compliant and deviating strategy.⁴¹

The critical points of (22) provide evolutionary stable fractions of compliant farmers (\hat{z}). It involves a monomorphic steady state characterized either by full compliance ($\hat{z}_1 = 1$) or full deviation ($\hat{z}_2 = 0$). A polymorphic steady state characterized by partial compliance ($\hat{z}_3 \in (0, 1)$) may also exist if CAP measures are equal to the critical values that make zero the profit divergence $\Omega = (\pi_i^C - \pi_i^{NC})$.

The type of the prevailing steady state depends on the profit divergence $(\pi_i^C - \pi_i^{NC})$ as can be seen by the stability condition:

$$\frac{d\hat{z}}{dz} = (1 - 2z)\Omega$$

Given that the social planner's ultimate target is to induce full compliance with farming standards, the stability requirement $\frac{d\hat{z}}{dz} |_{\hat{z}_1 = 1} < 0$ is satisfied if the CAP instruments $(s, \sigma_1, \sigma_2, p, \gamma)$ are selected to turn the compliant strategy more profitable than the deviating, setting thus the profit divergence $\Omega(s, \sigma_1, \sigma_2, p, \gamma)$ positive. To define the type and the range of values of the various CAP instruments that make Ω nonnegative and stimulated full compliance of the population, the critical values $(\tilde{s}, \tilde{\sigma}_1, \tilde{\sigma}_2, \tilde{p}, \tilde{\gamma})$ of CAP measures that set the divergence Ω equal to zero, along with their marginal impacts on the expression $\Omega(\tilde{s}, \tilde{\sigma}_1, \tilde{\sigma}_2, \tilde{p}, \tilde{\gamma}) = 0$ are respectively assessed. Two cases are examined:

Case 1

Consider that both compliant and deviating farmers are myopic and "hard wired" to their strategy in the sense that the impact of CAP measures on production choices is negligent. In such a case the type and range of values of the coupled payment \tilde{s} satisfying the requirement $\Omega = 0$ is given by:

⁴¹Profit divergence consists of four elements: (i) the divergence of market revenues and coupled payments, (ii) the divergence of input purchase costs, (iii) the divergence of Profit divergence consists of four elements: (i) the divergence of market revenues and coupled payments, (ii) the divergence of input purchase costs, (iii) the divergence of DPs, and (iv) the amount of DPs removed by farmers if found violating farming standards incorporated in direct payments regime DPs , and (iv) the amount of DPs removed by farmers if found violating farming standards incorporated in direct payments regime.

$$\tilde{s} = \frac{1}{P\Delta_{\#}^*(f(x, L_i^c))} [w\Delta_{\#}^*(x) - (\sigma_1 - \sigma_2)\Delta_{\#}^*(L_i^c) - p\gamma\Xi] - 1 \quad (23)$$

$$\frac{d\Omega(\tilde{s})}{ds} = P\Delta_{\#}^*(f(x, L_i^c)) \quad (24)$$

where $\Xi = \left[\sigma_1 L_{\#}^c (\bar{Q}_i - Q_i(x, L_{\#}^c)) + \sigma_2 (\bar{L} - L_{\#}^c) (L_{\#}^c - \tilde{L}^c) \right]$.

Given that $x^* < x^{\#}$ and $L_*^c < L_{\#}^c$ the expression (24) is negative implying that compliance of the entire population of farmers is eventually attainable if $s \in [0, \tilde{s})$. If s is set equal to the critical value \tilde{s} then partial compliance (\hat{z}_3) may emerge in the long-run steady state. Then:

Proposition 6 *Full compliance of the regulated population emerges if the dynamic CAP regime involves:*

- i) *A subsidy on crop yields if $\sigma_1 > \sigma_2$ simultaneously and hold $0 < [w\Delta_{\#}^*(x) - (\sigma_1 - \sigma_2)\Delta_{\#}^*(L_i^c) - p\gamma\Xi] > P\Delta_{\#}^*(f(x, L_i^c))$.*
- ii) *A penalty on crop yields if $\sigma_1 \leq \sigma_2$.*

However, in the case where (23) involves a penalty on crop yields, such an instrument is not foreseen by the current CAP structure, and the attainment of the full compliance target is infeasible.

The type and range of values of direct payments ($\tilde{\sigma}_1, \tilde{\sigma}_2$) and cross-compliance reduction rate ($\tilde{\gamma}$) inducing full compliance are also assessed involving similar findings.

Case 2

Farmers' production choices are affected by changes in CAP measures, and optimal choices under both strategies are:

$$\begin{aligned} x_i^*(P, w, s, \sigma_1, \sigma_2) \text{ and } b_{i*}^F(P, w, s, \sigma_1, \sigma_2) \\ x_i^{\#}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p) \text{ and } b_{i\#}^F(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p) \end{aligned}$$

and the replicator dynamic equation (22) is modified into:

$$\dot{z} = z(1-z) (\pi_i^C(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p) - \pi_i^{NC}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p))$$

with

$$\begin{aligned} \Delta_{\#}^*(x) &= x^*(P, w, s, \sigma_1, \sigma_2) - x^{\#}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p) \\ \Delta_{\#}^*(L_i^c) &= L_*^c(P, w, s, \sigma_1, \sigma_2) - L_{\#}^c(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p) \\ \Delta_{\#}^*(f(x, L_i^c)) &= f(x^*(\cdot), L_*^c(\cdot)) - f(x^{\#}(\cdot), L_{\#}^c(\cdot)) \end{aligned}$$

The type and range of values of given CAP measures satisfying the full compliance requirement $\Omega(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p) > 0$ provide identical expressions to case 1 for the critical values. The expressions describing the marginal

impact of CAP measures on profit divergence Ω are altered and depend, among other things, on the impact of the examined measure on farmers' production choices under the alternative strategies. In particular, the impact of the critical coupled payment \tilde{s} on $\Omega = 0$ is given by:

$$\begin{aligned} \frac{d\Omega(\tilde{s})}{ds} = & P(1+s)\Delta_{\#}^* \left(\frac{\partial f}{\partial x} \frac{\partial x}{\partial s} - \frac{\partial f}{\partial b^f} \frac{\partial b^f}{\partial s} \bar{L}_i \right) - (\sigma_1 - \sigma_2) \Delta_{\#}^* \left(\frac{\partial b^f}{\partial s} \bar{L}_i \right) \\ & - p\gamma\sigma_1 \left\{ L_{\#}^c \left(\frac{\partial Q_i^{\#}}{\partial x} \frac{\partial x^{\#}}{\partial s} - \frac{\partial Q_i^{\#}}{\partial b^f} \frac{\partial b_{\#}^f}{\partial s} \right) + \frac{\partial b_{\#}^f}{\partial s} \bar{L}_i (\bar{Q}_i - Q_i^{\#}) \right\} \\ & + \sigma_2 \frac{\partial b_{\#}^f}{\partial s} \bar{L}_i \left[(\bar{L}_i - \tilde{L}^c) - 2(\bar{L}_i - L_{\#}^c) \right] - w\Delta_{\#}^* \left(\frac{\partial x}{\partial s} \right) \end{aligned} \quad (25)$$

which depends on the marginal impact of on input and land usage (i.e. $\frac{\partial x}{\partial s}$ and $\frac{\partial b^f}{\partial s}$) under both strategies, turning the assessment of the sign of (25) infeasible given the informational requirements. Furthermore, it is evident that the attainment of full compliance from a given population of farmers with environmental considerations requires continuous change of the dynamic socially optimal CAP instruments. However, in practice dynamic CAP measures are neither time invariant nor allow for discrete changes over time, leading to suboptimal solutions.

7 Optimal Policy Design under the CAP Regime associated with Rural Development

Static and dynamic optimality analysis under the assumption of unbounded rationality, along with evolutionary dynamics analysis under the assumption of bounded rationality, indicated also that charges on secondary production choices instead of subsidies may be socially optimal, turning the CAP regime involved by Mid-term Review (i.e. rural development regime) socially suboptimal. In each case the type of the social optimal Pillar II CAP instruments, as well as the type of correlation between the various CAP instruments, is assessed through the following mechanisms:

7.1 Assessment of Optimal Static CAP Measures associated with RD

In a static context the social planner seeks to define the socially optimal equilibrium values for both the main and secondary production choices, given as $(\tilde{x}_i^{SP}, \tilde{b}_{SP}^f, \tilde{\ell}_{SP})$ and $(\tilde{t}_{ij}^x, \tilde{t}_i^c, \tilde{t}_i^{nc}, \tilde{t}^{\ell})$, so that the net social benefit from agricultural activities is maximized and thus the first-best level of aggregate land quality Q_{SP}^T is attained. The maximization problem of the social planner is:

$$\max_{\mathbf{x}, b^F, \ell, t^x, t^c, t^{nc}, t^\ell} \int_0^{\sum y} F(u) du - \mathbf{w}_j \mathbf{x} - \mathbf{v} \ell - \mathbf{TC} - D(Z)$$

where $(\mathbf{TC} = \sum_{i=1}^n (\sum_{j=1}^m \mathbf{r}_j \mathbf{t}_{ij}^x + \kappa t_i^{nc} + ct_i^c + dt_i^\ell))$ are the aggregate costs associated with secondary production choices, whilst $(\mathbf{v} \ell = \sum_{i=1}^n \mathbf{v} \ell_i)$ the aggregate labour costs.

The optimality conditions of the deviating farmer and the social planner define a system, the solution of which provides the type of the socially optimal CAP instruments, as well as the type of correlation between them, that induce the representative farmer to adopt the socially optimal production choices. To simplify analysis the set of production choices of farmer is restricted to three choice variables, for instance a single input (x_{ij}) and land usage (b_i^f) , along with the decision of the treatment (t_{ij}^x) on the usage of the x_{ij} input, while the rest of the production choices are treated as fixed. Thus, the system is given by:⁴²

$$\begin{aligned} P(1+s)\check{\alpha}_1 + [\sigma_1 \check{L}^c + \check{RD}] p\gamma \check{\beta}_1 \beta_i (1 - \check{t}^x) &= P\alpha_1^{SP} + \delta_1 \beta_i (1 - \check{t}_{SP}^x) \\ \alpha_2^{SP} [\sigma_2 \{1 - p\gamma B\} - \sigma_1 \{1 - p\gamma A\} + & \\ [\sigma_1 \check{L}^c + \check{RD}] p\gamma \beta_i (\check{\beta}_2 (1 - \check{t}^c) - \check{\beta}_3 (1 + \check{t}^{nc})) &] = \\ (1+s)\check{\alpha}_2 \beta_i [\delta_3 (1 + \check{t}_{SP}^{nc}) - \delta_2 (1 - \check{t}_{SP}^c)] & \\ [\sigma_1 \check{L}^c + \check{RD}] p\gamma \check{\beta}_1 \beta_i \check{x}^{SP} + rs^x \{1 - p\gamma A\} - rs^x &= \delta_1 \beta_i \check{x}^{SP} \end{aligned} \quad (27)$$

$$(28)$$

the solution of which defines the type of RD CAP instruments that induce the adoption of the social optimally production choices $(\check{x}_i^{SP}, \check{b}_{SP}^f, \check{t}_{SP}^\ell)$. Our analysis indicated that the maximization of the social welfare criterion may require that charges are imposed on farmers instead of farmers being provided subsidies on given production choices (such as crop yields, land usage and established input usage treatments). However, given the fact that such charges are not involved in the Agenda 2000 structure, the attainment of the first-best aggregate land quality target is infeasible.

7.2 Assessment of Optimal Dynamics CAP Measures associated with RD

Under the assumption that individual farmers are unbounded rational but do not take into account the evolution of aggregate land quality Q^T , the social planner

⁴²Let $\alpha_1^{SP}, \alpha_2^{SP}$ and $\check{\alpha}_1, \check{\alpha}_2, \check{\beta}_1, \check{\beta}_2, \check{\beta}_3$ represent the impact of the social and individual optimum production choices on crop yields and individual land quality respectively, while denote the impact of socially optimum choices on social damage. The expressions $\check{\beta}_3 = Q_{L^c}$ and $\delta_3 = D_{L^c}$ are both positive and represent the impact of set-aside decision on individual land quality and social damage respectively.

aims to define the optimal path of both main and secondary production choices so as to maximize the current value of the net social benefit from agricultural activities subject to the evolution of aggregate land quality. The associated maximization problem is given by:

$$\begin{aligned} \max_{\mathbf{x}_{ij}, L_i^c, \ell, t_{ij}^x, t_i^c, t_i^{nc}, t_i^\ell} \int_0^\infty e^{-rt} \left[\int_0^{\sum y} F(u) du - \mathbf{w}_j \mathbf{x} - \mathbf{v} \ell - \mathbf{TC} - D(Z) \right] dt \\ \text{st. } \dot{Q}^T = bQ^T - g(\mathbf{x}, \mathbf{L}^C, \dots) \end{aligned}$$

After following the standard procedure a system similar to the static system (26) - (28) is obtained, the solution of which provides the type of the dynamic socially optimum CAP measures.

Under bounded rationality the type and range of values of the socially optimal rural development CAP measures are assessed by employing the evolutionary framework, where the associated replicator dynamic equation is:⁴³

$$\begin{aligned} \dot{z} &= z(1-z)(\pi_i^C - \pi_i^{NC}) \\ \text{with} \\ \pi_i^C - \pi_i^{NC} &= \\ &P(1+s)\Delta_{NC}^C(f(x, L_i^c, (1+t^\ell)\ell)) - w\Delta_{NC}^C(x) - v\Delta_{NC}^C(\ell) \\ &- \Delta_{NC}^C(TC^o) + (\sigma_1 - \sigma_2)\Delta_{NC}^C(L_i^c) + \Delta_{NC}^C(RD) \\ &+ p\gamma \left[(\sigma_1 \check{L}^c + \check{RD}) (\bar{Q}_i - Q_i^{NC}) + \sigma_2 (\bar{L}_i - \check{L}^c) (\check{L}^c - \bar{L}^c) \right] \end{aligned}$$

which is similar to the expression (22) defined under the provision solely of CMOs payments. As expected our analysis indicated that the attainment of the target of full compliance may not always be feasible since the assessed critical rural development payments (*i.e.* s^x) may involve penalties on established treatments, instruments that however are not foreseen by the current CAP structure.

8 Conclusion

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

⁴³The profit divergence between the compliant and deviating strategy is decomposed into the following elements: (i) the divergence of market revenues and coupled payments, (ii) the divergence of purchase costs of input and land usage, as well as the establishment and maintenance costs of treatments, (iii) the divergence of direct payments and provided rural development subsidies, and (iv) the amount of decoupled payments and rural development subsidies removed if deviation from the environmental considerations incorporated in direct payments regime is detected.

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 the provided model allowed the assesment of 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.

The definition of socially optimal CAP measures associated with CMOs and RD in both a static and dynamic context indicated that it may be socially desirable on environmental grounds not only to maintain coupled payments but also to impose on farmers a set of charges on the various aspects of farming activity: crop yields, land-usage, set-aside-land and / or secondary production choices related to emission flows abatement. Given that such measures are not foreseen in the current structure of CAP and that the attainment of first-best aggregate land quality requires time-flexible CAP measures associated with CMOs and RD, suboptimalities occur and both the effectiveness and long-run viability of Agenda 2000 and Mid-term review CAP reforms is doubtful and depends on existing conditions.

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