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GENEDEC

A quantitative and qualitative assessment of the socio-economic and environmental impacts of decoupling of direct payments on agricultural production, markets and land use in the EU

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Possible options and impacts of decoupling within Pillar-2 of CAP

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Environmental Implications of CAP Reforms

FORTH-IESL

Deliverable 8 (D8) for Project: GENEDEC, No 502184
"A quantitative and qualitative assessment of the socio-economic and environmental impacts of decoupling of direct payments on agricultural production, markets and land use in the EU."

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Executive Summary

When the present project was conceived, there were strong indications in the European Commission, that the various CAP measures could be included among the factors responsible for a series of adverse environmental impacts related to agricultural activities. The recognition of this problem led policy makers to take explicitly into account environmental considerations in the design of the Common Agricultural Policy mainly through: the gradual decoupling of payments; the introduction of the principle of cross-compliance; the introduction of a series of rural development measures, as described by Agenda 2000 CAP reform known also as the Green CAP.

The analysis of environmental considerations in the reformed CAP is the focus of Partner 6 (FORTH-IESL) contribution within the Work Package 5 (WP5) of the Project GENEDEC entitled: *Ex-ante Evaluation of Alternative Options of Decoupled Schemes* which set the following objectives (see, Technical Annex I, pg 17):

Objective 1: To assess alternative options of decoupling:

- **Task 1**: Modifications within the COM proposal at a member state level (i.e. regional implementation of the single payment scheme, unified entitlements per hectare at regional level, non-transferable entitlements, tradable entitlements related to land)
- **Task 2**: Partially decoupled schemes at EU and member state level based on market regimes (decoupling of arable crop premia, transforming beef and premia, unified premia for arable land and grassland)
- **Task 3**: Pillar-2 measures (incentives for the production of positive externalities)

Objective 2: To provide information regarding the optimal combination of features of decoupled schemes.

The work to be undertaken under the WP5 can be described as follows:

- Detailed scenarios for alternative options of decoupling and pillar-2 measures based on the Commissions proposal will be defined. The farm models (WP2 and WP3) are then used to assess the impacts of these options on production, income and income distribution, rental values of land, quotas and entitlements. Comparisons between obligatory measures (cross-compliance) and voluntary measures (Pillar-2) will be made.

- Based on the impacts of specific measures, an optimal set-up of political instruments will be worked out, taking into account aspects of cost-benefit, efficiency, administrative handling and budget implications and environmental effects.

Work Package 5 will provide the following deliverables:

D7: A report on the detailed analysis of the impacts of options within the Commission proposal, and of partially decoupled schemes.

D8: A report on the possible options and impacts of decoupling within Pillar-2 of CAP.

Regarding the milestones and expected results the technical Annex I (pg 17) involves:

- – Scenarios defined and implemented through the models (month 20).
  – Impact analysis of the regional implementation of completed fully or partially decoupled schemes (month 23).
  – Analysis of options and impacts of decoupled Pillar-2 measures (month 25).
  – Information regarding the "optimal" combination of elements for decoupled schemes provided to WP7 for working out recommendations (month 30).

  FORTH-IESL (Partner 6) CONTRACTUAL OBLIGATIONS

The contractual obligation of Partner 6 under the Work Package 5 consists of objective 1, task 3 (see Technical Annex I, pg 17) which corresponds to Deliverable 8 (D8): *Report on possible options and impacts of decoupling within Pillar-2 of CAP*, and consists of two parts:

D8.1: Development of a conceptual framework of farming activity under the reforms of Agenda 2000 CAP in order to assess the environmental impacts of decoupling in the context of Pillar-2 measures.

D8.2: Case study for the estimation of individual agricultural emissions loadings, which has two parts

- D8.2a Empirical application of the maximum entropy approach (the entropy filter) to assess individual emissions loading for a given case study, based on data provided by the Prefecture of Crete, Greece. This deliverable covers the task of developing empirical methods for transforming a nonpoint source pollution problem, like agricultural nitrate leaching, to a point source pollution problem.
- D8.2b Use of the optimal control framework to analyze an agricultural production system which uses fertilizers and water from an aquifer with renewable resource characteristics and generated harmful nitrate leaching. Combined with the maximum entropy approach (deliverable D8.2a) this approach can be used to analyze policy impacts in agricultural nonpoint source pollution problems after transforming them through the maximum entropy approach into point source pollution problems

Deliverable 8 will provide material for Work Package 7 for working out recommendations regarding the quantitative and qualitative assessment of the socioeconomic and environmental impacts of decoupling of direct payments on agricultural production, markets and land use in EU. The more specific contribution of Deliverable 8 to the other workpackages of the project is to provide: (i) a conceptual framework for analyzing policy implications for the further reforms of the communal agricultural policy so that environmental problems linked with farming activities - such as nitrates leaching - are handled in a better way, and (ii) an empirical tool, through the entropy approach, for quantitative approximation of individual nitrates leaching which will allow for a more efficient application of environmental policy instruments, and for better monitoring of the impacts and the effectiveness of the Green CAP.

1.1 Summary of Deliverable 8

The assessment of environmental impacts of decoupling within the second pillar of EU Communal Agricultural Policy (CAP) requires the development of a theoretical model describing farming activity under the generalized CAP framework, as it is summarized into the 1999 or Agenda 2000 CAP reform. The particular reform also known as the "Green" CAP, involves reduction of coupled payments and replacement of coupled payments by direct payments linked with the alternative land usages, which along with a series of rural development measures are subject to the principle of cross-compliance. Under cross-compliance partial reduction or full cancellation of coupled payments might take place if farmers are found deviating from established performance standards incorporated into the policy framework. Although the European Commission expects that the Agenda 2000 CAP reform will be successful in inducing integration of environmental considerations into farming behavior in comparison to the previous CAP regimes, no theoretical analysis of the new "Green" CAP with respect its potential environmental impacts has been undertaken.

The purpose of the **first part** of the deliverable D8 is to develop a conceptual framework that describes adequately the impacts of the different type of CAP measures, as prescribed by Agenda 2000, in the decision making of a representative farmer. In particular, **Chapter 3** develops a conceptual, model of farming behavior that embodies the basic reforms of communal agricultural policy for the common market organizations (CMOs). The generalized nature of the developed model allows the assessment of the environmental impacts, in terms of farmer's input and land usage, of the various CMOs CAP regimes such as the old regime of fully coupled payments, the partial and full decoupling regime. The policy effectiveness of Agenda 2000 CAP reform is evaluated by discussing the problem of the optimal regulation both in a static and dynamic context. The type of socially optimal Pillar I CAP instruments inducing a welfare maximizing solution on both individual and aggregate level, along with type of interdependence characterizing them are assessed in a static context, while the long-run viability of the Agenda 2000 CAP reform is examined by employing the evolutionary conceptual framework of replicator dynamics. **Chapter 4** modifies the developed, conceptual model in order to take into consideration the voluntarily adopted rural development (RD) programs, known as the second Pillar of CAP. The relative environmental performance of the various CAP regimes when extended with Pillar II measures is examined in terms of impacts production choices, which are distinguished into two categories: main and secondary production choices. As previously, we proceed in the static and dynamic optimality analysis in order to assess the type of socially optimal Pillar I and Pillar II CAP instruments.

Analysis in Part I indicated that given the heterogeneity among the population of European farmers, the structure of socially optimal CAP measures under both the first and second pillar, need to be adapted to the specific farm characteristics, otherwise the 'first-best solution' in terms of either individual or aggregate land quality is unattainable. In practice the definition of such first-best nonuniform policy has enormous informational requirements since the regulatory authority needs to know not only the individual production choices (inputs, land usage, labor etc.), crop yields but also the individual by-products of production (i.e. individual nitrate leaching).

Although a 'perfect' discrimination might be too costly informationally, or politically infeasible, some kind of nonuniformity associated with a wide dispersion of farm characteristics or farm specific behavior might desirable. Our results suggest that for the design of an efficient policy either in the form of an 'optimal' CAP or in the form of enforcing the present one, the knowledge of emission flows associated with individual farmers or groups of homogeneous farmers is essential for:

(i) The definition of the individual performance standards associated with the provision of decoupled CMOs and RD payments as foreseen by the principle of horizontal regulation,

(ii) The verification of the farmers' compliant behavior so that the regulatory authority can impose the principle of cross-compliance.

It is well known from the theory of Environmental Policy, that in a point-source pollution problem the regulatory body can identify the location of polluting sources and the individual contributions to aggregate (or ambient) pollution, a fact that allows the differentiation of policy measures among decision makers (i.e. farmers).

However, the fact that agricultural pollution has non-point-source (NPS) characteristics (stochastic and diffuse pollution presses, multiple dischargers etc.) introduces uncertainty about the exact individual emission flows, as well as the marginal values of production choices. Given budgetary, technological, informational, or political constraints, the set and the type of feasible policy measures in practice, implies that the CAP is mainly restricted to second-best solutions, such as uniform or regionally specific performance standards; coupled and decoupled Pillar I measures; rural development measures. However, even if first best perfectly discrimination policies are not pursued, the enforcement of the present policy regimes requires knowledge of individual emissions, but this knowledge is impeded by the NPS pollution characteristics of agricultural emissions. Therefore the focus of the second part of D8 is to provide such a framework of analysis that allows the estimation of individual agricultural emission and which can transform, at least partly, a nonpoint source pollution problem of agricultural pollution into a point source pollution problem.

In particular the **second part** of deliverable D8 is to develop a maximum entropy approach which allows estimation of individual emissions,and demonstrate its applicability through a case study. In particular, **chapter 6** presents the development of the entropy formalism and provides a generalized cross entropy (GCE) formulation which by minimizing an entropy measure, can provide estimates of emissions associated with well defined and homogeneous farmer groups in a given location. The developed methodology is applied to a case study in the Greek island of Crete and explicit results are provided regarding individual nitrates leaching for the 1999-00 cropping season. The entropy approach developed in this deliverable can be used to provide a new way for the study of policy issues related to nitrate leaching and the CAP in particular. It can be used to help fine-tune policies and to infer violations of compliance by individuals or certain homogeneous groups, without excessive monitoring costs, bur also, in a more general context it can be used to analyze at an applied level nonpoint source agricultural pollution problems an area of current academic research. The method can be easily adopted to any EU region given data availability.

These estimates obtained by the maximum entropy approach, are further employed in a optimal control framework in order to analyze a dynamic agricultural production system, in **chapter 7.** The optimal paths for nitrate accumulation and fertilizers use, as well as a policy function which relates the stock of nitrates to the optimal fertilizers use are derived. This policy function can be employed by a regulatory authority for the design of a unified agri-environmental policy. This approach combined with the maximum entropy approach of the previous of chapter 6, can be used to analyze policy impacts in agricultural nonpoint source pollution problems after transforming them through the maximum entropy approach to point source pollution problems. The methodology developed in this chapter can be also easily adopted to any EU region given data availability.

Thus, **chapter 6** provides a framework for checking whether individual farmers or homogeneous groups of farmers comply with the a certain policy framework, such as the CAP, while **chapter 7** shows how the information about individual behavior obtained at the earlier stage can be used to design fully dynamic agri-environmental policies.

Thus deliverable D8 can be regarded as combining:

(i) A theoretical analysis of the 'Green' CAP which may used to analyze questions regarding CAP's expected implications regarding farmers responses to environmental targets, and the CAP's long run evolution. The theoretical model can be use to provide a sound theoretical foundation for further applied work that seeks to estimate specific impacts of the 'Green' CAP,

(ii) Applied tools for acquiring information about the behavior of individual or homogeneous groups of farmers, related to emissions, such as nitrate leaching in agricultural NPS pollution problem, which are necessary for both the successful enforcement of the CAP and its environmental targets, and for the efficient assessment and design of new optimal agri-environmental policies.

Part I

European Environment, Common Market Organizations and Rural Development CAP Reforms

2

Agricultural Behavior, Environmental Impacts and the Market Policy CAP Regime

2.1 Introduction

Agriculture is a decisive factor for the production of food and fibre; the maintenance of the viability and diversity of rural communities; the structure of landscape and habits; the provision of tourist services, recreational facilities and environmental protection. However, despite the potential beneficial environmental services[1] European agriculture has been regarded as contributing to a number of environmental problems such as: (i) *loss of biodiversity*,[2] (ii) *loss of landscape diversity and quality*, as well as *deterioration of important habitants*, (iii) *threats to high natural value farming systems and traditional forms of agriculture in marginal areas*, (iv) *soil quality pollution* (i.e. salinization, erosion, acidification), (v) *air pollution* (i.e. ammonia, greenhouse gases),[3] and (vi) *water pollution* (i.e. eutrophication, salinization).

Among the wide number of factors that have led to such an unbalance in the agricultural-environment relationship, the Common Agricultural Policy (CAP) measures are considered of primary importance.[4] Despite the fact that the first formal recognition that

[1] The environmentally beneficial services associated with farming activities include: maintenance of many cultural pastoral and arable landscapes, decline of greenhouse emissions, gains to biodiversity, sustainability and resource management (Baldock D. et al., 2002).

[2] For example in a UK RAMSAR site an average of 35 species was recorded in spring-fed areas in the 1950s but by 1992 only 5 species were found.

[3] In several EU countries agriculture accounts for 95% of ammonia emissions - about 80% arises from livestock wastes, and the most of the reminder from nitrogen fertilizers and fertilized crops. In 1990-1997 agriculture contributed about 11% of total EU greenhouse gas emissions (Baldock D. et al., 2002).

[4] Within the identified driving forces of the unbalance in the agricultural-environment relationship are also included: (i) changes in market conditions (i.e. changes in input prices, consumer preferences), (ii) commercial considerations (target cost minimization, profit maximization), (iii) institutional changes, (iv) technology development (i.e.

European agricultural activity might not be environmental friendly is dated back to 1975, no substantial actions to encourage the positive effects of agriculture and eliminate the negative was undertaken by Commission until 1992 (Fennell, 1997).[5] Such a attitude is attributed to the fact that until this point of time communal policies - including CAP - were not legally required to incorporate issues of environmental protection given that environmental policy was not included in the Treaty of Rome. Nevertheless, the relative reform of the Treat of Rome at 1986 and its further strengthening by the Treaty of Maastricht at 1992 stimulated a turning point for the communal agricultural policy, integrating more environmental considerations into the CAP and attributing to it a greener dimension.

CAP supports linked with output levels (i.e. coupled payments) are a characteristic example of CAP measures related to a series of adverse environmental effects, since there is evidence that increased production at levels that would have not occurred otherwise, resulting into intensification and specialization, expansion of cropped area and rise in livestock numbers (Baldock D. et al., 2002). Even though coupled payments have not yet been cancelled out by the EU market policy (Pillar I), European Commission indicated in 1988 that the particular price policy could be liable for environmental damages (Fennel, 1997) and decided to move gradually away from price support measures and proceed further into a wider reorganization of CAP in order to integrate environmental concerns as a response to the wider criticism and demand for an environmentally oriented CAP.[6]

Indeed the major element of the 1992 or *McSharry CAP reform* was the gradual reduction or even elimination of production subsidies

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changes in input prices, consumer preferences), (v) broader economic and social changes in rural areas (i.e. changes in cost of labor and land, population mobility), (vi) independent and partly endogenous environmental changes (i.e. natural disasters, global warming, flooding), as well as (vii) various public policy measures of EU CAP or in different policy realms (i.e. land ownership and tax, food safety and hygiene, social security).

[5] In particular, at 1977 the 5th Action program underlined the need to identify the effects of agriculture and hence define actions that encourage the positive effects and eliminate the negative. However, the fact that environmental policy was not included in the Treaty of Rome lead to no substantial reform of CAP.

[6] According to EU (1999) the Agenda 2000 package of reforms is among others a response to popular demands in Europe for passing on to the next generation a natural environment that is beginning to recover from the damage and degradation inflicted in the past.

(decoupling) and the introduction of direct aid payments, which are independent of production level and are provided on a per hectare basis to compensate farmers for cuts in support prices (EC, 2003). A further substitution of price support measures by direct aid payments is performed under the 1999 or *Agenda 2000 reform*, which requires also that of environmental considerations are taken into account in the implementation of pillar I measures (i.e. horizontal regulation). Additionally, the 1999 reform proposes a long-term set-aside mechanism[7] and promotes a *package of rural development measures* (Pillar II),[8] which have been actually designed to complement reforms of the common market organizations (CMOs) and internalize many major environmental considerations. In order to maximize environmental benefits, both direct payments and pillar II measures are set under the *principle of cross-compliance*, a sanctioning approach incorporated in the horizontal regulation that involves proportionate penalties for environmental infringements entailing, where appropriate, either partial or full removal of aid in the event of deviation from certain farming standards (EC, 1999). Finally, via the introduction of *dynamic modulation* the CAP reformers proposed a compulsory reduction of coupled and decoupled payments, along with the transfer of funds released from market policy, to the rural development measures contributing to environmentally benign practices.

Finally, the given reforms are further extended and strengthened by the 2003 CAP reform that mostly has as its basis a revision of the market policy via the introduction of a single payment scheme that is to be put into action in 2005 or 2006 (EC, 2004b). Under this regime farmers are also eligible for an annual income payment based on sums of direct payments received over the 2000-2002 reference period and the number of hectares entitled for those payments. Such payments are conditional to the cross-compliance principle that is further redefined to become dependent on the detected noncompli-

[7] Farmers that set-aside their arable land for ten years are eligible for direct payments, which are dependent on meeting this requirement. According to European Commission (2004a) farmers are able to grow non-food crops (i.e. energy crops) on set-aside-land.

[8] The series of rural development measures include: (i) early retirement and set-up of young farmers, (ii) reafforestation of agricultural land, (iii) compensatory payments for mountainous and other less-favoured areas, (iv) agri-environmental programs (the only compulsory measure for all Member States), (v) vocational training, (vi) investment in agricultural holdings and (vii) improving processing and marketing of agricultural products (EC, 2004a).

ance type. In particular, 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. Furthermore, the 2003 or Mid-term reform aims to further expand and strengthen rural development by transferring funds from the first pillar (market and income support) to the second pillar (rural development) according to the principle of dynamic modulation as a response to the growing public concern on food quality, environmental protection and animal welfare (EC, 2004b).

Based on the prospects of European Commission the Agenda 2000 CAP reform is expected to bring greater quality to environmental integration into the communal agricultural policy and therefore the characterization "*Green CAP*" is rightfully attributed to it. However, no extensive theoretical analysis of this new regime has been undertaken.

The intention of the present chapter is to assess both the environmental impacts and policy effectiveness of the 1999 CAP reform in a static and dynamic context. To do so a conceptual, theoretical framework, describing the farming behavior under the provisions of Agenda 2000 CAP regime is developed by considering a representative farmer operating under a reduced production subsidy and two types of direct payments, provided for two alternative and conflicting treatments of agricultural land: (i) cultivation and (ii) set-aside. Given the costs associated with the attainment of the environmental requirements incorporated in direct aid payments, two alternative behavioral rules are considered regarding the farmer's attitude: compliance with and deviation from defined farming standards. Such a deviating behavior can be detected via the realization of an exogenously defined number of random inspections,[9] due to the non-point-sourse (NPS) characteristics of agricultural pollution,[10]and can

[9]The simultaneous inspection of the entire population of farmers within a given geographical region is a technically very demanding task and potentially prohibitively costly (Xepapadeas and Passa, 2005).

[10]A pollution problem is called NPS problem if there is uncertainty from the regulator's part about the location of the decision makers (polluters) and the degree of each agent's contribution to the aggregate pollution. In short the origins of this uncertainty can either be attributed to stochastic influences affecting fate and transport of pollutants, the great number of sources of pollution emissions that can be either static (farms, households) or mobile (vehicles), and/or the regulator's inability to infer individual emissions from ambient pollution levels or inputs used (Xepapadeas, 1995).

be further deterred via the enforcement of the principle of cross-compliance.

The nature of the provided farm model is quite generalized since under the proper simplifying assumptions the different CMOs CAP regimes can be reproduced, a fact that allow us to conduct comparisons between the various CAP regimes in terms of the equilibrium values of the farmer's production choices, defined as input usage and land set-aside. Among the examined CMOs CAP regimes are: (i) *full coupling regime* that involves only the provision of production subsidies independently of environmental requirements, (ii) *partial decoupling regime*, involving the simultaneous provision of coupled and decoupled payments, and (iii) *full decoupling regime*, where farmers are provided only with direct payments. The unregulated competitive regime, where farmers are provided neither coupled nor decoupled payments, is employed as a benchmark regime.

In order to assess whether and how the representative farmer's production choices are altered by the introduction of environmental requirements and the principle of cross-compliance, the regimes of partial (ii) and full (iii) decoupling are respectively examined under both the absence and presence of such considerations. Likewise the compliant and deviating behavioral rule can be compared in terms of their equilibrium input and land usage values.

The chapter discusses also the problem of the optimal regulation, through which *socially optimal* or *first best* CAP instruments under the common market organizations are obtained. Emphasis is given to three pairs of optimal CMOs CAP measures: (i) production subsidy and land-usage direct payment, (ii) production subsidy and set-aside direct payment, and (iii) production subsidy and cross-compliance term, which are defined for fixed values of the rest CAP measures. For each optimal pair the type of interdependence between the various CAP measures, as well as the conditions under which a particular CAP regime is optimal are provided. After defining the socially optimal combination of production choices the effectiveness of Agenda 2000 CAP reform 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.

Based on the above framework the assertion that the communal agricultural policy, as shaped by the reforms of Agenda 2000 CAP, achieves to integrate environmental considerations into farming behavior needs certain qualifications. . In particular, comparative static analysis pointed that even though the reduction of coupled payments and the incorporation of environmental constraints is expected to induce farmers to restrict production choices, and adopt a more environmentally friendly behavior, the final impact of direct payments regime and cross-compliance enforcement mechanism is not unambiguous. The comparison of behavioral rules suggests that the introduction of both direct payments and the compliance enforcement mechanism may not be sufficient to induce potentially noncomplying farmers to alter their production choices and adopt a behavior that is approximating (or even matching with) the compliant behavioral rule.

As expected the regime of non intervention is preferable on environmental grounds to intervention via production subsidies, justifying the wide critic towards coupled payments. However, the environmental performance of the Agenda 2000 regime (partial or full decoupling) can not be clearly inferred as superior compared to the unregulated and full coupling regime under both behavioral rules. In particular, even though both the partial and full decoupling regime involve less input usage, there is uncertainty about their relative performance in terms of set-aside land due to the fact that direct payments are provided on conflicting land usages: cultivation and set-aside. Nevertheless, it is evident that the forthcoming CAP regime involving only payments independent of production level, is environmentally superior both in terms of input and land usage to the present regime involving both coupled and decoupled payments, justifying the Commission's decision to proceed in the full cancellation of coupled payments. Furthermore, the environmental performance of the fully decoupled regime can be further enhanced by the incorporation of further environmental considerations.

The assessment of the socially optimal CMOs CAP regimes both in static and dynamic context indicated that it may be socially desirable not only to maintain certain coupled payments but also to augment the compliance enforcement mechanism with a possible charges on certain crop yields, land-usage. Given the present structure of the communal agricultural policy such measures are not politically feasible. Another source of potential suboptimality is introduced by the fact that the attainment of first-best solutions requires both nonuniform and time-flexible CAP measures which are however practically infeasible given the high informational or / and administrative requirements they involve.

2.2 The Farm Model under the CMOs CAP Regime

Consider a farmer i that produces a single crop and possesses $\bar{L}_i$ gross land. Let $\left(1-b_i^F\right)$ be the percentage of gross land used for cultivation and b_i^F the remaining percentage that is voluntarily set aside by the farmer (case of non-production). Henceforth, the gross land $\bar{L}_i$ is decomposed into:

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

where for simplification let $\left(1-b_i^F\right)\bar{L}_i = L_i^c$.

Crop yields are a function of farmer i's production choices $(\mathbf{x}_{ij}, L_i^c)$ given by:[11]

$$y_i = f(\mathbf{x}_{ij}, L_i^c) \tag{2.1}$$

where $\mathbf{x}_{ij} = (x_{i1}, x_{i2}, ..., x_{im})$ is the vector of farmer i's input choices among a set of $j = 1, ..., m$ inputs.

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

$$e_i = e(\mathbf{x}_{ij}, L_i^c) \tag{2.2}$$

[11] Crop yields are characterized by $\frac{\partial f(\cdot)}{\partial \mathbf{x}}, \frac{\partial f(\cdot)}{\partial L^c} > 0$ and $\frac{\partial^2 f(\cdot)}{\partial \mathbf{x}^2}, \frac{\partial^2 f(\cdot)}{\partial (L^c)^2} < 0$, with $\frac{\partial^2 f(\cdot)}{\partial \mathbf{x} \partial L^c} > 0$ since applied inputs and cultivated land are considered to be complements. Given that $L_i^c = \left(1-b_i^F\right)\bar{L}_i$, it alternatively holds $\frac{\partial f(\cdot)}{\partial b^F} = (-\bar{L}_i)\frac{\partial f(\cdot)}{\partial L^c} < 0$ and $\frac{\partial^2 f(\cdot)}{\partial (b^F)^2} = \left(-\bar{L}_i\right)^2 \frac{\partial^2 f(\cdot)}{\partial (L^c)^2} < 0$.

that is positively correlated to production and defined as a positive function of $\mathbf{x}_{ij}$ inputs and cultivated land.[12]

In the absence of any 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 price of the commodity and $\mathbf{w}_j$ the vector of input prices in the competitive output and input market respectively.[13]

Under the regime of Agenda 2000 the chosen crop type is eligible both for a reduced production subsidy (s) and two types of direct aid payments (DPs), dissociated by the production level and coupled with the alternative and conflicting land usages: (i) cultivation and (ii) set-aside. The provided direct payments are supplementary to farmer income and are 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 provided per hectare of set-aside land and $\left(\bar{L}_i - L_i^c\right)$ the size of gross land voluntarily set-aside by the farmer i. Given that the Commission has defined a certain proportion of land that is compulsory to be set-aside $\left(b^R\right)$, farmers setting-aside higher fraction of gross land $\left(b_i^F > b^R\right)$ are not eligible for the set-aside premium for the additional range $\left(b_i^F - b^R\right)$.[14]

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[12] It holds $\frac{\partial e_i(\cdot)}{\partial \mathbf{x}}, \frac{\partial e_i(\cdot)}{\partial L^c} > 0$ and $\frac{\partial^2 e_i(\cdot)}{\partial \mathbf{x}^2}, \frac{\partial^2 e_i(\cdot)}{\partial (L^c)^2} > 0$, with $\frac{\partial^2 e_i(\cdot)}{\partial \mathbf{x} \partial L^c} > 0$ given that inputs and cultivated land are treated as complements. It alternatively holds $\frac{\partial e_i(\cdot)}{\partial b^F} < 0$ and $\frac{\partial^2 e_i(\cdot)}{\partial (b^F)^2} > 0$.

[13] Land is not included in this vector since it is considered to be owned by the farmer.

[14] The additional range could be eligible of a direct payment under the rural development (Pillar II) measure for the forestry sector, where farmers are compensated to afforest their land (EC, 2004a). However, such a case is not examined.

According to the horizontal regulation the direct payments provided under the EU market policy (Pillar I) are conditional to certain environmental requirements, implying that:

- The land usage direct payment DP_1 is subject to an individual land quality standard, defined as:

  $$Q_i(e_1, e_2, ..., e_n) \geq \bar{Q}_i \tag{2.3}$$

  Given that land quality Q_i is a negative function of emission flows[15] the attainment of the land quality target $\bar{Q}_i$ involves costs in terms of forgone market revenues.[16]

  A strategic interaction among the farmers within a given geographical area is evident since the land quality of farmer i is not only affected by his individual emission flows but also by the by-products of neighboring farmers. Typical example of such an interaction is the upstream and downstream farmer. Even though the emission flows of the upstream farmer can affect the land quality value of the downstream farmer, the land quality of the former cannot be affected by the later's by-products. This implies that in this case individual land quality Q_i cannot be regarded as a function of aggregate emissions.[17]

- The set-aside direct payment DP_2 is granted on the basis of meeting the nonproduction requirement, as described by the land usage constraint:

  $$b^F \geq b^R \text{ or } L_i^c \leq \tilde{L}^c \tag{2.4}$$

  where the constraint constant $\tilde{L}^c = (1 - b^R)\bar{L}_i$ represents the maximum, permissible size of cultivated land, the attainment of which involves also costs in terms of forgone market revenues.

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[15] Given that $\frac{\partial Q_i}{\partial e_i}, \frac{\partial^2 Q_i}{\partial (e_i)^2} < 0$ it holds that $\frac{\partial Q_i}{\partial x}, \frac{\partial Q_i}{\partial L^c} < 0$ and $\frac{\partial^2 Q_i}{\partial x^2}, \frac{\partial^2 Q_i}{\partial (L^c)^2} < 0$, with $\frac{\partial^2 Q_i(\cdot)}{\partial x \partial L^c} > 0$. Alternatively, it holds $\frac{\partial Q_i}{\partial b^F} > 0$ and $\frac{\partial^2 Q_i}{\partial \left(b^F\right)^2} < 0$.

[16] The attainment of the target requires cut of emission flows either through the reduced use of inputs $\mathbf{x}$ or by restricting the size of cultivated land L^c, resulting however into a reduction in crop yields.

[17] It is logical that in an area with steep slope the land quality valuation of a farmer located on the top of a hill ($i = 1$) cannot be adversely affected by the emission flows of a farmer located at the bottom ($i = 2$). This implies that: $\frac{\partial Q_2}{\partial e_1} < 0$ but $\frac{\partial Q_1}{\partial e_2} = 0$.

Incentives not to attain the particular 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 their production choices unchanged and thus prevent the revenues losses that compliance with the land usage and land quality constraint entails. Nevertheless, it is worth mentioning that such a deviation from established performance standards cannot always be attributed to deliberate actions but also to farmers' negligence or inability to comply. In any case deliberate and negligent deviating behavior can be detected via the realization of an exogenously defined number of random inspections, given the regulator's inability to inspect simultaneously the entire population of farmers receiving direct payments.[18]

Such a deviating behavior can be detected under a fixed probability p and then deterred via the principle of cross-compliance that involves reduction or even cancellation of provided direct payments by the amounts:[19]

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

where γ is a positive parameter representing the reduction rate of direct payments, laying within the range $[0, 1]$.[20] The reduction of direct payments is proportional to the deviations from the constraint constant and it is reasonable to consider, based on 2003 CAP reform, that the higher the deviation is, the more evident deliberate noncompliance is, justifying the higher reduction of direct provisions.

[18] According to European Commission (2004a) the introduction of a system of audits will help farmers become aware of the requirements on food safety and the environment.

[19] The inspection probability of a deviating farmer can also be dependent on the deviation of the measured aggregate land quality Q^T from the aggregate quality target $\bar{Q}^T$. In such a case it would hold:

$$\text{If } \bar{Q}^T > Q^T(Q_1, .., Q_i, ..., Q_n) \text{ then } p_i(\bar{Q}^T - Q^T) > 0$$

with $\frac{\partial p_i}{\partial Q^T}, \frac{\partial p_i}{\partial Q_i} < 0$ and $\frac{\partial^2 p_i}{\partial (Q^T)^2}, \frac{\partial^2 p_i}{\partial (Q_i)^2} < 0$. However, such a case is not considered to avoid complications.

[20] The reduction rate γ is equal to zero if the farmer goes beyond existing standards, implying that: $\gamma = 0 \quad$ if $\bar{Q}_i < Q_i$ and / or $L^c < \tilde{L}^c$.

2.3 Alternative Behavioral Strategies under the CMOs CAP Regime

Under the described, generalized CAP regime two alternative behavioral rules and thus maximization problems can be distinguished, depending on the farmers' attitude towards the land usage and land quality constraint. It is evident that if the constraints (2.3) and (2.4) enter the farmer i's problem then the compliant rule is considered. On the contrary, if the farmer considers the possibility of noncompliance with environmental standards, then the constraints do not enter the model and the deviating rule occurs. Hence, under the presence of performance standards and the compliance enforcement mechanism the following maximization problems can be defined:

1. **Compliant Behavioral Rule**.

$$\begin{aligned} &\max_{\mathbf{x},b^F} \pi_i^C = P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j\mathbf{x}_{ij} + \\ &\sigma_1 L_i^c + \sigma_2\left(\bar{L}_i - L_i^c\right) \\ &\text{subject to} \\ &L_i^c \leq \tilde{L}^c \\ &Q_i(e_1, e_2, ..., e_n) \geq \bar{Q}_i \end{aligned} \tag{2.5}$$

2. **Deviating Behavioral Rule**.

$$\begin{aligned} &\max_{\mathbf{x},b^F} \pi_i^{NC} = P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j\mathbf{x}_{ij} + \\ &\sigma_1 L_i^c\left\{1 - p\gamma\left(\bar{Q}_i - Q_i\right)\right\} + \sigma_2\left(\bar{L}_i - L_i^c\right)\left\{1 - p\gamma(\tilde{L}^c - L_i^c)\right\} \end{aligned} \tag{2.6}$$

where the various CAP Pillar I payments (s, σ_1, σ_2), the 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.

It is evident that in the absence of environmental considerations there is no distinction between the compliant and deviating farmer and the maximization problem reduces into: $\max_{\mathbf{x},b^F} \pi_i = P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j\mathbf{x}_{ij} + DP_1 + DP_2$.

The generalized nature of the described CAP regime,[21] allows the definition of the different CAP regimes via the proper simplifying assumptions. Thereupon, the environmental performance of the farming activity i in terms of set-aside decision $\left(b_i^F\right)$ and inputs usage $(\mathbf{x}_{ij})$ can be also examined under the:

1. *Unregulated competitive regime*: $s = 0$ and $\sigma_1, \sigma_2 = 0$. It can be viewed as the regime prior the establishment of the CAP or as an extreme CAP regime characterized by cancellation of both coupled and decoupled payments. In both cases the farmer's production choices are determined fully by market conditions.

2. *Full coupling regime*: $s > 0$ and $\sigma_1, \sigma_2 = 0$. It is the so-called *old regime*, involving only the provision of production subsidies independently of environmental requirements.

3. *Partial decoupled regime*: $s > 0$ and $\sigma_1, \sigma_2 > 0$. It is the *current regime* involving both coupled and decoupled payments.[22] Even though under Agenda 2000 CAP reform decoupled payments are subject to environmental requirements it is worth examining the performance of the given regime under the following subcases:

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

   (b) Existence of land quality and usage constraints.

   in order to verify the perception that the combined provision of decoupled payments with environmental standards induces farmers to restrain their production choices.

[21] It is the regime of partial decoupling denoted below by the indication (3b) since it involves both the provision of coupled and decoupled payments, under the presence of environmental considerations and a compliance enforcement mechanism.

[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] The distinction between the compliant and deviating behavioral rule is associated with the presence of environmental considerations. Hence, when examining the performance of the given CAP regime under the deviating rule the subcase a) is similar to examining the case of nonenforcement of existent environmental standards in the sense that either no farmer is inspected (*i.e.* $p = 0$) or if inspected and found deviating farming standards then no reduction direct payments takes place (*i.e.* $\gamma = 0$).

4. *Full decoupled regime*: $s = 0$ and $\sigma_1, \sigma_2 > 0$. It can be viewed as the *forthcoming regime*, involving the complete cancellation of coupled payments and the provision only of direct payments.[24] As previously two subcases can be examined: (a) absence and (b) existence of environmental constraints.

Finally, the regime foreseen by 2003 Midterm review is identical to the later regime since it involves the provision of direct payments and a single farm payment that is a fixed amount given that it depends on the total direct payments received the period 2000-2002 and the number of hectares eligible for those payments.

2.3.1 Profit Maximization by Farmers under Compliance

Considering the whole problem (2.5) the Langrangean function is defined as:

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

where the langrangean multipliers λ represent the farmer i's shadow valuation of the constraint constants.

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

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

$$FOC_{x_j} : P(1+s)\frac{\partial f}{\partial x_{ij}} - w + \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x_{ij}} = 0 \tag{2.7}$$
$$\text{if } x^*_{ij} > 0$$
$$\text{or } \frac{\partial \mathcal{L}\left(\mathbf{x}^*_{ij}, b^F_{i*}, \lambda_1, \lambda_2\right)}{\partial x_{ij}} < 0 \qquad \text{if } x^*_{ij} = 0$$
$$FOC_{b^f_i} : \lambda_2 - \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L^c_i} - P(1+s)\frac{\partial f}{\partial L^c_i} - \tag{2.8}$$
$$\sigma_1 + \sigma_2 = 0 \text{ if } b^F_{i*} > 0$$
$$\text{or } \frac{\partial \mathcal{L}\left(\mathbf{x}^*_{ij}, b^F_{i*}, \lambda_1, \lambda_2\right)}{\partial b^F_i} < 0 \qquad \text{if } b^F_{i*} = 0$$
$$FOC_{\lambda_1} : Q_i(e_1, e_2, ..., e_n) - \bar{Q}_i = 0 \qquad \text{if } \lambda_1 > 0$$
$$\text{or } Q_i(e_1, e_2, ..., e_n) - \bar{Q}_i > 0 \qquad \text{if } \lambda_1 = 0$$
$$FOC_{\lambda_2} : \tilde{L}^c - L^c_{i*} = 0 \qquad \text{if } \lambda_2 > 0$$
$$\text{or } \tilde{L}^c - L^c_{i*} > 0 \qquad \text{if } \lambda_2 = 0$$

It is evident that if the constraints are nonbinding then the associated langrangean multipliers are zero, otherwise they are nonzero. By the Envelop Theorem it holds:

$$\frac{\partial \mathcal{V}(P, w, s, \sigma_1, \sigma_2)}{\partial \bar{Q}_i} = \frac{\partial \mathcal{L}\left(\mathbf{x}^*_{ij}, b^F_{i*}, \lambda_1, \lambda_2\right)}{\partial \bar{Q}_i} = -\lambda_1$$
$$\frac{\partial \mathcal{V}(P, w, s, \sigma_1, \sigma_2)}{\partial \tilde{L}^c} = \frac{\partial \mathcal{L}\left(\mathbf{x}^*_{ij}, b^F_{i*}, \lambda_1, \lambda_2\right)}{\partial \tilde{L}^c} = \lambda_2$$

implying that the multiplier λ_1 expresses the marginal cost due to a change in the land quality constraint constant $\bar{Q}_i$, while the multiplier λ_2 the marginal benefit resulting from a change in the land usage constraint constant $\tilde{L}^c$.

Conditions (2.7) and (2.8) provide the equilibrium values of farmer i's production choices regarding the input usage x^*_{ij} and set-aside fraction b^F_{i*} under the compliant behavioral rule, which are given as:[25]

[25] The sufficient conditions for maximum are satisfied, in the sense that the objective

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

According to the condition (2.7) the farmer i applies the input x_{ij} up to the point that the marginal revenues from production $\left(P(1+s)\frac{\partial f(\cdot)}{\partial x}\right)$ equate with the marginal costs from the purchase of the j input (w_j) 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 the condition (2.8) equates marginal revenues in terms of set-aside premium (σ_2), 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 $\left(-P(1+s)\frac{\partial f(\cdot)}{\partial L^c_i}\right)$ and foregone land usage premium ($-\sigma_1$).

The effects from changes in the various CAP measures on the compliant farmer's optimum production choices x^*_{ij} and b^F_{i*} can be assessed through the comparative static analysis. It is noticeable that if the constraints (2.3) and (2.4) are binding then the optimum production choices $\left(x^*_{ij}, b^F_{i*}\right)$ are unaffected by changes in the value of the provided CAP payments. Nevertheless, if the constraints are nonbinding then the comparative static results are:

	s	σ_1	σ_2
x^*_{ij}	$+$	$+$	$-$
b^F_{i*}	$-$	$-$	$+$

indicating that the optimum production choices $\left(\mathbf{x}^*_{ij}, L^c_{i*}\right)$ of the compliant farmer are restricted and thus his/her *environmental performance* is enhanced only if the CAP regime is characterized by a reduction of coupled payments s and land usage direct premium σ_1, along with an increased set-aside direct premium σ_2. This suggest that the following could be stated:

Remark 1 *There might be uncertainty about the final impact of the current structure of CAP on the compliant farmers' environmental*

function is concave and the constraints are either linear or convex.

performance given that the principle of dynamic modulation involves gradual reduction of both coupled and decoupled payments.

It should be noted that the gradual reduction of both production subsidies and land usage direct payments are foreseen by the current structure of CAP. However, given that this principle applies also for set-aside direct payments, there might be uncertainty about the final impact of Agenda 2000 on the compliant farmers' production choices and thus environmental performance. *It seems the non-declining set aside payments support the attainment of environmental targets.*

2.3.2 Profit Maximization by Farmers under the Deviating Behavior

Under the deviating behavioral rule the farmer i's payoff function is:

$$\begin{aligned}
&\max_{\mathbf{x},b^F} \pi_i^{NC} = P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j\mathbf{x}_{ij} + \\
&\sigma_1 L_i^c \left\{1 - p\gamma\left(\bar{Q}_i - Q_i(e_1, e_2, ..., e_n)\right)\right\} \\
&+\sigma_2(\bar{L}_i - L_i^c)\left\{1 - p\gamma(L_i^c - \tilde{L}^c)\right\}
\end{aligned} \tag{2.9}$$

where $\left\{1 - p\gamma\left(\bar{Q}_i - Q_i(\cdot)\right)\right\}$ and $\left\{1 - q\gamma(L_i^c - \tilde{L}^c)\right\}$ represent the net percentage of the direct payments DP_1 and DP_2 provided to farmer i after the detection of deviation from the land quality and land usage constraint respectively, and the enforcement of the cross-compliance principle.

The Kuhn-Tucker necessary conditions of the noncompliant problem are:

$$
\begin{aligned}
FOC_{x_{ij}} \quad &: \quad P(1+s)\frac{\partial f}{\partial x_{ij}} - w_j + \sigma_1 L^c p\gamma \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x_{ij}} = 0 \text{ if } x_{ij}^{\#} > 0 \qquad (2.10)\\
&\quad \text{or } \frac{\partial \pi_i^{NC}}{\partial x_{ij}} < 0 \qquad \text{if } x_{ij}^{\#} = 0\\
FOC_{b^f} \quad &: \quad -P(1+s)\frac{\partial f(\mathbf{x}_{ij}^{\#}, L_{i\#}^c)}{\partial L_i^c} - \qquad (2.11)\\
&\quad \sigma_1\left\{1 - p\gamma\left[\left(\bar{Q}_i - Q_i(\cdot)\right) - \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L_i^c}L^c\right]\right\}\\
&\quad +\sigma_2\left\{1 - p\gamma\left(\left(\bar{L}_i - \tilde{L}^c\right) - 2\left(\bar{L}_i - L_{\#}^c\right)\right)\right\} = 0 \qquad \text{if } b_{i\#}^F > 0\\
&\quad \text{or } \frac{\partial \pi_i^{NC}}{\partial b_i^F} < 0 \qquad \text{if } b_{i\#}^F = 0
\end{aligned}
$$

where the equilibrium values of input usage $x_{ij}^{\#}$ and set-aside fraction $b_{i\#}^F$ under the deviating behavioral rule, as provided by the conditions (2.10) and (2.11) are:[26]

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

According to the condition (2.10) inputs are applied up to the point that the marginal revenues from production $\left(P(1+s)\frac{\partial f(\cdot)}{\partial x}\right)$ equate with the marginal costs from the purchase of the j input (w_j) and the reduction of land usage payment DP_1 due to both the detection of deviation from the land quality constraint constant and the enforcement of the cross-compliance principle $\left(\sigma_1 L_i^c p\gamma\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x}\right)$. Similarly the condition (2.11) defines the set-aside fraction that equates the marginal revenues in terms of the provided set-aside premium (σ_2) and the preserved amount of the direct payment DP_1 resulting from the enhanced land quality $\left(\sigma_1 p\gamma\left[\left(\bar{Q}_i - Q_i\right) - \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L_i^c}L_i^c\right]\right)$, with marginal costs in terms of foregone market revenues $\left(-P(1+s)\frac{\partial f(\cdot)}{\partial L_i^c}\right)$

[26] It is assumed that the principle minors of the bordered Hessian satisfy the requirement: $|H_1| < 0$ and $|H_2| > 0.$, so that the second-order sufficient conditions for maximum are satisfied.

and foregone land usage premium $(-\sigma_1)$. The last term

$$\left(-\sigma_2 p\gamma\left(\left(\bar{L}_i-\tilde{L}^c\right)-2\left(\bar{L}_i-L_i^c\right)\right)\right)$$

can either reflect a marginal cost or a marginal revenue depending on the relationship between the size of the voluntarily and compulsory set-aside land.

The optimum production choices $\left(\mathbf{x}_{ij}^{\#}, L_{i\#}^c\right)$ of the deviating farmer i are altered by changes of the various CAP measures, as indicated by the following comparative static table:[27]

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

As expected reductions in the value of the production subsidy s or increases in the value of both the constraint constants b^R and $\bar{Q}_i$ stimulate reductions in the equilibrium production choices $\left(\mathbf{x}_{ij}^{\#}, b_{i\#}^F\right)$. On the other hand, the exact impact of direct payments (σ_1, σ_2) and the compliance enforcement mechanism (p, γ) is ambiguous and is highly dependent on the magnitude of the voluntarily set-aside land $\left(\bar{L}_i-L_i^c\right)$ compared to the compulsory set-aside size $\left(\bar{L}_i-\tilde{L}^c\right)$.[28] Nevertheless, if the reduction of direct payments in the event of detected noncompliance is independent of the deviation from the constraint constants then the impact of a change of σ_1 and σ_2 premiums can be clearly assessed, while uncertainty is retained about the final impact of the compliance enforcement mechanism.[29]

It is worth mentioning that if the inspections to verify compliance with environmental standards b^R and $\bar{Q}_i$ are not realized by the

[27] The presented comparative static results relay on the assumption that $F_{xbf} < 0$.

[28] If $\left(\bar{L}-L^c\right) \geq \left(\left(\bar{L}-\tilde{L}^c\right)/2\right)$ then increases in the value of the specific CAP measures induce reductions in the equilibrium value of both applied inputs and cultivated land. In the opposite case there is uncertainty about their exact impact on the equilibrium pair.

Finally, it is stressed this does not hold for the case of the land usage premium σ_1.

[29] In such a case the provided net amount of direct payments is $\sigma_1 L_i^c\{1-p\gamma\}$ and $\sigma_2(\bar{L}_i-L_i^c)\{1-p\gamma\}$. The impact of a change of direct premiums on production choices implies $\frac{\partial x^{\#}}{\partial \sigma_1}, \frac{\partial b_{\#}^F}{\partial \sigma_2} > 0$ and $\frac{\partial x^{\#}}{\partial \sigma_2}, \frac{\partial b_{\#}^F}{\partial \sigma_1} < 0$, while the respective impact of the enforcement mechanism is dependent on the relative magnitude of direct payment premiums σ_1 and σ_2. In particular, if $\sigma_1 > \sigma_2$ then the farmer i restricts equilibrium input and land usage.

same regulatory body, then the inspection probability p and further the cross-compliance reduction rate γ can be differentiated for the two types of direct payments DP_1 and DP_2. Hence in the case of the land quality constraint a strict enforcement mechanism (p_1, γ_1) stimulates reduced input and land usage, while in the case of the land usage constraint the relative impact is still dependent on the relative magnitude of the voluntarily and mandatory set-aside land.[30]

The above suggest that:

Remark 2 *The final impact of the current structure of CAP on the deviating farmer i's environmental performance are ambiguous due to the opposing impact on production choices* $\left(\mathbf{x}_{ij}^{\#}, b_{i\#}^{F}\right)$ *of the various measures of the Agenda 2000 CAP reform.*

On the one hand, the decision of the European Commission to proceed with the gradual reduction of coupled payments and to incorporate environmental considerations within direct payments obviously enhances environmental performance. On the other hand, the final impact of the regime of direct payments and the cross-compliance, enforcement mechanism is characterized by uncertainty and conditional on farmers' evaluation of the costs and benefits given that decoupled payments are provided for conflicting land usages, as well as on the existing relation between the size of voluntarily and compulsory set-aside land.

2.4 Assessment of the various CMOs CAP regimes and the two behavioral strategies

The relative environmental performance of the various CAP regimes under both behavioral rules can be assessed in terms of their profit maximizing production choices $(\mathbf{x}_{ij}, b_i^f)$ through the proper use of the defined optimality conditions.

Consider two CAP regimes, given as g and h, that involve different type of payments. In order to compare the equilibrium production choices $\left(\mathbf{x}_{ig}, b_{ig}^f\right)$ resulting under the regime g with the associated

[30] The relevant comparative statics are given by:

	p_1	p_2	γ_1	γ_2
x^*	$-$	? (0)	$-$	? (0)
$b_{\#}^F$	$+$	? (0)	$+$	? (0)

choices $\left(\mathbf{x}_{ih}, b_{ih}^{f}\right)$ of the regime h, the optimality conditions π_x^g and $\pi_{b^f}^g$ of the initial regime are evaluated at the equilibrium choices of the latter regime. This implies that the following expressions are evaluated:

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

where both $\pi_x^h(\mathbf{x}_{ih}, b_{ih}^f)$ and $\pi_{b^f}^h(\mathbf{x}_{ih}, b_{ih}^f)$ are equal to zero.

If the expressions are zero then the examined regimes are identical in environmental terms since they involve the same production choices. However, if the expressions are nonzero then there is deviation in the equilibrium choices and the environmental performance of the given regime.. In such a case the regime g is environmentally inferior to the regime h in the sense that it involves 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 case that $\pi_x^g(\mathbf{x}_{ih}, b_{ih}^f) < 0$ and $\pi_{b^f}^g(\mathbf{x}_{ih}, b_{ih}^f) > 0$ it is environmentally superior since it involves less input usage and higher land-set-aside.

After following the described procedure the findings regarding the relative environmental performance of the various CAP regimes in terms of both input usage and set aside fraction are summarized in the table.[31]

[31] The analysis is carried out both under the compliant and deviating behavioral rule, providing exactly the same results regarding the relative impact of the various CAP regimes on input usage $\left(\Delta x_j^i\right)$. Only in two cases the indication regarding the relative impact on the set-aside decision $\left(\Delta \left(b^f\right)_j^i\right)$ is modified under the deviating strategy compared to the compliant strategy, and it is indicated in the table via the parenthesis.

$\Delta x_h^g = (x_g - x_h)$					
$g \setminus h$	2	3_a	3_b	4_a	4_b
1	$-$	$-$	?	0	$+$
2		0	$+$	$+$	$+$
3_a			$+$	$+$	$+$
3_b				?	$+$
4_a					$+$

$\Delta\left(b^f\right)_h^g = \left(b_g^f - b_h^f\right)$					
$g \setminus h$	2	3_a	3_b	4_a	4_b
1	$+$	?	?	?	?
2		?	?	?	?
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 (a) absence and (b) existence of environmental considerations.[32]

It is evident that nonintervention (UN) is preferable on environmental grounds to intervention via payments coupled to production (FC) in terms of both input usage and set-aside fraction. In particular, the UN regime involves less both input and land usage compared to the FC regime since it can be easily verified that it holds:[33]

$$\begin{aligned} \pi_x^1(\mathbf{x}_2^*, b_2^{*f}) &= \left\{P(1+s)\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial x} - w\right\} - Ps\frac{\partial f(\cdot)}{\partial x} = \\ = \quad -Ps\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial x} &< 0 \\ \pi_{b^f}^1(\mathbf{x}_2^*, b_2^{*f}) &= \left\{-P(1+s)\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial L_i^c}\right\} + Ps\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial L_i^c} = \\ = \quad Ps\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial L_i^c} &> 0 \end{aligned}$$

[32] The indication ($-$) in the table of Δx_h^g implies that the regime h involves higher usage of a given input j $\left(\Delta x_h^g < 0\right)$, while the same indication in the table of $\Delta\left(b^f\right)_h^g$ denotes that under the same regime more land is set aside $\left(\Delta\left(b^f\right)_h^g < 0\right)$. Moreover, (0) denotes that no deviation in the given production choice is observed between the examined regimes, while (?) denotes that there is uncertainty regarding the relative performance of the examined regimes.

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

. Hence,

Remark 3 *The FC regime is clearly environmentally inferior compared to the rest CAP regimes in terms of input usage, its relative performance in terms of set-aside fraction is ambiguous*

In the same context,[34]

Remark 4 *Intervention via decoupled payments (FD) is environmentally preferable in terms of both inputs and set-aside to intervention via a combination of coupled and decoupled payments (PD) under both the absence and presence of farming standards, indicating the distorting role of production subsidies on farmer's production choices.*

Remark 5 *The incorporation of farming standards within the regime of direct payments has enhanced the environmental performance of the compliant farmer under both partial and full decoupling CAP regimes,*[35] *while there is associated uncertainty about their exact impact on the production choices of the deviation farmer under these regimes.*[36] *There is no doubt that the provision of direct payments, as well as the introduction of farming constraints have restrained input usage compared to the UN and FC regime, however, their final impact on set-aside fraction is ambiguous due to the fact that they are associated with alternative and conflicting land usages.*

The given procedure can be further employed to compare the compliant and deviating behavioral rules in terms of farmer's production choices. Therefore, the marginal profits of the input j and b^f under the deviating strategy, evaluated at the equilibrium values x_j^* and b_*^f of the compliant strategy are given as:

[34] It can be easily verified that under both behavioral rules $x_{3a} > x_{4a}$ and $b_{3a}^f < b_{4a}^f$, as well as $x_{3b} > x_{4b}$ and $b_{3b}^f < b_{4b}^f$, given the financial benefits resulting from increased production under the provision of payments coupled to production.

[35] It holds $x_{3a}^* > x_{3b}^*$ and $b_{3a}^{f*} < b_{3b}^{f*}$, as well as $x_{4a}^* > x_{4b}^*$ and $b_{4a}^{f*} < b_{4b}^{f*}$.

[36] The uncertainty is located on the relative impact of environmental considerations on the deviating farmer's set-aside decision since it holds $x_{3a}^{\#} > x_{3b}^{\#}$ and $b_{3a}^{f\#} \lesseqgtr b_{3b}^{f\#}$, as well as $x_{4a}^{\#} > x_{4b}^{\#}$ and $b_{4a}^{f\#} \lesseqgtr b_{4b}^{f\#}$.

$$\pi_{x_j}^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) = \tag{2.12}$$
$$\{\sigma_1 L_{i*}^c p\gamma - \lambda_1\} \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(\mathbf{x}_{ij}^*, L_{i*}^c)}{\partial x_j}$$

$$\pi_{b^f}^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) = \tag{2.13}$$
$$\sigma_1 p\gamma \left[(\bar{Q}_i - Q_i^*) - \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(\mathbf{x}_{ij}^*, L_{i*}^c)}{\partial L_i^c} L_{i*}^c \right]$$
$$+\lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i^*}{\partial L_i^c} - \lambda_2 - \sigma_2 p\gamma \left[(\bar{L}_i - L_{i*}^c) - 2\left(\bar{L}_i - \tilde{L}^c\right) \right]$$

It is evident that if the partial or full decoupling CAP regime is characterized by non-enforcement of land quality and land usage constraints, in the sense that either no inspection is realized to verify compliance ($p = 0$) or no detected deviating farmer is penalized ($\gamma = 0$), then the deviating strategy involves environmentally inferior production choices.[37] However, such a performance is expected also to occur under the existence of a lax cross-compliance enforcement mechanism. Therefore the introduction of an enforcement mechanism under Agenda 2000 CAP regime may not be sufficient itself to induce deviating farmers to adopt a complying behavior. Hence:

Remark 6 *In the absence of the cross-compliance mechanism or under the existence of a lax enforcement mechanism the relationship between the production choices of the compliant and deviation farmer are characterized by:*

$$\pi_x^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) > 0 \quad \textit{with } \mathbf{x}_{ij}^* < \mathbf{x}_{ij}^{\#} \textit{ and}$$
$$\pi_{b^f}^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) < 0 \quad \textit{with } b_{i*}^f > b_{i\#}^f \quad \textit{if } p \textit{ or } \gamma \geq 0$$

where p, γ are sufficiently small if considered to be nonzero.[38]

It is worth mentioning that under the generalized CAP regime the signs of (2.12) and (2.13) are uncertain, implying that in equilibrium the deviating behavioral rule may involve less input usage

[37] In such a case the conditions (2.12) and (2.13) reduce into: $\pi_x^{NC}(x^*, b_*^f) = -\lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(x^*, L_*^c)}{\partial x}$ and $\pi_{b^f}^{NC}(x^*, b_*^f) = -\lambda_2 + \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(x^*, L_*^c)}{\partial L^c}$, that both are positive expressions.

[38] 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.

and higher set-aside fraction compared to the compliant behavioral rule.[39] In particular, the deviating farmer applies less inputs $\mathbf{x}_{ij}^{\#}$ compared to a compliant farmer either if the the land quality constraint (2.3) is nonbinding involving $\lambda_1 = 0$, or if the marginal costs in terms of forgone direct payment on land usage $\left(\sigma_1 L_*^c p\gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial x_j}\right)$ resulting from a marginal increase of input usage are higher than the associated marginal benefits from the nonattainment of the land quality constraint $\left(-\lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial x_j}\right)$. Similarly the deviating behavioral rule involves higher set-aside fraction if the cost-benefit analysis indicates that a marginal decrease in the size of cultivated land stimulates higher marginal benefits than costs.

2.5 Optimal Regulation under the CMOs Regime

In this section we examine the problem of optimal regulation. This means that the instruments of CAP defined as fixed parameters in the previous sections are chosen so that a social welfare indicator is maximized. Although this is a normative approach and the results might not be directly applicable due to informational, technical or even political constraints, we include this type of analysis since it provides a measure of assessing the structure of a given regulatory regime in comparison to some ideal regime.

We start by setting up the appropriate modelling framework. Individual emission flows do not only affect individual land quality but also aggregate land quality $\left(Q^T\right)$ defined as:

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

Deviations of the aggregate land quality from a given reference level $\left(\bar{Q}^T\right)$ impose external social costs on society in terms of both natural environment (e.g. ecosystem services) and human health consequences. Hence, the social damage is given by:

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

[39] This implies that $\pi_x^{NC}(x^*) < 0$ and $\pi_{b^f}^{NC}(b_*^f) > 0$ with $x^* > x^{\#}$ and $b_*^f < b_{\#}^f$.

where for simplicity let $\left(\bar{Q}^T - Q^T\right) = Z$.[40]

We analyze the optimal regulation problem by considering the case of a social planner wishing to define the vectors of production choices $\left(\bar{\mathbf{x}}^{SP}, \bar{\mathbf{b}}^f_{SP}\right)$ that maximize the net social benefit from agricultural activities,[41] given as the sum of consumers' and farmer's surplus from agricultural production less the associated social damage:[42]

$$\max_{x,b^f} \int_0^{\sum y} F(u)du - \mathbf{w_j}\bar{\mathbf{x}} - D(Z) \tag{2.14}$$

where u denotes the aggregate crop yields $(\sum_{i=1}^n f(\mathbf{x}_{ij}, L_i^c))$ and hence $F(u)$ the aggregate demand of the crop. By the term $\mathbf{w}_j\mathbf{x}$ is represented the aggregate costs from the purchase of the m inputs $\left(i.e.\ \sum_{i=1}^n \sum_{j=1}^m \mathbf{w}_{ij}\mathbf{x}_{ij}\right)$.

The associated Kuhn-Tucker necessary conditions are given by:

$$FOC_{x_i}^{SP} : P\frac{\partial f}{\partial x_i} - w + \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x_i} = 0 \tag{2.15}$$

$$\text{if } x_i^{SP} > 0, \text{or } \frac{\partial SW}{\partial x} < 0 \qquad \text{if } x_i^{SP} = 0$$

$$FOC_{b_i^f}^{SP} : -P\frac{\partial f}{\partial L_i^c} - \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L_i^c} \text{ if } b_{iSP}^f > 0 \tag{2.16}$$

$$\text{or } \frac{\partial SW}{\partial b_i^f} < 0 \qquad \text{if } b_{iSP}^f = 0$$

The conditions (3.20) and (3.21) define the socially optimal equilibrium values for the input usage vector $\mathbf{x}_i^{SP}$ and set-aside fraction b_{iSP}^f for each farmer i as:[43]

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[40] It holds $\frac{\partial D(Z)}{\partial Z}, \frac{\partial^2 D(Z)}{\partial Z^2} > 0$, or equivalently $\frac{\partial D(Z)}{\partial Q^T} < 0$ and $\frac{\partial^2 D(Z)}{\partial (Q^T)^2} > 0$.

[41] Let $\bar{\mathbf{x}}^{SP} = \left(\mathbf{x}_1^{SP}, \mathbf{x}_2^{SP}, ..., \mathbf{x}_n^{SP}\right)$ and $\bar{\mathbf{b}}^f_{SP} = \left(\left(b^f_{SP}\right)_1, \left(b^f_{SP}\right)_2, ..., \left(b^f_{SP}\right)_n\right)$ are vectors of the socially optimal input and set-aside choices of the $1 = 1, 2, ..., n$ individual farmer.

[42] Equivalently the problem could be defined in terms of a Stackelberg leader-follower problem. In such a case, the regulator (Stackelberg leader) chooses the CAP instruments: $s, \sigma_1, \sigma_2, \gamma, \bar{Q}_i, b^R, p, q$.

[43] It is assumed that the signs of the principle minors of the Hessian matrix evaluated

$$\mathbf{x}_i^{SP}(P,w) \quad \text{and} \quad b_{iSP}^f(P,w)$$

If socially optimal production choices are adopted by each farmer i then the first-best level of aggregate land quality Q_{SP}^T occurs.

It is evident that inputs need to be applied up to the point that marginal market revenues $\left(P\frac{\partial f(\mathbf{x},L_i^c)}{\partial x_j}\right)$ are equated with marginal costs from the purchase of j input (w_j) and the associated land quality deterioration $\left(\frac{\partial D(\cdot)}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x_j}\right)$. Similarly, land needs to be set-asided up to the point that marginal revenues in terms of reduced social damage due to enhanced land quality are equated with marginal costs in terms of foregone market revenues due to the shrink of cultivated land area.

It is worth mentioning that the condition (3.21) is considered to involve an interior solution for the socially optimum fraction of set-asided land, in the sense that $b_{SP}^f > 0$. However, this cannot always be the case since if $\frac{\partial SW}{\partial b^f} < 0$ occurs then the solution for the socially optimum fraction b_{SP}^f is on the boundaries $\left(i.e.\ b_{SP}^f = 0\right)$ and any increase of the set-asided land by farmer i involves a reduction of the social welfare.[44]

The evaluation of the individual marginal profits of x_{ij} and b_i^f under both the compliant and deviating strategy at the socially optimum equilibrium values x_{ij}^{SP} and b_{iSP}^f, indicated that depending on the cost-benefit comparison both behavioral rules may involve environmentally superior production choices compared to the social optimum. Nevertheless, in the forthcoming analysis it is assumed that the production choices of the compliant farmer match with the socially optimum choices (i.e. $\pi_x^C(\mathbf{x}_i^{SP}, b_{SP}^f), \pi_{b^f}^C(\mathbf{x}_i^{SP}, b_{SP}^f) = 0$),[45]

---

at the equilibrium pair $\left(\mathbf{x}^{SP}, b_{SP}^f\right)$ are $|H_1| < 0$ and $|H_2| > 0$, in order to guarantee that the defined pair achieves the maximum.

[44] Hence, if in a certain case the marginal productivity of land $\left(\frac{\partial f(\cdot)}{\partial L_i^c}\right)$ is too high or if its marginal social damage is too low, then the Agenda 2000 CAP reform is suboptimal given that land usage constraint incorporated in the direct payments regime. However, this might not be relevant in reality and in order to avoid complexities in the forthcoming analysis it is assumed that b_{SP}^f is nonzero.

[45] However, it is evident that in the presence of nonbinding performance standards (i.e. $\lambda_1, \lambda_2 = 0$) the compliant strategy involves higher input usage, while there is uncertainty about the relationship between the individual and social optimum land-usage fraction.

while the uncertainty about the relative performance of the deviating farmer is retained.

2.5.1 Assessment of Optimal CMOs CAP Measures

The optimality conditions of the social planner and deviating farmer i define a system the solution of which provides the form of the CAP instruments that induce the later to adopt the socially optimal production choices $\left(\mathbf{x}_i^{SP}, b_{SP}^f\right)$, as well as allows the determination of the type of correlation between the elements of the Agenda 2000 CAP reform. The system is given as:[46]

$$P(1+s)\alpha_1^{\#} + \sigma_1 L_{\#}^c p\gamma\beta_1^{\#} = P\alpha_1^{SP} + \delta_1 \tag{2.17}$$

$$\alpha_2^{SP}\left[\sigma_2\left\{1 - p\gamma B\right\} - \sigma_1\left\{1 - p\gamma A\right\}\right] = -(1+s)\alpha_2^{\#}\delta_2 \tag{2.18}$$

To simplify analysis the set of production choices of the farmer i is reduced into a single input (x) and the set-aside decision. Nevertheless, such an assumption introduces indeterminacy in the definition of optimal CAP instruments,[47] implying that by the system (2.17) and (2.18) the optimal values only for two CAP measures can be assessed for fixed values of the remaining CAP measures.

Consider the following cases of socially optimal CAP pairs:

Pair 1^{st}: Production subsidy and land usage premium

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[46] Let $\alpha_1^{SP}, \alpha_2^{SP}, \beta_1^{SP}, \beta_2^{SP}$ 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. In particular, it holds:

$\alpha_1^{SP} = \frac{\partial f(\mathbf{x}^{SP}, L_{SP}^c)}{\partial x}$, $\alpha_2^{SP} = \frac{\partial f(\mathbf{x}^{SP}, L_{SP}^c)}{\partial L^c}$ and $\beta_1^{SP} = \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}, L^c)}{\partial x}$, $\beta_2^{SP} = \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}, L^c)}{\partial L^c}$

$\alpha_1^{\#} = \frac{\partial f(\mathbf{x}^{\#}, L_{\#}^c)}{\partial x}$, $\alpha_2^{\#} = \frac{\partial f(\mathbf{x}^{\#}, L_{\#}^c)}{\partial L^c}$ and $\beta_1^{\#} = \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}^{\#}, L_{\#}^c)}{\partial x}$, $\beta_2^{\#} = \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}^{\#}, L_{\#}^c)}{\partial L^c}$

$\delta_1 = \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}^{SP}, L_{SP}^c)}{\partial x}$ and $\delta_2 = \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}^{SP}, L_{SP}^c)}{\partial L^c}$ which at the equilibrium are known and thus treated as parameters.

Also, let $A = \left[\left(\bar{Q}_i - Q_i(\cdot)\right) - \beta_2 L_{i\#}^c\right]$ and $B = \left\{1 - p\gamma\left(2(\bar{L}_i - L_{i\#}^c) - \left(\bar{L}_i - \tilde{L}^c\right)\right)\right\}$.

[47] Such an indeterminacy occurs because the number of instruments is higher than the number of externalities. A unique determination of policy instruments could be feasible if the number of production choices is equal to the number of instruments.

$$\bar{s} = \frac{1}{P\alpha_1^{\#}} \left[P\left(\alpha_1^{SP} - \alpha_1^{\#}\right) + \delta_1 - \bar{\sigma}_1 L_{\#}^c p\gamma\beta_1^{\#} \right] \tag{2.19}$$

$$\bar{\sigma}_1 = \tag{2.20}$$

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

The fact that the sign of both expressions is uncertain,[48] entails that the simultaneous cancellation of coupled payments and direct payments paid on cultivated land is socially optimal only if both nominators are equal to zero. In such a case it is evident that non-intervention is the preferred CAP regime if no set-aside premium is provided (i.e. $\sigma_2 = 0$), while if $\sigma_2 \neq 0$ then the recommended CAP regime should be characterized only by the provision of set-aside premiums. On the other hand, if both (2.19) and (2.20) is nonzero then intervention via partially decoupled measures is indicated, which may involve charges on both crop yields and land usage if both nominators are nonpositive. However, such kind of penalties are not foreseen by the current structure of CAP justifying suboptimalities in the configuration of farmer's production choices.

Consequently,

Remark 7 *The European Commission's decision to proceed gradually in the cancellation of coupled payments is the socially optimum decision only if:*

$$P\left(\alpha_1^{SP} - \alpha_1^{\#}\right) - \bar{\sigma}_1 L_{\#}^c p\gamma\beta_1^{\#} = \delta_1 \tag{2.21}$$

when $\alpha_1^{SP} \geq \alpha_1^{\#}$*, or*

$$P\left(\alpha_1^{SP} - \alpha_1^{\#}\right) + \delta_1 = -\bar{\sigma}_1 L_{\#}^c p\gamma\beta_1^{\#} \tag{2.22}$$

when $\alpha_1^{SP} < \alpha_1^{\#}$

According to (2.21) this can be the case if the marginal revenues from the adoption of the social optimum input usage value $\left(x^{SP}\right)$

[48] In both expressions the denominators are positive, while the sign of the nominators is uncertain.

defined in terms of additional market revenues $\left(\alpha_1^{SP} \geq \alpha_1^{\#}\right)$ and retained land usage direct payments are equal to marginal costs in terms of incurred social damage. Similarly, the expression (2.22) implies that the retained land usage direct payment must be equal to marginal cost in terms of foregone market revenues $\left(\alpha_1^{SP} < \alpha_1^{\#}\right)$ and incurred social damage.

Given that a marginal change in the value of a given CAP measure alters the farmer's production choices, the optimal CAP pair $(\bar{s}, \bar{\sigma}_1)$ needs to be modified analogously in order to retain farmer i at the social optimum level of production choices. To do so, the total derivatives of (2.19) and (**??**) with respect to the rest CAP measures are assessed, providing the type of interdependencies between the optimal CAP pair and the rest elements of 1999 reform:[49]

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

It is evident that the optimum CAP measures $\bar{\sigma}_1$ and $\bar{s}$ are characterized by interdependence, since the impact of a given CAP element on the optimum coupled payment is affected by its prior impact on the optimum land usage premium. Unfortunately, the type of correlation between the optimum CAP measures and the most CAP elements is uncertain and can be assessed only under restrictive assumptions.[50] Nevertheless, it is clear that the optimum land usage

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

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

premium $\bar{\sigma}_1$ is negatively correlated to the land usage constraint constant b^R, while there is complementarity between the optimal pair $(\bar{\sigma}_1, \bar{s})$ and the set-aside premium σ_2 if $\left(\bar{L}_i - L_i^c\right) \geq \left(\left(\bar{L}_i - \tilde{L}^c\right) \big/ 2\right)$.

Under non-enforcement of environmental requirements the optimum land usage premium and land-set-aside premium are characterized by a definite positive, "one-to-one" relation, while uncertainty remains about the exact impact of the land quality constraint constant $\bar{Q}_i'$ and the inspection probability p on $\bar{s}$. Changes of the values of the rest CAP elements leave the optimal CAP pair intact, indicating absence of interdependence.[51]

It is evident that:

Remark 8 *Given that the type of interdependence cannot be clearly inferred for all the CAP measures, the maintenance of the socially optimum production choices is difficult since the optimal CAP pair may not be always modified properly to changes of the rest CAP measures inducing suboptimalities.*

Pair 2^{nd}: Production subsidy and set-aside premium

$$\bar{\sigma}_2 = \frac{\left\{\alpha_2^{SP}\sigma_1\left(1 - p\gamma A\right) - \alpha_2^{\#}\delta_2\left(1 + \bar{s}\right)\right\}}{\left\{\alpha_2^{SP}\left(1 - p\gamma B\right)\right\}} \tag{2.23}$$

$$\bar{s} = \frac{1}{P\alpha_1^{\#}}\left[P\left(\alpha_1^{SP} - \alpha_1^{\#}\right) + \delta_1 - \sigma_1 L_{\#}^c p\gamma\beta_1^{\#}\right] \tag{2.24}$$

The sign of the expression (2.23) is uncertain,[52] implying that the provision of a set-aside premium may not always be the socially optimal type of intervention. In particular, if the denominator is negative then it is socially optimal to impose on farmers a charge to prevent excessive land-set-aside behavior.[53] Nevertheless, in the absence of an enforcement mechanism of performance standards the optimal CAP pair $(\bar{s}, \bar{\sigma}_2)$ involves definitely a set-aside premium. Hence, given that

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and $\bar{s}$.

[51] The optimum pair $(\bar{\sigma}_1, \bar{s})$ is inflexible to b^R. Similarly, $\bar{\sigma}_1$ is inflexible to $\bar{Q}_i'$ and p, while the same occurs between the $\bar{\sigma}_1$ and set-aside premium.

[52] The nominator is positive, while the sign of the denominator is ambiguous.

[53] This requires that $\left(\bar{L} - L^c\right) > \left(\left(\bar{L} - \tilde{L}^c\right) \big/ 2\right)$.

the sign of the expression (2.24) is also uncertain, the socially desired CAP regime may involve either nonintervention,[54] intervention via land usage premiums[55] or intervention via partially decoupled payments[56] that may involve either subsidies or charges on both crop yields and land set aside.

The type of correlations between the optimum pair $(\bar{s}, \bar{\sigma}_2)$ and the rest CAP measures is given by:[57]

$$\begin{aligned}
\frac{d\bar{\sigma}_2}{d\sigma_1} &= \frac{U}{\alpha_2^{SP}(1-p\gamma B)} \text{ and } \frac{d\bar{s}}{d\sigma_1} = \frac{1}{P\alpha_1^{\#}}\left[-p\gamma\beta_1^{\#}L_{\#}^{c}\right] \\
\frac{d\bar{\sigma}_2}{d\bar{Q}_i'} &= \frac{-\sigma_1\alpha_2^{SP}p\gamma}{\alpha_2^{SP}(1-p\gamma B)} \text{ and } \frac{d\bar{s}}{d\bar{Q}_i'} = 0 \\
\frac{d\bar{\sigma}_2}{db^R} &= \frac{\alpha_2^{SP}p\gamma\bar{L}_iV}{\left(\alpha_2^{SP}(1-p\gamma B)\right)^2} \text{ and } \frac{d\bar{s}}{db^R} = 0 \\
\frac{d\bar{\sigma}_2}{dp} &= \frac{\gamma W}{\alpha_2^{SP}(1-p\gamma B)} \text{ and } \frac{d\bar{s}}{dp} = \frac{1}{P\alpha_1^{\#}}\left[-\sigma_1\gamma\beta_1^{\#}L_{\#}^{c}\right]
\end{aligned}$$

where the optimum coupled payment $\bar{s}$ is positively correlated with the land usage premium σ_1 and inspection probability p (or γ), while it is inflexible to changes of both constraint constants. On the other hand, the final impact of both σ_1 and $\bar{Q}_i'$ on the optimum set-aside premium $\bar{\sigma}_2$ is dependent on the relation between the voluntarily and compulsory set-aside land, while the impact of the constraint constant b^R and the probability p (or γ) on $\bar{\sigma}_2$ is ambiguous. Finally, inflexibility of the optimum CAP pair to changes of the most CAP measures is assessed under the nonenforcement of environmental requirements.

Pair 3^{rd}: Production subsidy and cross-compliance reduction rate[58]

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[54] This requires that the denominator of (2.23) and the nominator of (2.24) are both zero, as well as that $\sigma_2 = 0$.

[55] It requires that both the denominator of (2.23) and the nominator of (2.24) are zero, as well as that $\sigma_2 \neq 0$.

[56] The denominator of (2.23) and the nominator of (2.24) must be both nonzero.

[57] Let $U = \left(\alpha_2^{SP}(1-p\gamma A) + \frac{\alpha_2^{\#}}{P\alpha_1^{\#}}\delta_2 L_{\#}^{c} p\gamma\beta_1^{\#}\right) > 0$

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

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

[58] The inspection probability $\bar{p}$ can be equivalently assessed by replacing γ by the term

$$\bar{\gamma} = \tag{2.25}$$
$$\frac{\left\{\alpha_2^{SP}(\sigma_1-\sigma_2)+\frac{\alpha_2^{\#}}{\alpha_1^{\#}}\left[\delta_2\left(\alpha_1^{SP}-\alpha_1^{\#}\right)+\frac{1}{p}\delta_1\delta_2\right]+\alpha_2^{\#}\delta_2\right\}}{\left\{p\left[\alpha_2^{SP}\left(\sigma_2 B-\sigma_1 A\right)+\sigma_1 L_{\#}^{c}\beta_1^{\#}\delta_2\frac{\alpha_2^{\#}}{P\alpha_1^{\#}}\right]\right\}}$$

$$\bar{s} = \frac{1}{P\alpha_1^{\#}}\left[P\left(\alpha_1^{SP}-\alpha_1^{\#}\right)+\delta_1-\sigma_1 L_{\#}^{c} p\bar{\gamma}\beta_1^{\#}\right] \tag{2.26}$$

The sign of the expression (2.25) is uncertain,[59] implying that under certain circumstances it is socially desirable not only to retain the full amount of provided direct payments but also to increase the provided amount. Moreover, if the nominator is equal to zero then no action should be undertaken to enforce the performance standards since it is socially optimal either to realize no inspections ($\bar{p}=0$) or equivalently to proceed in no reduction of direct payments ($\bar{\gamma}=0$).[60] Finally, the relative impacts of the rest CAP measures on the social optimum pair $(\bar{s},\bar{\gamma})$ is ambiguous and the type of correlation is highly dependent on assumptions.

Given the farmers' heterogeneity the first-best level of aggregate land quality Q_{SP}^{T} is attainable if the CAP measures are applied in a nonuniform base among the European farmers. This implies that different sets of CAP measures adapted to farmers' individual characteristics, should be defined so that the socially optimal production choices $\left(x_i^{SP}, b_{iSP}^{f}\right)$ are adopted by each farmer.[61] However, analysis indicated that:

Remark 9 *For some farmers the social optimum set of CAP measures may need to involve instruments that are not foreseen by the current structure of CAP (i.e. penalties dealing with the various aspects of farming activity). In such a case the adoption of socially*

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p.

[59] The sign of both the nominator and denominator is uncertain.

[60] It is worth mentioning that if the nominator and denominator have reverse signs then by definition there is nonpositive solution for the inspection probability, while in the absence of an inspection regime then the cross-compliance reduction rate γ cannot be defined.

[61] If the total types of farmers in the EU is n then n different pairs of CAP measures should be defined.

optimal production choices is not feasible by all farmers and hence the first-best level of aggregate land quality is unattainable.

Nevertheless, it needs to be stressed out that even if such measures where foreseen by CAP such a type of farm-specific policy is practically infeasible since it requires knowledge of each farmer's attributes fact that involves high informational or / and administrative requirements.

2.6 Assessment of CAP regimes in a Dynamic Context

In this section the problem of the social planner is discussed in a dynamic context in order to assess the problem of the optimal regulation in a dynamic context. Furthermore, the policy effectiveness of Agenda 2000 CAP reform is assessed in a dynamic context using an evolutionary framework that allows the joint definition of the type and range of values of the given CAP measures that induce the majority or even all the farmers to adopt the compliant behavioral rule.

2.6.1 Optimal CMOs CAP measures in a Dynamic Framework

Consider that the social planner pursues to define the optimal path of both production choices $\mathbf{x}^{SP}$ and $\mathbf{b}^{f}_{SP}$ that maximize the discounted value of the net social benefit from agricultural activities subject to a transition equation describing the evolution of aggregate land quality given by (2.27). In such a case the maximization problem is:[62]

$$\begin{aligned} &\max_{x,b^f} \int\limits_0^\infty e^{-rt} \left[\int_0^{\sum y} F(u)du - \mathbf{wx} - D(Z) \right] dt \\ &st. \quad \dot{Q}^T = b\left(Q^T\right) - g(\mathbf{x}, \mathbf{L}^C) \end{aligned} \tag{2.27}$$

[62] Let $\mathbf{x}^{SP} = \left(x_1^{SP}, x_2^{SP}, ..., x_n^{SP}\right)$ and $\mathbf{b}^f_{SP} = \left(b^f_{1SP}, b^f_{2SP}, ..., b^f_{nSP}\right)$ represent the vectors of the dynamic socially optimal input and set-aside choices of the $1 = 1, 2, ..., n$ individual farmer.

where $P = F(u)$ is an inverse demand curve, $\int_0^{\sum y} F(u)du$ denotes willingness to pay, or area under the demand curve, $g(x, L^C)$ represents the collective emissions generated each period t and $b\left(Q^T\right)$ the natural ability to enhance land quality characterized by. $\frac{\partial b}{\partial Q} > 0$ for $Q < \bar{Q}$ and $\frac{\partial b}{\partial Q} < 0$ for $Q > \bar{Q}$, while $\frac{\partial^2 b}{\partial Q^2} < 0$.[63]

The current value Hamiltonian function is defined as:

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

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:[64]

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

while the Arrow type transversality condition at infinite is:

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

Under the simplifying assumption that farmers systematically ignore the evolution of aggregate land quality Q^T (i.e. myopic informa-

[63] Where $\mathbf{L}^C = (L_1^c, L_2^c, ..., L_n^c)$ is the vector of individual choices regarding land usage. Moreover, aggregate emissions flows can be represented by the sum of individual emission flows, implying that $g(\mathbf{x}, \mathbf{L}^C) = \sum_{i=1}^n e_i(x_i, L_i^c)$.

[64] The comparison of the social planner's optimality conditions under the static and dynamic setup provides that the static socially optimal production choices involve less input and land usage: $x_{dyn}^{sp} >.x_{stat}^{sp}$ and $b_{dyn}^f < b_{stat}^f$.

tional structure)[65] the system by which the dynamic social optimum CAP pairs are assessed is:[66]

$$P(1+s)\alpha_1^{\#} + \sigma_1 L_{\#}^c p\gamma\beta_1^{\#} = P\alpha_{1d}^{SP} + \delta_{1d} + \mu\varphi_{1d} \tag{2.28}$$

$$\alpha_{2d}^{SP}\left[\sigma_2\left\{1 - p\gamma B\right\} - \sigma_1\left\{1 - p\gamma A\right\}\right] = \tag{2.29}$$

$$-(1+s)\alpha_2^{\#}\left\{\delta_{2d} - \mu\varphi_{2d}\right\}$$

It is evident that the dynamic system (2.28) and (2.29) is identical to the static system (2.17) and (2.18), indicating that the expressions of the dynamic socially optimum CAP measures are identical to the static optimal expressions. The only modification is the incorporation of the Hamiltonian multiplier (μ) which in a static context is equal to zero[67].

2.6.2 Dynamic CMOs CAP Measures and Farmers' Compliance

The assessed dynamic socially optimum set of CAP instruments $(\bar{s}, \bar{\sigma}_1, \bar{\sigma}_2, \bar{p}, \bar{\gamma})$ is provided to a population of n homogeneous farmers. If farmers take the set of instruments as given then the socially optimum production choices $\left(x_i^{SP}, L_{iSP}^c\right)$ are adopted, inducing full integration of environmental considerations into individual behavior. Nevertheless, it is likely that farmers may perceive that the announced enforcement mechanism (p, γ) is not enforceable and that both the anticipated inspection probability (p^a) and cross-compliance

[65] Given that the evolution of aggregate land quality is treated as fixed farmers face a static problem defined either by (2.5) or (2.6), accordingly to the adopted behavioral rule.

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

$\alpha_{1d}^{SP} = \frac{\partial f(\mathbf{x}^{SP}, L_{SP}^c)}{\partial x}$, $\alpha_{2d}^{SP} = \frac{\partial f(\mathbf{x}^{SP}, L_{SP}^c)}{\partial L^c}$ and

$\delta_{1d} = \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}^{SP}, L_{SP}^c)}{\partial x}$, $\delta_{2d} = \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}^{SP}, L_{SP}^c)}{\partial L^c}$ and

$\phi_{1d} = \frac{\partial g}{\partial e_i}\frac{\partial e_i(\mathbf{x}^{SP}, L_{SP}^c)}{\partial x_i}$, $\phi_{2d} = \frac{\partial g}{\partial e_i}\frac{\partial e_i(\mathbf{x}^{SP}, L_{SP}^c)}{\partial L_i^c}$.

[67] The dynamic socially optimal CAP instruments can be also assessed under the open-loop (OL) or feed-back (FB) informational structure. This implies that farmers take into account the evolution of aggregate land quality into their maximization problem, which is no longer static. In particular, under the OL behavioral rule the farmer i treats the emission path of the rest farmers as fixed at the best response, while under the FB behavioral rule he perceives that the rest farmers take into account the current state of the system. However,such informational contexts are not examined in this chapter.

reduction rate (γ^a) are either sufficiently small or even equal to zero. In such a case a suboptimal pair of production choices $\left(x^{\#}, L^c_{\#}\right)$ is adopted, stimulating a deviation from the land quality and usage environmental standards. Consequently, if:[68]

$$(\bar{p}, \bar{\gamma}) > (p^a, \gamma^a) \geq 0 \quad \text{then} \quad (x^*_i, L^c_{i*}) < \left(x^{\#}_i, L^c_{i\#}\right)$$

and the population of farmers is divided into two subgroups, where z is the proportion of farmers adopting the compliant behavioral rule while $(1 - z)$ is the remaining proportion that deviates from defined farming standards incorporated in the direct payment regime.

It is assumed that although farmers are profit maximizers in the output choice, they adopt a passive decision making and not an explicit optimizing behavior when it comes to choose the strategy regarding compliance with or deviation from environmental requirements. Particularly, in every time period dt there is a positive probability adt that a farmer i, following a certain strategy, will compare its profits and consequently its strategy, with the corresponding profits and strategy of another randomly chosen farmer j.[69] If farmer i perceives that the farmer j's profits are sufficiently higher, then it switches its strategy. There is imperfect information concerning the difference in the expected profits of the two strategies, since there is uncertainty in the law determining the probability of legislation and possible uncertainty regarding the true cost functions. In this context the higher the profits difference is, the higher the probability is that farmer i will change strategy.

Henceforth, under the regime of CAP provisions the farmer i that did not comply with farming standards at time t, might decide to switch strategy and comply with the land quality and usage constraints if his expected profits π^{NC}_i, defined by (2.9), are less than the profits π^C_i of the complying farmer. The probability that a deviating farmer changes his strategy and ultimately complies with the

[68] It is assumed that the optimum production choices under the compliant behavioral rule are identical with the socially optimum production choices, involving that $(x^*, L^c_*) = \left(x^{SP}, L^c_{SP}\right)$.

Even though the conditions (2.12) and (2.13) indicated that there is uncertainty regarding the divergence of the two strategies in terms of input usage $\Delta^*_{\#}(x)$ and land usage $\Delta^*_{\#}(L^c)$, it assumed that $x^* < x^{\#}$ and $L^c_* < L^c_{\#}$ in order to avoid complexities in the forthcomming analysis.

[69] In motivating the replicator dynamics we follow Gindis (2000).

environmental requirements involved by horizontal regulation, after comparing profits, is given as:

$$P_{NC}^{t} = \begin{cases} \beta\left[\pi_i^C - \pi_i^{NC}\right] & \text{for } \pi_i^C > \pi_i^{NC} \\ 0 & \text{for } \pi_i^C \leq \pi_i^{NC} \end{cases}$$

The expected proportion of farmers that decide to comply at time $t + dt$ is:

$$\mathcal{E}z^{t+dt} = z^t + \alpha dt z^t \sum_{j=1}^{n} z_N \beta(\pi_i^{NC} - \pi_i^C)$$

$$\mathcal{E}z^{t+dt} = z^t + \alpha dt z^t \beta(\pi_i^C - \bar{\Pi}(x, L_i^c))$$

where $\bar{\Pi}(x, L_i^c)$ denotes average profits for the whole population, defined by:

$$\bar{\Pi}(x, L_i^c) = z\pi_i^C + (1 - z)\pi_i^{NC} \tag{2.30}$$

The population of farmers is assumed to be large and thus Ez^{t+dt} can be replaced by z^{t+dt}. Moreover, if we subtract from both sides the term z^t, divide by dt and finally take the limit as $dt \to 0$, an equation that describes the behavior of the fraction z over time is derived:

$$\dot{z} = \alpha\beta z^t \left[\pi_i^C - \bar{\Pi}(x, L_i^c)\right]$$

which is the replicator dynamics equation indicating that the frequency of the compliant strategy increases when its profits π_i^C are above the average profits $\bar{\Pi}(x, L_i^c)$. If we substitute from (2.30) then under the generalized CAP regime the replicator dynamics equation of the compliant strategy is rewritten as:

$$\begin{aligned} &\dot{z} = z\,(1 - z)\left(\pi_i^C - \pi_i^{NC}\right) \qquad (2.31)\\ &\textit{with}\\ &\pi_i^C - \pi_i^{NC} = P(1 + s)\Delta_{\#}^{*}(f(x, L_i^c)) - w\Delta_{\#}^{*}(x) + (\sigma_1 - \sigma_2)\,\Delta_{\#}^{*}(L_i^c)\\ &\qquad\qquad + p\gamma\left[\sigma_1 L_{\#}^c\left(\bar{Q}_i - Q_i(x, L_{\#}^c)\right) + \sigma_2\left(\bar{L}_i - L_{\#}^c\right)\left(L_{\#}^c - \tilde{L}^c\right)\right] \end{aligned}$$

where $\left(\pi_i^C - \pi_i^{NC}\right)$ is the divergence between the payoff of the compliant and deviating behavioral rule that consists of the following elements:

- $P(1+s)\Delta_{\#}^*(f(x, L_i^c))$: the divergence of the two strategies in terms of market revenues and coupled payments.
- $w\Delta_{\#}^*(x)$: the divergence of input purchase costs of the two behavioral rules.
- $(\sigma_1 - \sigma_2)\,\Delta_{\#}^*(L_i^c)$: the divergence of the two behavioral rules in terms of direct payments.
- $p\gamma\left[\sigma_1 L_{\#}^c\left(\bar{Q}_i - Q_i(x, L_{\#}^c)\right) + \sigma_2\left(\bar{L}_i - L_{\#}^c\right)\left(L_{\#}^c - \tilde{L}^c\right)\right]$: the amount of direct payments removed by the farmer i if found into deviation from the environmental considerations incorporated in direct payments regime.

The long-run steady state proportion of compliant farmers ($\hat{z}$) is provided by the solution of the replicator dynamics equation (2.31), indicating either the existence of a monomorphic equilibrium point associated with either full or no compliance or polymorphic equilibrium point which is associated with partial compliance. It is evident that the evolutionary stable critical point is characterized either by full compliance ($\hat{z}_1 = 1$), full deviation ($\hat{z}_2 = 0$) or partial compliance ($\hat{z}_3 \in (0,1)$) if the CAP instruments are equal to the critical values $(\tilde{s}, \tilde{\sigma}_1, \tilde{\sigma}_2, \tilde{p}, \tilde{\gamma})$ that set $\Omega = \left(\pi_i^C - \pi_i^{NC}\right) = 0$. The type of the prevailing steady state is strongly dependent on the profit divergency between the two behavioral rules as it can be seen by the stability condition:

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

Given that the ultimate target of the social planner is to induce full compliance with environmental requirements ($\hat{z}_1 = 1$), it is evident that the stability requirement $\frac{d\dot{z}}{dz}\,|\hat{z}_1 = 1\, < 0$ is satisfied if the expression $\Omega(s, \sigma_1, \sigma_2, p, \gamma)$ is positive. Therefore, the type and the range of values of the various CAP measures that imply $\Omega \geq 0$ can be defined, by assessing the critical values of CAP measures that set Ω equal to zero along with their marginal impact on the expression $\Omega\left(\tilde{s}, \tilde{\sigma}_1, \tilde{\sigma}_2, \tilde{p}, \tilde{\gamma}\right) = 0$.

Two different cases are examined regarding the impact of CAP instruments on production choices:

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 instruments on production choices is negligent. In such a case the type and range of values of the main CAP measures satisfying the requirement $\Omega = 0$ is given as:[70]

- Coupled payment $\tilde{s}$

$$\tilde{s} = \frac{\left[w\Delta^*_{\#}(x) - (\sigma_1 - \sigma_2)\Delta^*_{\#}(L^c_i) - p\gamma\Xi \right]}{P\Delta^*_{\#}(f(x, L^c_i))} - 1 \tag{2.32}$$

$$\frac{d\Omega(\tilde{s})}{ds} = P\Delta^*_{\#}(f(x, L^c_i)) \tag{2.33}$$

Given that $x^* < x^{\#}$ and $L^c_* < L^c_{\#}$ the expression (2.33) is negative implying that the target of full compliance $(\hat{z}_2 = 1)$ is attainable if the coupled subsidy is set within the range $[0, \tilde{s})$.[71] In the special case that s is set equal to the critical value $\tilde{s}$, then the long-run steady state is characterized by partial compliance $(\hat{z}_3)$. It is worth mentioning that:

Remark 10 *If $\sigma_1 \leq \sigma_2$ then the expression (2.32) involves a penalty on crop yields, an instrument which is however not foreseen by the current CAP structure. If such a case occurs then the attainment of the full compliance target is infeasible.*

- Cross-compliance reduction rate $\tilde{\gamma}$

$$\tilde{\gamma} = \frac{\left[w\Delta^*_{\#}(x) - (\sigma_1 - \sigma_2)\Delta^*_{\#}(L^c_i) - P(1+s)\Delta^*_{\#}(f(x, L^c_i)) \right]}{p\sum DP} \tag{2.34}$$

$$\frac{d\Omega(\tilde{\gamma})}{d\gamma} = p\Xi \tag{2.35}$$

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

[71] This requires that the sign of the expression (2.32) is positive.

where equivalent expressions are defined for the critical inspection probability $\tilde{p}$.

Based on (2.35) if the cross-compliance reduction rate lies within the range $(\tilde{\gamma}, 1]$ then the social planner induces all the farmers to adopt the compliant behavioral rule.

- Decoupled payment premiums $\tilde{\sigma}_1$ and $\tilde{\sigma}_2$

$$\tilde{\sigma}_1 = \frac{1}{\Gamma}\left\{w\Delta^*_{\#}(x) - P(1+s)\Delta^*_{\#}(f(x, L^c_i)) + \sigma_2\Theta\right\} \quad \text{with } \frac{d\Omega(\tilde{\sigma}_1)}{d\sigma_1} = \Gamma$$
$$\tilde{\sigma}_2 = \frac{1}{(-\Theta)}\left\{w\Delta^*_{\#}(x) - P(1+s)\Delta^*_{\#}(f(\cdot)) - \sigma_1\Gamma\right\} \quad \text{with } \frac{d\Omega(\tilde{\sigma}_2)}{d\sigma_2} = -\Theta$$

Due to the fact that the sign of both Θ and Γ is uncertain, the type and range of values of direct payments inducing full compliance is dependent on assumptions.[72]

Case 2

The assumption that farmers' production choices are unaffected by changes of CAP instruments is relaxed, implying that the private optimum production choices under the two behavioral rules are defined as:

$$x^*_i(P, w, s, \sigma_1, \sigma_2) \text{ and } b^F_{i*}(P, w, s, \sigma_1, \sigma_2)$$
$$x^{\#}_i(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p) \text{ and } b^F_{i\#}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p)$$

and the replicator dynamic equation (2.31) is modified as follows:

$$\begin{aligned}
&\dot{z} = z\,(1-z)\left(\pi^C_i(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p) - \pi^{NC}_i(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p)\right)\\
&\textit{with}\\
&\Delta^*_{\#}(x) = x^*(P, w, s, \sigma_1, \sigma_2) - x^{\#}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p)\\
&\Delta^*_{\#}(L^c_i) = L^c_*(P, w, s, \sigma_1, \sigma_2) - L^c_{\#}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p)\\
&\Delta^*_{\#}(f(x, L^c_i)) = f(x^*(\cdot), L^c_*(\cdot)) - f(x^{\#}(\cdot), L^c_{\#}(\cdot))
\end{aligned}$$

[72] Let $\Theta = \left[\Delta^*_{\#}(L^c_i) - p\gamma\left(\bar{L}_i - L^c_{\#}\right)\left(L^c_{\#} - \tilde{L}^c\right)\right]$ and $\Gamma = \left[\Delta^*_{\#}(L^c_i) + p\gamma L^c_{\#}\left(\bar{Q}_i - Q_i(x, L^c_{\#})\right)\right]$.

The standardized procedure was repeated to assess the type and range of values of the given CAP instruments satisfying the full compliance requirement: $\Omega(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \bar{Q}_i, p) > 0$. Even though the expressions providing the critical values of the CAP instruments are not modified, the expressions describing their marginal impact on profit divergence Ω are altered and dependent among others on the impact of the examined measure on the farmer's production choices under the alternative behavioral strategies.

In particular, the impact of the critical coupled payment $\tilde{s}$ on $\Omega(\cdot) = 0$ is given by:[73]

$$
\begin{aligned}
&\frac{d\Omega(\tilde{s})}{ds} = \qquad (2.36)\\
&P(1+s)\Delta^*_{\#}\left(\frac{\partial f(x, L_i^c)}{\partial x}\frac{\partial x}{\partial s} - \frac{\partial f(x, L_i^c)}{\partial b^f}\frac{\partial b^f}{\partial s}\bar{L}_i\right) -\\
&(\sigma_1 - \sigma_2)\,\Delta^*_{\#}\left(\frac{\partial b^f}{\partial s}\bar{L}_i\right)\\
&-p\gamma\sigma_1\left\{\begin{array}{c} L^c_{\#}\left(\frac{\partial Q_i^{\#}(\cdot)}{\partial x}\frac{\partial x^{\#}}{\partial s} - \frac{\partial Q_i^{\#}(\cdot)}{\partial b^f}\frac{\partial b^f_{\#}}{\partial s}\right) + \\ \frac{\partial b^f_{\#}}{\partial s}\bar{L}_i\left(\bar{Q}_i - Q_i(x^{\#}, L^c_{\#})\right)\end{array}\right\}\\
&+\sigma_2\frac{\partial b^f_{\#}}{\partial s}\bar{L}_i\left[\left(\bar{L}_i - \tilde{L}^c\right) - 2(\bar{L}_i - L^c_{\#}))\right] - w\Delta^*_{\#}\left(\frac{\partial x}{\partial s}\right)
\end{aligned}
$$

which is dependent on the impact of coupled payment on the production choices, $\frac{\partial x}{\partial s}$ and $\frac{\partial b^f}{\partial s}$, under both behavioral rules. It is evident that the assessment of the sign of (2.36) has high informational requirements, turning the attainment of the target of full compliance difficult even if the critical value of the given CAP measure is known.

It is evident that:

Remark 11 *The attainment of full compliance of a given population of farmers with environmental considerations not only requires farm-specific policy given the farmers' heterogeneity, but also continuous change of the dynamic socially optimal CAP instruments.*

However, given the informational requirements and the political

[73] In a similar way the impacts of the cross-compliance reduction rate $\tilde{\gamma}$ (or equivalently $\tilde{p}$) and decoupled payments $\tilde{\sigma}_1$ and $\tilde{\sigma}_2$ on profit divergence are assessed.

constraints, the defined dynamic CAP instruments must be uniformly applied and either be time invariant or allow for discrete changes over time (i.e. semi-flexible), leading to suboptimal solutions in a dynamic context. This suggests that given the current structure of CAP, the attainment of full compliance of a given population of farmers with environmental considerations might be questioned. Our analysis suggests policy regimes that might induce full compliance.

3

Rural Development CAP Regime: Environmental Impacts and Policy Implications

3.1 Introduction

When CAP was established in the 1950s emphasis was given to the regime of common market organizations due to the keen memories of food shortages of European citizens after the 2nd World war. Given that this target has been attained and the market supply has been stabilized against uncontrolled factors, new challenges dealing with other aspects of agricultural activity has been set to CAP reformers the last decade. A turn towards issues dealing with environment, food safety and quality, animal welfare and vitality of rural life has occurred. These issues are promoted through a package of rural development (RD) measures established under the second pillar of CAP (EC, 1999).

Rural development policy involves a coherent series of measures that complement the market policy reforms (Pillar I) and have turned to be essential for the balanced development of the Union since they aim at promoting the competitiveness and viability of the multifunctional European farming activity in a sustainable way. First established at 1992 under the McSharry report pillar II measures can be distinguished into (i) *early retirement schemes* aiming the renew of labor force through the provision of annual support to farmers and farm workers over the age of 55 years but not yet of retirement age to stop all commercial farming activity definitively and reassigned their land to other farmers or to non-agricultural uses (i.e. forestry, ecological reserves),[1] (ii) *agri-environment programs* providing per hectare

[1] Farmers who retire early must have practised farming for at least 10 years before stopping, while farm workers must have devoted at least half of their working time to farm work during the five years before stopping (EC, 2004). Moreover, they can receive the annual payment up to the retirement age (age of 75), but not for a total period of

supports to farmers that use agricultural production methods designed to protect the environment and maintain countryside (agri-environment) for a minimum five year period[2] and aiming to promote environmental planning, extensification, conservation of farmed environments of high natural value and the upkeep of landscape (EC, 2004a), and (iii) *less-favored areas schemes* involving per hectare compensatory payments to farmers operating in less-favoured areas (i.e. mountain areas,), areas affected by specific handicaps and areas subject to specific environmental constraints[3] so that farmers in order to apply for at least five years usual good farming practices compatible with the requirements of environmental protection, maintenance of countryside and sustainable farming.

The given package of Pillar II measures were further extended and strengthened at 1999 by the Agenda 2000 CAP reform to promote also the modernization and diversification of agricultural holdings. Actually, the extended package includes measures dealing with the: (i) *set-up of young farmers* providing aid in the form either of a single premium or an interest subsidy on loans taken to cover establishment costs to farmers who are under the age of 40 years and set up in farming for the first time, (ii) *reafforestation of agricultural land* offering aid to private forest owners or municipalities in order to preserve woodlands (i.e. maintaining fire breaks), afforest farm land, and proceed in investments on non-farm land to upgrade harvesting, processing and marketing of forestry products, and open up new outlets for forestry products, (iii) *vocational training* intending to improve the occupational skill and competence of persons involved in agricultural and forestry activities, facilitate their adaptability to changing market conditions and opportunities, as well as to raise awareness of environmental impacts and management techniques that are compatible with environmental protection

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more than 15 years per farmer and 10 years per farm worker (Garaulet and Lawyer, 1999).

[2] A longer period may be set for certain types of undertaking (Garaulet and Lawyer, 1999).

[3] Less favoured areas and areas with environmental disadvantages are defined as *mountainous areas* - with min. 700m altitude or min. 20% inclination or min. 500m altitude and 50% inclination. Other less favoured areas with agricultural disadvantages are defined by: number of agricultural holdings: max. 30 and max. 55 inhabitants/km^2 or high employment rate in agriculture (>15%), and by *small areas* - with max. 30 agricultural holdings per region, hilly regions, wetlands and flood plains, border regions (EC, 2004b).

and maintain landscape, hygiene and animal welfare (Baldock et al., 2002), (iv) *investment in agricultural holdings* involving aid for investments that pursue certain objectives such as reducing production costs, promoting best possible product quality, improving or diversifying productive activities, conservation and improvement of natural environment, health and hygiene conditions or animal welfare standards,[4] and (v) *improved processing and marketing of agricultural products*[5] aiming at increasing the competitiveness and added value of agricultural products by improving their presentation, processing procedures and marketing channels, reorienting production to new outlets, applying new technologies, monitoring quality and health conditions, encouraging innovation and protecting the environment (EC, 2004a).

Each Member State has to design its own national or regional rural development programs, which according to the specific country's needs can consist of many different pillar II measures while have as compulsory element actions that preserve and maintain Europe's natural heritage, illustrating the political priority attached to agri-environment schemes. To safeguard that the provided rural development programs integrate environmental aspects into the CAP and do not support environmentally harmful developments, the most Pillar II measures are subject to the horizontal regulation and the principle of cross-compliance alike with market policy measures.[6] Finally, rural development has been further strengthened under the 2003 Mid-term Review by the transfer of funds from the first to the second pillar of the CAP as involved by the principle of dynamic modulation to ensure that farmers are primarily awarded for their general contribution to society rather than agricultural production.

Given the prospect of European Commission that the incorporation of rural development measures within the CAP regime is about to enhance further the "green" character of Agenda 2000 CAP re-

[4] The total aid is limited to a maximum of 40% of the investment value and 50% for less-favoured regions. The percentages increase to 45% and 55% respectively in the case of young farmers (Garaulet and Lawyer, 1999).

[5] The aid is limited to 50% of the total investment eligible in Objective 1 regions and up to 40% elsewhere. Where Objectives 1 includes the regions which are lagging behind, having either per capita gross domestic product below 75% of the EU average or being less populated (Garaulet and Lawyer, 1999).

[6] It is logical that aid provided for vocational training can not be conditional to environmental performance standards.

form, inducing farmers to integrate in a better way environmental considerations in their decision making, the conceptual theoretical framework of farming activity developed in the previous chapter is being properly modified in order to analyze this extension. It is considered that the land quality target incorporated within the provision of direct CMOs payments can be attained either through the restriction of main production choices (i.e. input, land and labour usage) or secondary production choices (i.e. treatments on input usage etc.) allowing their environmental benign use. The adoption costs of such treatments can either be self-financed or financed partially by participating into a Rural Development (RD) program. Henceforth, the representative farmer is considered not only to be eligible for coupled and decoupled payments under the common market organizations of CAP (Pillar I) but also for a set of rural development subsidies provided per unit of established treatments to abate emission flows under the second pillar of CAP, which similarly to CMOs direct payments are subject to environmental standards and the principle of cross-compliance in the event detected violation of the given considerations.

The modified, generalized farm model is employed to examine the relative environmental performance of farming activity under the provision of different type of payments under the CAP regime, especially when the later is being extended to include rural development payments. The environmental performance is assessed in terms of the equilibrium values of farmers' main and secondary production choices under the CAP regimes involving either only the provision of CMOs payments (i.e. full coupling, partial and full decoupling regime), the combined provision of Pillar I and Pillar II payments (i.e. extended full coupling, partial and full decoupling regime) or solely the granting of rural development payments (i.e. rural development regime). As previously, the problem of the optimal regulation is discussed in a static context in order to assess the type of socially optimal common market organizations (CMOs) and rural development (RD) CAP instruments. Emphasis is given three pairs of CAP measures: (i) production subsidy, land-usage direct payment and subsidy for input usage treatment, (ii) production subsidy, set-aside direct payment and subsidy for input usage treatment, along with the pair involving (iii) production subsidy, subsidy for input usage treatment and cross-compliance term. Finally, the type of the dynamic CAP measures that induce farmers to attain the socially optimal path of both main and secondary production choices is examined and the effectiveness of the structure of Agenda 2000 CAP reform is being discussed in an evolutionary context.

It is worth mentioning that the incorporation of both environmental considerations and / or second pillar payments enhances environmental performance of a given CAP regime since main production choices are restricted and secondary production choices are increased, justifying the decision of Commission to modify to this direction the communal agricultural policy.

3.2 Modelling of Farming Activity under the Rural Development CAP Regime (Pillar II)

Consider that the expression of farmer i's crop yields (2.1) is being modified into:

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

to include an additional production choice, the labor (ℓ) employed in the production of the crop representing either hired or family labor.

Given that farming is activity is inevitably associated with the emissions production function (2.2) is restructured as:

$$e_i = e_i(\mathbf{x}_{ij}, L_i^c, \bar{L} - L_i^c, \ell_i)$$

so that it is an increasing function of inputs ($\mathbf{x}_{ij}$), cultivated land (L^c) and labour (ℓ), while a decreasing function of set-asided land $\left(\bar{L} - L_i^c\right)$.

Under the EU market policy (CMOs) the chosen crop type is eligible both for a reduced production subsidy (s) and two types of direct aid payments (DPs) conditional to certain environmental requirements according to the horizontal regulation as described by conditions (2.3) and (2.4) respectively. Given the environmental requirements incorporated within the land usage direct payment DP_1, farmers can comply with the land quality constraint $\bar{Q}_i$ by either restricting production choices ($\mathbf{x}_{ij}, L_i^c, \ell_i$) or by treating given production choices in an environmentally benign way so that individual emissions flows are reduced. In such a case four types of treatments can be distinguished:

t_i^x *Treatment on input usage*: involving for instance advanced irrigation or fertilizer application technics. Such kind of treatments do not affect the productivity of inputs in terms of crop yields but their productivity in emission generation.[7] Given that $\frac{\partial e_i}{\partial x_{ij}} > 0$ the treatment t_{ij}^x reduces the positive impact of the input x_{ij} on emission flows.

Let $\mathbf{x}_{ij}^e$ be the vector of the effective input usage in emission generation that is equal to:

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

where $\mathbf{t}_{ij}^x = (t_{i1}^x, t_{i2}^x, ..., t_{im}^x)$ denotes a vector of the undertaken treatments on input usage given that the farmer employes a set of $j = 1, ..., m$ inputs.

It is evident that under $\mathbf{t}_{ij}^x \neq 0$ there is a mismatch between the applied amount of inputs and the amount of inputs that is actually responsible for the emission generation.[8] This implies that even though farmer i employs ε units of inputs the amount of inputs that is actually responsible for the generated emission flows is reduced to $\left(1 - \mathbf{t}_{ij}^x\right) \varepsilon$ and henceforth less emission flows are released into the agricultural environment.[9]

t_i^c *Treatment on cultivated land*: in the sense of storage capacity of manures and crop silage, land management practices (i.e. contour farming, strip cropping, terracing aim at controlling soil erosion by water). Characteristic example of land usage treatment is the conservation tillage, defined as soil cover crops sown during autumn so that the fertile layer of soil is not removed by rainfall or wind (Owen et al., 1998) and the nitrates

[7] This implies that $\frac{\partial y_i}{\partial t^x} = 0$ while $\frac{\partial e_i}{\partial t^x} \neq 0$.

[8] It is worth mentioning that if $\mathbf{t}_{ij}^x = 0$ then the actually employed amount of inputs matches with amount of effective input on emission generation $\left(i.e.\ \mathbf{x}_{ij} = \mathbf{x}_{ij}^e\right)$.

[9] Alternatively, if the employment ε units of inputs results into ν units of emissions then under the careful treatment of input usage the same amount of emission flows (ν) is associated with a higher amount of input usage ($i.e.\ \varepsilon\,(1 + u)$).

leaching is being reduced effectively at the most critical time of the year.[10] According to DEFRA (2004) when such a cover crop is destroyed during the winter the nitrogen will be slowly released from the crop residues.

Given that $\frac{\partial e_i}{\partial L^c} > 0$ the effective cultivated land usage in emission generation is:

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

Under $t_i^c > 0$ the generated emissions are less as if the farmer had set less land on production and thus more land on set-aside.

t_i^{NC} *Treatment on land-set aside*: non-fertilised grass strips, hedges and trees along watercourses and ditches (EC, 2002), along with the cultivation of crops that have the ability to absorb nitrates. Given that $\frac{\partial e_i}{\partial L^{nc}} < 0$ such treatments turn the set-asided land more effective in emission abatement as if the farmer had set aside more land:

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

t_i^ℓ *Treatment on human capital*: in the sense of vocational training or advisory services. Such kind of treatments allow farmers to develop skills,[11] affecting the impact of human capital (ℓ) on both crop yields and emission flows. Let ℓ_y^e represent the effective labor in crop yields generation and ℓ_e^e the effective labor in emission generation, involving respectively:

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

Henceforth the farmer i's set of production choices can be extended and distinguished into the *main production choices* $(\mathbf{x}_{ij}, L_i^c, \ell_i)$ that

[10] According to DEFRA (2004) catch crops for grazing can also be effective in reducing nitrates loss when used late in the year in fields that would otherwise be bare over the autumn and winter.

[11] Turn employees from white-collar to blue-collar.

are directly related with the production of the crop yields and the *secondary production choices* $\left(\mathbf{t}_{ij}^{x}, t_i^c, t_i^{nc}, t^{\ell}\right)$ that are disassociated by the crop production but highly related with the abatement of emission flows. It is worth mentioning that even though the treatment on labor usage $\left(t^{\ell}\right)$ is being classified among the secondary production choices, it actually represents a production choice with mixed effects since it affects both the generation of crop yields and emission flows.

Consequently, the farmer $i's$ production and emission function are modified into:

$$y_i = f(\mathbf{x}_{ij}, L_i^c, \ell_y^e) \tag{3.1}$$

$$e_i = e\left(\mathbf{x}_{ij}^e, L_c^e, L_{nc}^e, \ell_e^e\right) \tag{3.2}$$

Nevertheless, the final impact of the main and secondary production choices $\left(\mathbf{x}_{ij}, L_i^c, \ell, \mathbf{t}_{ij}^x, t_i^c, t_i^{nc}, t_i^{\ell}\right)$ on individual emission flows is affected by the natural characteristics of the agricultural land (i.e. soil type, slope).[12] For instance, for the same level of production choices a farmer located on light-textured soils is more vulnerable to nitrates pollution generation to a farmer located on high-quality soils. Hence, (3.2) is modified into:[13]

$$e_i = e\left(\beta_i x_i^e, \beta_i L_c^e, \beta_i L_{NC}^e, \beta_i \ell_e^e\right)$$

The adoption of the described treatments involves some costs (i.e. installing, maintenance costs etc.), which the farmer can either self-finance or finance partially by participating into a Rural Development (RD) program. For instance, the farmer i can participate into a RD program that involves the granting of aid either for agri-environmental services, investment in farms, land improvement and/ or water resource management (EC, 2004b).

[12] For instance light-textured soils, such as mocho soils and loamy soils, are more porous and are characterized as nitrate pollution intensive since they permit nitrogen and water to leach more readily below the crop root zone (Helfand and House, 1995). On the other hand high-quality soils, such as clay loam soil and silty soils, are less porous and thus less vulnerable to nitrogen leaching (Wu and Babcock, 2001).

[13] Notice that it there might exist a treatment level (*i.e.* $\bar{t}^x$) capable of absorbing fully the released emission flows. However such a case is not considered in the analysis for all the types of treatments.

With no participation into a Pillar II program the farmer bears the full cost of treatments given as:

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

where $\mathbf{r}_j$ denotes the vector of the per unit cost of the $j = 1, ..., m$ input usage treatments, κ the per unit cost of treatments on set-aside land, c the per unit cost of land usage treatment and d the per unit cost of human capital treatment in the competitive market.

On the other hand, a farmer participating into a RD program is partially compensated for the costs of undertaken treatments via subsidies provided per unit of treatment. The total amount of payments under the Pillar II regime that the farmer i can receive is:

$$RD = \mathbf{r}_j s^{x} \mathbf{t}_{ij}^{x} + \kappa s^{nc} t_i^{nc} + cs^{c} t_i^{c} + ds^{\ell} t^{\ell}$$

where s^{x} is the subsidy per unit of input usage treatment characterized by $1 > s^{x} > 0$,[14] s^{c} the subsidy per unit of treatment on cultivated land and s^{nc} the subsidy per unit of treatment on set-asided land. Finally s^{ℓ} denotes the support provided by EC under the RD regime for vocational training to compensate trained farmers for their loss in terms of leisure time. It is stressed that $s^{\ell} = 0$ if t^{ℓ} involves just the provision of advisory services.

Hence, the cost of treatments under the Pillar II regime of CAP is defined by:

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

Given the NPS characteristics of agricultural pollution and the technical inability of the regulatory authority to inspect simultaneously, there are incentives to deviate from established environmental standards. In such a case deviating behavior can be detected via random inspections[15] and be deterred via the implementation of the

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[14] The provided per unit subsidy is uniform no matter the kind of the undertaken input usage treatment (t_{ij}^{x}).

[15] According to the Nitrates Directive farmers that have the greatest potential for emission flows are given priority when it comes to verify compliance. Hence the inspection probability can be dependent on the farmers' land characteristics ($p(\beta_i)$). Given that the definition of such a type of probability requires individual information that can be acquired with some cost, the inspection probability can be initially treated as fixed.

principle of cross-compliance, involving a probabilistic reduction (or even cancellation) of rural development payments provided under the Pillar II CAP regime given by:

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

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 the fact that the support for vocational training is not subject to the land quality constraint.

3.3 Alternative Behavioral Rules under the CMOs and Rural Development CAP Regime

Under the existence of environmental considerations, as expressed by the land usage and quality constraint, two behavioral rules can be considered regarding the farmers' attitude towards such considerations. In particular, farmer i can adopt either:

- **Compliant behavioral rule under the participation in RD regime**

If the farmer takes into account the performance standards into the profit maximization process then the compliant behavioral rule occurs. In such a case the maximization problem is defined as such:

$$\begin{aligned}
&\max_{\left(\mathbf{x}_{ij}, L_i^c, \ell, \mathbf{t}_{ij}^x, t_i^c, t_i^{nc}, t_i^\ell\right)} \pi_i^C = \\
&P(1+s) f(x_i, L_i^c, (1+t^\ell)\ell) - wx - v\ell + \sigma_1 L^c \\
&+\sigma_2\left(\bar{L} - L^c\right) - (TC^o - RD) \\
&\text{subject to} \\
&L^c \leq \tilde{L}^c \\
&Q_i(e_1, e_2, ..., e_n) \geq \bar{Q}_i
\end{aligned} \tag{3.3}$$

Compared to the model describing the farming behavior solely under the provisions of the marker policy regime (Pillar I), the farmer's set of choices variables is being increased when the model is being extended to include and rural development regime since it accounts both for main and secondary production choices. In such a case the farmer has seven production choices, while in the initial model his choice variables were just two.

It is worth mentioning that if t^ℓ represents vocational training then it does not represent a choice variable since the amount of undertaken training is predetermined by the EC. Therefore in the forthcoming analysis t^ℓ is treated as advice, involving $s^\ell = 0$.

- **Deviating Behavioral Rule under the participation in RD regime**.

If the farmer does not take into consideration the land quality and land usage constraint then the deviating behavioral rule is adopted and the maximization problem is given by:

$$\begin{aligned}
&\max \pi_i^{NC} = \\
&P(1+s)f(x_i, L_i^c, (1+t^\ell)\ell) - wx - v\ell - TC^o + ds^\ell t^\ell \\
&+ \left[\sigma_1 L^c + \tilde{R}D\right]\left\{1 - p\gamma\left(\bar{Q}_i - Q_i\right)\right\} + \\
&\sigma_2\left(\bar{L} - L^c\right)\left\{1 - p\gamma(\tilde{L}^c - L^c)\right\}
\end{aligned} \tag{3.4}$$

where $\left\{1 - p\gamma\left(\bar{Q}_i - Q_i\right)\right\}$ represents the net percentage of the land usage direct payment DP_1 and the rural development subsidies $\tilde{R}D$ after the detection of deviation from the land quality constraint and the enforcement of the cross-compliance principle, while $\left\{1 - p\gamma(\tilde{L}^c - L^c)\right\}$ respectively denotes the net percentage of the set-aside direct payment DP_2 after the detection of deviation from the land usage constraint.

By setting s^x, s^C, s^{NC}, s^ℓ equal to zero the maximization problem of the compliant and deviating farmer under the nonparticipation in a RD program are alternatively assessed.

In the absence of environmental considerations in the provision of Pillar I and Pillar II CAP payments there is no distinction between compliant and deviating behavioral rule and the maximization problem is restricted into:

$$\pi_i = P(1+s)f(x_i, L_i^c, (1+t^\ell)\ell) - \mathbf{w}_j\mathbf{x}_{ij} - v\ell + DP_1 + DP_2 - (TC^o - RD)$$

The nature of the described CAP regime[16] is quite generalized, allowing under simplifying assumptions the definition of the different CAP regimes and then after the assessment of their relative environmental performance in terms of production choices $\left(\mathbf{x}_{ij}, b_i^F, \ell, \mathbf{t}_{ij}^x, t_i^c, t_i^{nc}, t^\ell\right)$. The farming activity is examined under the following CAP regimes:

1. *Unregulated competitive regime*: $s = 0$ and $\sigma_1, \sigma_2 = 0$, along with $RD = 0$. It can be viewed as the *initial regime*, prior the establishment of the CAP, characterized by the nonprovision of both Pillar I and Pillar II payments.

2. *Full coupling regime*: $s > 0$ and $\sigma_1, \sigma_2 = 0$, along with $RD = 0$. It is the so-called *old regime*, involving only the provision of production subsidies independently of environmental requirements and in the absence of rural developments subsidies.

3. *Partial decoupled regime*: $s > 0$ and $\sigma_1, \sigma_2 > 0$, along with $RD = 0$. It involves both the provision of coupled and decoupled payments, without involving the provision of Pillar II payments. Under this regime the following subcases are also examined,

   (a) Absence of land quality and usage constraints.

   (b) Existence of land quality and usage constraints.

   in order to verify (or not) the perception that the combined provision of decoupled payments with environmental standards induces farmers to simultaneously restrict the main production choices $(\mathbf{x}_{ij}, L^c, \ell)$ and expand undertaken treatments $\left(t^x, t^c, t^{nc}, t^\ell\right)$.

4. *Full decoupled regime*: $s = 0$ and $\sigma_1, \sigma_2 > 0$, along with $RD = 0$. Such a regime involves the complete cancellation of coupled payments and the provision only of direct payments, while no rural development payments are considered. As previously two subcases can be examined: (a) absence and (b) existence of environmental constraints respectively.

[16] It is the regime of partial decoupling denoted below by the indication (6) since it involves both the provision of coupled and decoupled payments, along with rural development payments under the presence of environmental considerations and a compliance enforcement mechanism.

The described CAP regimes are also extended to include rural development measures. Such a modification allow us to conduct comparison in terms of production choices within a given CAP regime (i.e. FD) in order to examine whether (or not) the provision of the rural development payments induces farmers to enhance further their environmental performance.

5. *Extended full coupling regime*: $s > 0$ and $\sigma_1, \sigma_2 = 0$, as well as $RD > 0$. Given the fact that coupled payments are still maintained for some crop types a farmer i can also be provided Pillar II subsidies. Two subcases are also considered: (a) absence and (b) existence of environmental constraints respectively.
6. *Extended partial decoupling regime*: $s > 0$ and $\sigma_1, \sigma_2 > 0$, as well as $RD > 0$. It can be regarded as the generalized, *current regime* (EPD) involving the simultaneous provision of both coupled and decoupled payments, along with Pillar II subsidies. The given regime is also examined under the (a) absence and (b) existence of environmental constraints respectively.
7. *Extended full decoupling regime*: $s = 0$ and $\sigma_1, \sigma_2 > 0$, as well as $RD > 0$. It can be viewed as the *forthcoming regime* providing farmers both decoupled and Pillar II payments, which can either be provided under (a) the absence or (b) the existence of environmental constraints.
8. *Rural development regime*: $s = 0$ and $\sigma_1, \sigma_2 = 0$, while $RD > 0$. Such a regime constitutes the ultimate target of the EC and it involves only the provision of rural development measures in the (a) absence and (b) presence of environmental considerations respectively.

3.3.1 Profit Maximization by Farmers under Compliance

The associated Langrangean function of the (3.3) problem is:

$$\begin{aligned}\mathcal{L} &= P(1+s)f(x_i, L_i^c, (1+t^\ell)\ell) - wx - v\ell + \sigma_1 L^c + \sigma_2\left(\bar{L} - L^c\right) \\ &\quad - \left(TC^o - \tilde{R}D\right) + \lambda_1\left[Q_i(e_1, e_2, ..., e_n) - \bar{Q}_i\right] + \lambda_2\left[\tilde{L}^c - L^c\right]\end{aligned}$$

The Kuhn-Tucker necessary conditions of the problem are:

$$FOC_{x_{ij}} : P(1+s)f_x - w + \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x^e_{ij}}\beta_i\left(1 - t^x_{ij}\right) = 0 \tag{3.5}$$

$$\text{if } \hat{x}_{ij} > 0, \frac{\partial \mathcal{L}}{\partial x} < 0 \quad \text{if } \hat{x}_{ij} > 0$$

$$FOC_{b^f} : -P(1+s)f_{L^c} - \tag{3.6}$$

$$\lambda_1 \beta_i \frac{\partial Q_i}{\partial e_i}\left[\frac{\partial e_i}{\partial L^e_c}\left(1 - t^c_i\right) - \frac{\partial e_i}{\partial L^e_{nc}}\left(1 + t^{nc}\right)\right] - \sigma_1 + \sigma_2 + \lambda_2 = 0$$

$$\text{if } \hat{b}^f > 0, \frac{\partial \mathcal{L}}{\partial b^f} < 0 \quad \text{if } \hat{b}^f = 0$$

$$FOC_{\ell} : P(1+s)\frac{\partial y_i}{\partial \ell^e_y}(1 + t^{\ell}_i) - v + \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial \ell^e_e}\beta_i\left(1 - t^{\ell}_i\right) \tag{3.7}$$

$$\text{if } \hat{\ell} > 0, \frac{\partial \mathcal{L}}{\partial \ell} < 0 \quad \text{if } \hat{\ell} = 0$$

$$FOC_{t^x} : r(s^x - 1) - \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x^e}\beta_i x = 0 \quad \text{if } \hat{t}^x > 0 \tag{3.8}$$

$$\frac{\partial \mathcal{L}}{\partial t^x} < 0 \quad \text{if } \hat{t}^x = 0$$

$$FOC_{t^c} : c\left(s^c - 1\right) - \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L^e_c}\beta_i L^c \quad \text{if } \hat{t}^c > 0 \tag{3.9}$$

$$\frac{\partial \mathcal{L}}{\partial t^c} < 0 \quad \text{if } \hat{t}^c = 0$$

$$FOC_{t^{NC}} : \kappa\left(s^{nc} - 1\right) + \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L^e_{nc}}\beta_i\left(\bar{L} - L^c\right) \quad \text{if } \hat{t}^{nc} > 0 \tag{3.10}$$

$$\frac{\partial \mathcal{L}}{\partial t^{nc}} < 0 \quad \text{if } \hat{t}^{nc} = 0$$

$$FOC_{t^{\ell}} : P(1+s)\frac{\partial y_i}{\partial \ell^e_y}\ell - d - \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial \ell^e_e}\beta_i \ell = 0 \quad \text{if } \hat{t}^{\ell} > 0 \tag{3.11}$$

$$\frac{\partial \mathcal{L}}{\partial t^{\ell}} < 0 \quad \text{if } \hat{t}^{\ell} = 0$$

$$FOC_{\lambda_1} : Q_i(e_1, e_2, ..., e_n) - \bar{Q}_i = 0 \quad \text{if } \lambda_1 > 0 \qquad (\text{or } < 0 \text{ if } \lambda_1 = 0)$$

$$FOC_{\lambda_2} : \tilde{L}^c - L^c = 0 \quad \text{if } \lambda_2 > 0 \qquad (\text{or } < 0 \text{ if } \lambda_2 = 0)$$

By the Envelop Theorem it holds:

$$
\begin{aligned}
\frac{\partial \mathcal{V}\left(P,w,v,s,r,c,\kappa,d,\sigma_1,\sigma_2,s^x,s^c,s^{nc},s^\ell\right)}{\partial \bar{Q}_i} &= \\
\frac{\partial \mathcal{L}\left(\hat{x}_{ij},\hat{b}_i^F,\hat{\ell},\hat{t}^x,\hat{t}^c,\hat{t}^{nc},\hat{t}^\ell,\lambda_1,\lambda_2\right)}{\partial \bar{Q}_i} &= -\lambda_1 \\
\frac{\partial \mathcal{V}\left(P,w,v,s,r,c,\kappa,d,\sigma_1,\sigma_2,s^x,s^c,s^{nc},s^\ell\right)}{\partial \tilde{L}^c} &= \\
\frac{\partial \mathcal{L}\left(\hat{x}_{ij},\hat{b}_i^F,\hat{\ell},\hat{t}^x,\hat{t}^c,\hat{t}^{nc},\hat{t}^\ell,\lambda_1,\lambda_2\right)}{\partial \tilde{L}^c} &= \lambda_2
\end{aligned}
$$

implying that the multiplier λ_1 expresses the marginal cost due to a change in the land quality constraint constant $\bar{Q}_i$, while the multiplier λ_2 the marginal benefit resulting from a change in the land usage constraint constant $\tilde{L}^c$.

It is evident from the optimality conditions (3.5) - (3.11) that the compliant farmer i's optimum production choices $\left(\hat{\mathbf{x}}_{ij},\hat{L}^c,\hat{\ell},\hat{t}^x,\hat{t}^c,\hat{t}^{nc},\hat{t}^\ell\right)$ are a function of the product's market price (P), the input and labor purchase price (w,v), the per unit costs of treatments (r,c,κ,d), the market policy CAP measures (s,σ_1,σ_2) along with the rural development CAP measures $\left(s^x,s^c,s^{nc},s^\ell\right)$. For instance the optimum main production choices $\left(\hat{\mathbf{x}}_{ij},\hat{L}^c,\hat{\ell}\right)$ are given as:

$$
\begin{aligned}
&\hat{\mathbf{x}}_{ij}(P,w,v,s,r,c,\kappa,d,\sigma_1,\sigma_2,s^x,s^c,s^{nc},s^\ell) \\
&\hat{L}^c(P,w,v,s,r,c,\kappa,d,\sigma_1,\sigma_2,s^x,s^c,s^{nc},s^\ell) \\
&\hat{\ell}(P,w,v,s,r,c,\kappa,d,\sigma_1,\sigma_2,s^x,s^c,s^{nc},s^\ell)
\end{aligned}
$$

According to the condition (3.5) the input x_{ij} should be applied up to the point that the marginal revenues from production $(P(1+s)f_x)$ equate with the marginal costs from the purchase of the j input (w_j) and the net shadow cost from the nonattainment of the land quality constraint $\left(\lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x^e}\beta_i\left(1-t_i^x\right)\right)$ given the fact that input usage is being treated in environmental benign way (*i.e.* $t_i^x>0$).[17] In the

[17] In such a case the term $\left(\lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x^e}\beta_i\right)$ represents the gross shadow cost from the attainment of the land quality constraint, while the term $\left(-\lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x^e}\beta_i t_i^x\right)$ denotes

same context the condition (3.6) equates marginal revenues in terms of set-aside premium (σ_2), net shadow cost savings due to compliance with the land quality and the set-aside constraint constants $\left(-\lambda_1\beta_i\frac{\partial Q_i}{\partial e_i}\left[\frac{\partial e_i}{\partial L_c^e}\left(1-t_i^c\right)-\frac{\partial e_i}{\partial L_{nc}^e}\left(1+t^{nc}\right)\right]+\lambda_2\right)$ given that both the cultivated and set-asided land is treated in environmental benign way (*i.e.* $t_i^c, t_i^{nc} > 0$), with marginal costs in terms of foregone market revenues and coupled payments ($-P(1+s)f_{L^c}$) and foregone land usage premium ($-\sigma_1$) due to the marginal reduction of the size of the cultivated land. Finally, the condition (3.7) defines the optimum labour value that equates marginal revenues from production $\left(P(1+s)\frac{\partial y_i}{\partial \ell_y^e}(1+t_i^\ell)\right)$ as enhanced by the undertaken treatment t_i^ℓ with marginal costs associated with the labor purchase ($-v$) and the net shadow costs from the nonattainment of the land quality constraint $\left(\lambda_1\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial \ell_e^e}\beta_i\left(1-t_i^\ell\right)\right)$ given the fact that labor is being treated to develop environmental benign skills $\left(i.e.\ t_i^\ell > 0\right)$.[18]

It is evident from conditions (3.5) to (3.6) that the establishment of nonzero secondary production choices (*i.e.* $t_{ij}^x, t_i^c, t_i^{nc}, t_i^\ell > 0$) allows farmers to employ higher levels of main production choices compared to the case of nonestablishment (*i.e.* $t_{ij}^x, t_i^c, t_i^{nc}, t_i^\ell = 0$). For instance, it can be easily seen that:

$$\pi^{x_{ij}}_{t_{ij}^x=0}(\hat{x}_{ij}|_{t_{ij}^x>0}) = \lambda_1\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x_{ij}^e}\beta_i t_{ij}^x < 0 \quad \text{involving} \quad \hat{x}_{ij}\left(t_{ij}^x > 0\right) > \hat{x}_{ij}\left(t_{ij}^x = 0\right)$$

while analogous conditions hold for land and labor usage. Such an inequality is reasonable to occur given the fact that such treatments handle main production choices in an environmental benign way allowing farmers to proceed in increased usage of land, labor and inputs without violating the given environmental land quality requirement.

The optimal secondary production choices can be defined as:

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the reduction of the incurred shadow cost due to the environmental benign treatment of input usage $\left(i.e.\ t_i^x > 0\right)$.

[18] In this case $t_i^\ell > 0$ increases the marginal revenues from production $\left(P(1+s)\frac{\partial y_i}{\partial \ell_y^e}t_i^\ell\right)$ and reduces the shadow cost of attainment of the land quality constraint $\left(-\lambda_1\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial \ell_e^e}\beta_i t_i^\ell\right)$.

$$\hat{\mathbf{t}}^x_{ij}(P, w, v, s, r, c, \kappa, d, \sigma_1, \sigma_2, s^x, s^c, s^{nc}, s^\ell)$$
$$\hat{t}^c(P, w, v, s, r, c, \kappa, d, \sigma_1, \sigma_2, s^x, s^c, s^{nc}, s^\ell)$$
$$\hat{t}^{nc}(P, w, v, s, r, c, \kappa, d, \sigma_1, \sigma_2, s^x, s^c, s^{nc}, s^\ell)$$
$$\hat{t}^\ell(P, w, v, s, r, c, \kappa, d, \sigma_1, \sigma_2, s^x, s^c, s^{nc}, s^\ell)$$

In particular, the condition (3.8) equates marginal revenues in terms of shadow cost savings due to the attainment of the land quality constraint $\left(-\lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial x^e} \beta_i x\right)$ and the marginal costs associated with the establishment and maintenance of a unit of input usage treatment $(r(s^x - 1))$. In the same context lies the condition (3.9) and (3.10) given their identical structure, while the condition (3.11) involves that marginal revenues from production $\left(P(1+s)\frac{\partial y_i}{\partial \ell^e_y}\ell\right)$ and shadow cost savings from the attainment of the land quality constraint $\left(-\lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial \ell^e_e} \beta_i \ell\right)$ must equate with marginal costs from labor treatment purchase $(-d)$.

It is considered that the optimality conditions involve interior solutions for the given production choices. However, in the conditions (3.8) - (3.11) if the marginal costs exceed the marginal revenues then it is suboptimal for the farmer i to comply with the land quality constraint by treating main production choices $(\mathbf{x}_{ij}, L^c, \ell)$ in an environmental benign way. Nevertheless, in order to avoid complexities in the forthcoming analysis it is assumed that the secondary production choices are nonzero.[19]

Finally, the impact of a marginal change of the value of a CAP measure on the equilibrium value of the farmer i's optimum production choices can be assessed via the comparative static analysis. However, given the large number of production choices the comparative statics analysis can not be undertaken[20] and results can only be assessed under restrictive assumptions.

[19] An analogous assumption is made for the condition (3.6), since if $\frac{\partial \mathcal{L}}{\partial b^f} < 0$ occurred then the solution for the optimum fraction $\hat{b}^f$ would be on the boundaries and compliance with the land usage constraint would be suboptimal.

[20] Even though the Hessian matrix can be assumed to be negative so that the maximization problem is defined, the sign of the associated Hessian matrix of the exogenous variables is hard to be assess. Therefore the Cramer rule can provide us results only under restrictive assumptions.

3.3.2 Profit Maximization by Farmers under Deviating Behavior

The associated Kuhn-Tucker conditions of the (3.4) problem are:

$$FOC_{x_{ij}} : P(1+s)f_x - w_j + \left[DP_1 + \tilde{R}D\right] p\gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial x^e_{ij}} \beta_i \left(1 - t^x_{ij}\right) = 0 \tag{3.12}$$

if $\check{x}_{ij} > 0$

$\dfrac{\partial \mathcal{L}}{\partial x} < 0 \quad \text{if } \check{x}_{ij} > 0$

$$FOC_{b^f} : -P(1+s)f_{L^c} - \tag{3.13}$$

$$\left[DP_1 + \tilde{R}D\right] p\gamma\beta_i \frac{\partial Q_i}{\partial e_i} \left[\frac{\partial e_i}{\partial L^e_c}\left(1 - t^c_i\right) - \frac{\partial e_i}{\partial L^e_{nc}}\left(1 + t^{nc}\right)\right] -$$

$$\sigma_1 \left\{1 - p\gamma\left(\bar{Q}_i - Q_i\right)\right\} + \sigma_2 \left[1 - p\gamma\left\{\left(\bar{L} - \tilde{L}^c\right) - 2\left(\bar{L} - L^c\right)\right\}\right] = 0 \quad \text{if } \check{b}^f > 0$$

$\dfrac{\partial \mathcal{L}}{\partial b^f} < 0 \quad \text{if } \check{b}^f = 0$

$$FOC_\ell : P(1+s)\frac{\partial y_i}{\partial \ell^e_y}(1 + t^\ell_i) - v + \tag{3.14}$$

$$\left[DP_1 + \tilde{R}D\right] p\gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial \ell^e_e} \beta_i \left(1 - t^\ell_i\right) = 0 \quad \text{if } \check{\ell} > 0$$

$\dfrac{\partial \mathcal{L}}{\partial \ell} < 0 \quad \text{if } \check{\ell} = 0$

$$FOC_{t^x_{ij}} : r_j(s^x - 1) - \left[DP_1 + \tilde{R}D\right] p\gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial x^e} \beta_i x_{ij} \tag{3.15}$$

$$+ rs^x \left\{1 - p\gamma\left(\bar{Q}_i - Q_i\right)\right\} = 0 \quad \text{if } \check{t}^x_{ij} > 0$$

$\dfrac{\partial \mathcal{L}}{\partial t^x} < 0 \quad \text{if } \check{t}^x_{ij} = 0$

$$FOC_{t^c} : c\left(s^c - 1\right) - \left[DP_1 + \tilde{R}D\right] p\gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial L^e_c} \beta_i L^c \tag{3.16}$$

$$+ cs^c \left\{1 - p\gamma\left(\bar{Q}_i - Q_i\right)\right\} = 0 \quad \text{if } \check{t}^c > 0$$

$\dfrac{\partial \mathcal{L}}{\partial t^c} < 0 \quad \text{if } \check{t}^c = 0$

$$FOC_{t^{NC}} : \kappa\left(s^{nc} - 1\right) + \left[DP_1 + \tilde{R}D\right] p\gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial L^e_{nc}} \beta_i \left(\bar{L} - L^c\right) + \tag{3.17}$$

$$\kappa s^{NC} \left\{1 - p\gamma\left(\bar{Q}_i - Q_i\right)\right\} = 0 \quad \text{if } \check{t}^{nc} > 0$$

$\dfrac{\partial \mathcal{L}}{\partial t^{nc}} < 0 \quad \text{if } \check{t}^{nc} = 0$

$$FOC_{t^\ell} : P(1+s)\frac{\partial y_i}{\partial \ell^e_y}\ell - \left[DP_1 + \tilde{R}D\right] p\gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial \ell^e_e} \beta_i \ell - d = 0 \quad \text{if } \check{t}^\ell > 0 \tag{3.18}$$

$\dfrac{\partial \mathcal{L}}{\partial t^\ell} < 0 \quad \text{if } \check{t}^\ell = 0$

The equilibrium values of the main and secondary production choices $\left(\check{\mathbf{x}}_{ij}, \check{b}^f, \check{\ell}, \check{t}^x, \check{t}^c, \check{t}^{nc}, \check{t}^\ell\right)$ are given as a function of:

$$\left(P, \mathbf{w}_j, v, r, c, k, d, s, \sigma_1, \sigma_2, s^x, s^c, s^{nc}, s^\ell, \bar{Q}_i, \tilde{L}^c, p, \gamma\right)$$

the competitive market price of the crop (P), the purchase price of input and labor $(\mathbf{w}_j, v)$, the per unit costs of treatments (r, c, κ, d), the market policy CAP measures (s, σ_1, σ_2) and the rural development CAP measures $\left(s^x, s^c, s^{nc}, s^\ell\right)$, as well as the environmental considerations $\left(\bar{Q}_i, \tilde{L}^c\right)$ and the cross-compliance enforcement mechanism (p, γ).

According to the condition (3.12) input x_{ij} is applied up to the point that the marginal revenues from production $\left(P(1+s)\frac{\partial f(\cdot)}{\partial x}\right)$ equate with the marginal costs from the purchase of the j input (w_j) and the net reduction of both the land usage direct payment DP_1 and the rural development payments $\tilde{R}D$ due to both the detection of deviation from the land quality constraint constant and the enforcement of the cross-compliance principle $\left(\left[DP_1 + \tilde{R}D\right] p\gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial x^e} \beta_i \left(1 - t_i^x\right)\right)$ given the fact that input usage is being treated in environmental benign way.[21] Similarly the condition (3.13) defines the set-aside fraction that equates the marginal revenues in terms of the provided set-aside premium (σ_2) and the net preserved amount of the direct payment DP_1 and the rural development payments $\tilde{R}D$ resulting from the enhanced land quality

$$\left(\left[DP_1 + \tilde{R}D\right] p\gamma\beta_i \frac{\partial Q_i}{\partial e_i}\left[\frac{\partial e_i}{\partial L_c^e}\left(1 - t_i^c\right) - \frac{\partial e_i}{\partial L_{nc}^e}\left(1 + t^{nc}\right)\right] + \sigma_1 p\gamma\left(\bar{Q}_i - Q_i\right)\right)$$

given also the fact that both cultivated and set-aside land is being treated in environmental benign way, with marginal costs in terms of foregone market revenues $\left(-P(1+s)\frac{\partial f(\cdot)}{\partial L_i^c}\right)$ and foregone land usage premium $(-\sigma_1)$. The last term $\left(-\sigma_2 p\gamma\left(\left(\bar{L}_i - \tilde{L}^c\right) - 2\left(\bar{L}_i - L_i^c\right)\right)\right)$ can either reflect a marginal cost or a marginal revenue depending on

[21] The gross reduction of direct payment DP_1 and $\tilde{R}D$ is given by the term $\left[DP_1 + \tilde{R}D\right] p\gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial x^e} \beta_i$, while the term $\left(-\left[DP_1 + \tilde{R}D\right] p\gamma \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i}{\partial x^e} \beta_i t_i^x\right)$ denotes the amount of direct payment DP_1 and $\tilde{R}D$ that are saved due to the treatment of input usage in a more environmental benign way.

the relationship between the size of the voluntarily and compulsory set-aside land. Moreover, the condition (3.14) involves that the deviating farmer i should employ labor up to the point that the marginal revenues from production $\left(P(1+s)\frac{\partial y_i}{\partial \ell_y^e}(1+t_i^\ell)\right)$ as enhanced by the undertaken treatment t_i^ℓ,with marginal costs from the labor purchase and the net reduction of both the direct payment DP_1 and the rural development payments $\tilde{R}D$ due to both the detection of deviation from the land quality constraint constant and the enforcement of the cross-compliance principle $\left(\left[DP_1+\tilde{R}D\right]p\gamma\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial \ell_e^e}\beta_i\left(1-t_i^\ell\right)\right)$ given the fact that labor is being treated in environmental benign way.

Regarding the undertaken treatments the condition (3.15) defines the optimum value of the input usage treatment that equates the marginal revenues defined as the net preserved amount of the direct payment DP_1 and the rural development payments $\tilde{R}D$ resulting from the enhanced land quality $\left(-\left[DP_1+\tilde{R}D\right]p\gamma\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x^e}\beta_i x\right)$ due to the nonzero treatment of input usage, with marginal costs associated with establishment and maintenance of the undertaken treatment $r(s^x-1)$. Given the identical structure of the conditions (3.16) and (3.17) with the condition (3.15), the optimum values of the treatments on both land usage and land set-aside are defined in a similar way. Finally, according to the condition (3.18) the farmer i treats labor up to the point that the marginal revenues from production $\left(P(1+s)\frac{\partial y_i}{\partial \ell_y^e}\ell\right)$ and the net preserved amount of the direct payment DP_1 and the rural development payments $\tilde{R}D$ resulting from the enhanced land quality $\left(-\left[DP_1+\tilde{R}D\right]p\gamma\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial \ell_e^e}\beta_i\ell\right)$ due to the nonzero treatment of employed labor, the equate with the marginal costs associated with the uptake of advisory services $(-d)$.

As previously it is considered that the optimality conditions involve interior solutions both for the main and secondary production choices. Moreover, given the large number of production choices the comparative statics analysis can also not be undertaken.

3.4 An Assessment of the Environmental Effectiveness of the various CAP Regimes

In order to compare the equilibrium values of the main and secondary production choices $\left(\mathbf{x}_{ig}, b_{ig}^{f}, \ell_{ig}, t_{ig}^{x}, t_{ig}^{c}, t_{ig}^{nc}, t_{ig}^{\ell}\right)$ resulting under the CAP regime g with the associated equilibrium choices $\left(\mathbf{x}_{ih}, b_{ih}^{f}, \ell_{ih}, t_{ih}^{x}, t_{ih}^{c}, t_{ih}^{nc}, t_{ih}^{\ell}\right)$ of the CAP regime h, involving a different type of CMOs and / or RD payments, the optimality conditions of the initial regime are evaluated at the equilibrium choices of the latter regime. This implies that the following expressions are evaluated:

$$\begin{aligned}
&\pi_{x}^{g}(\mathbf{x}_{ih}), \quad \pi_{b^f}^{g}(b_{ih}^{f}) \quad \text{and} \quad \pi_{\ell}^{g}(\ell_{ih}) \\
&\pi_{t^x}^{g}(\mathbf{t}_{ih}^{x}), \quad \pi_{t^c}^{g}(t_{ih}^{c}), \quad \pi_{t^{nc}}^{g}(t_{ih}^{nc}) \quad \text{and} \quad \pi_{t^\ell}^{g}(t_{ih}^{\ell})
\end{aligned}$$

where $\pi_{x}^{h}(\mathbf{x}_{ih})$, $\pi_{b^f}^{h}(b_{ih}^{f})$ and $\pi_{\ell}^{h}(\ell_{ih})$ along with $\pi_{t^x}^{h}(\mathbf{t}_{ih}^{x})$, $\pi_{t^c}^{h}(t_{ih}^{c})$ and $\pi_{t^{nc}}^{h}(t_{ih}^{nc})$, $\pi_{t^\ell}^{h}(t_{ih}^{\ell})$ are simultaneously equal to zero.

If the expressions are zero then the examined regimes are identical in environmental terms since they involve the same values of production choices. However, if the expressions are nonzero then deviation in the equilibrium values of the production choices and thus in the environmental performance of the given CAP regimes is evident. In such a case the regime g is environmentally inferior to the regime h in the sense that it involves both higher usage of the main production choices $\left(\left(\mathbf{x}_{ig}, L_{ig}^{c}, \ell_{ig}\right) > (\mathbf{x}_{ih}, L_{ih}^{c}, \ell_{ih})\right)$ and less usage of treatments $\left(\left(t_{ig}^{x}, t_{ig}^{c}, t_{ig}^{nc}, t_{ig}^{\ell}\right) < \left(t_{ih}^{x}, t_{ih}^{c}, t_{ih}^{nc}, t_{ih}^{\ell}\right)\right)$ if:

$$\begin{aligned}
&\pi_{x}^{g}(\mathbf{x}_{ih}), \pi_{\ell}^{g}(\ell_{ih}) > 0 \quad \text{and } \pi_{b^f}^{g}(b_{ih}^{f}) < 0 \\
&\pi_{t^x}^{g}(t_{ih}^{x}), \pi_{t^c}^{g}(t_{ih}^{c}), \pi_{t^{nc}}^{g}(t_{ih}^{nc}), \pi_{t^\ell}^{g}(t_{ih}^{\ell}) < 0
\end{aligned}$$

On the contrary if the inequalities hold at the opposite direction then the CAP regime g is environmentally superior since it involves less usage of the main production choices $(\mathbf{x}_{ij}, L_{i}^{c}, \ell_{i})$ and higher usage of the secondary production choices $\left(t_{i}^{x}, t_{i}^{c}, t_{i}^{nc}, t_{i}^{\ell}\right)$.

After following the described procedure both under the compliant and deviating behavioral rule, the findings regarding the relative environmental performance of the various CAP regimes in terms of both main and secondary production choices are summarized in the following tables.[22]

In particular the results for the main production choices are presented in the tables 1 and 2:

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 (+)
$8a$													$+$

(1) unregulated 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 (a) absence and (b) existence of environmental considerations, (5) extended full coupling regime (EFC) under the

[22] The indication $(-)$ in the table of Δx_h^g and $\Delta \ell_h^g$ along with $\Delta\left(t^x\right)_h^g, \Delta\left(t^c\right)_h^g$ and $\Delta\left(t^{nc}\right)_h^g, \Delta\left(t^\ell\right)_h^g$ implies that the regime h involves higher usage of the given main or secondary production choice, while the same indication in the table of $\Delta\left(b^f\right)_h^g$ denotes that under the same regime more land is set aside $\left(\Delta\left(b^f\right)_h^g < 0\right)$. Moreover, (0) denotes that no deviation in the given production choice is observed between the examined regimes, while (?) denotes that there is uncertainty regarding the relative performance of the examined regimes. It is worth mentioning that if the indication regarding the relative impact of two CAP regimes on a given production choice is modified under the deviating strategy compared to the compliant strategy, then it is indicated in the tables via the indication in the parenthesis.

absence (5a) and presence (5b) of the land quality constraint, (6) extended partial decoupled regime (EPD) under the (6a) absence and (6b) existence of environmental considerations, (7) extended full decoupled regime (EFD) under the (7a) absence and (7b) existence of performance standards, (8) rural development regime (RD) under the absence (5a) and presence (5b) of the land quality constraint.

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

$\Delta(b^f)^g_h = b^f_g - b^f_h$													
$g\backslash^h$	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 $(-)$	?	?
$5a$							$-$	?	?	?	?	$-$	$-$
$5b$								?	?	?	?	?	$-$
$6a$									$-$ (?)	$-$	$-$ (?)	?	?
$6b$										?	$-$	?	?
$7a$											$-$ (?)	?	?
$7b$												?	?
$8a$													$-$

It can be seen that:

Remark 12 *The regime of nonintervention (UN) is environmentally superior to the regime of full coupling (FC) even if the later is being extended with rural development payments (EFCa). Nevertheless, if the RD payments are associated with environmental considerations (EFCb) then their relative environmental performance in terms of main production choices* $(\mathbf{x}_{ij}, L^c_i, \ell_i)$ *becomes ambiguous.*

In particular, if the following expressions:[23]

[23]It holds $\pi^{5b}_x(\mathbf{x}_{5b}) = P(1+s)\, f_x(\mathbf{x}_{5b}) - w + \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(\mathbf{x}_{5b})}{\partial x^e} \beta_i \left(1 - t^x_{5b}\right) = 0,$

$$\pi_x^1(\mathbf{x}_{5b}) = \left\{ P\,(1+s)\, f_x(\mathbf{x}_{5b}) - w + \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i\,(\mathbf{x}_{5b})}{\partial x^e} \beta_i\,(1 - t_{5b}^x) \right\} -$$

$$P s f_x(\mathbf{x}_{5b}) - \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i\,(\mathbf{x}_{5b})}{\partial x^e} \beta_i\,(1 - t_{5b}^x)$$

$$\pi_{b^f}^1(b_{5b}^f) = \Bigg\{ -P\,(1+s)\, f_{L^c}(b_{5b}^f) -$$

$$\lambda_1 \frac{\partial Q_i}{\partial e_i} \left[\frac{\partial e_i \left(b_{5b}^f \right)}{\partial L_c^e} (1 - t_{5b}^c) - \frac{\partial e_i}{\partial L_{nc}^e} (1 + t_{5b}^{nc}) \right] \Bigg\}$$

$$+ P s f_{L^c}(b_{5b}^f) + \lambda_1 \frac{\partial Q_i}{\partial e_i} \left[\frac{\partial e_i \left(b_{5b}^f \right)}{\partial L_c^e} (1 - t_{5b}^c) - \frac{\partial e_i}{\partial L_{nc}^e} (1 + t_{5b}^{nc}) \right]$$

$$\pi_\ell^1(\ell_{5b}) = \left\{ P\,(1+s)\, f_\ell(\ell_{5b}) \left(1 + t_{5b}^\ell \right) - v + \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i\,(\ell_{5b})}{\partial \ell_e^e} \beta_i\,(1 - t_{5b}^x) \right\}$$

$$- P\,(1+s)\, f_\ell(\ell_{5b}) \left(1 + t_{5b}^\ell \right) - \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i\,(\ell_{5b})}{\partial \ell_e^e} \beta_i\,(1 - t_{5b}^x)$$

are assessed with: $\pi_x^1(x_{5b}), \pi_\ell^1(\ell_{5b}) > 0$ and $\pi_{b^f}^1(b_{5b}^f) < 0$ then the incorporation of RD measures that are subject to a land quality performance standard within the extended fully coupled regime (EFCb) induces farmer i to restrict main production choices, enhancing their environmental performance compared to the nonintervention regime (UN). The inequalities are satisfied if marginal loses in term of foregone market revenues and coupled payments induced by the restricted input and labor usage under the EFC regime, are less compared to the associated marginal revenues losses due to the attainment of the land quality target.

Remark 13 *Furthermore, the UN regime is environmentally inferior to the regime characterized solely by the provision of Pillar II payments that are subject to farming standards (i.e. RDb regime),*[24] *underlining the role that the rural development programs can have in the promotion of environmental services of farming activities.*

$\pi_x^{5b}(L_{5b}^c) = -P\,(1+s)\, f_{L^c}(b_{5b}^f) - \lambda_1 \frac{\partial Q_i}{\partial e_i} \left[\frac{\partial e_i \left(b_{5b}^f \right)}{\partial L_c^e} (1 - t_{5b}^c) - \frac{\partial e_i}{\partial L_{nc}^e} (1 + t_{5b}^{nc}) \right] = 0$ and $\pi_x^{5b}(\mathbf{x}_{5b}) = P\,(1+s)\, f_\ell(\ell_{5b}) \left(1 + t_{5b}^\ell\right) - v + \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i(\ell_{5b})}{\partial \ell_e^e} \beta_i \left(1 - t_{5b}^x\right) = 0.$

[24] This implies that $\mathbf{x}_{8b} < \mathbf{x}_1$ and $\ell_{8b} < \ell_1$, while $b_{8b}^f > b_1^f$.

It can be seen from the table (1) and (2) that:[25]

Remark 14 *The RD payments when incorporated within the fully coupled regime (FC) are not sufficient to induce a switch in the environmental behavior of the farmer i if disassociated by the land quality constraint.*

Even though the FC regime is clearly environmentally inferior compared to the rest CAP regimes in terms of input and labor usage, its relative performance in terms of set-aside fraction is ambiguous. As a consequence, there is no clear evidence that the transition from the FC regime to the regime of partially or fully decoupled payments, both under the absence and presence of Pillar II subsidies, has indeed induced farmers to enhance their environmental performance in terms of main production choices compared to the old regime. However,

Remark 15 *The fact that the rural development CAP regime (RD) is environmentally superior to the fully coupled CAP regime (FC), both under the absence and presence of environmental considerations,*[26] *supports the European Commission's decision to proceed gradually in the full cancellation of Pillar I payments and their replacement by Pillar II payments according to the principle of dynamic modulation.*

Finally,

Remark 16 *The superiority of the fully decoupled regime (EFD) to the partially decoupled regime (EPD) when both extended with rural development payments is retained.*

Regarding the secondary production choices $\left(\mathbf{t}_{ij}^{x}, t_i^c, t_i^{nc}, t^{\ell}\right)$ the results are:

Table 4: 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})

[25] This implies that $\mathbf{x}_2 = \mathbf{x}_{5a}$, $\ell_2 = \ell_{5a}$ and $b_{5a}^f = b_2^f$.
[26] This implies that $\mathbf{x}_2 > \mathbf{x}_{8a}, \mathbf{x}_{8b}$, $\ell_2 > \ell_{8a}, \ell_{8b}$ and $b_{8a}^f, b_{8b}^f > b_2^f$.

$\Delta(t^x)^g_h, \Delta(t^c)^g_h$ and $\Delta(t^{nc})^g_h$													
$g\backslash^h$	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 5: The relative environmental performance of the CAP regimes g and h in terms of labor usage treatment (t^ℓ)

$\Delta(t^\ell)^g_h$													
$g\backslash^h$	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 (+)
$8a$													−

It is notable that:

Remark 17 *Compared to the unregulated regime (UN), the rest CAP regimes involve higher level of treatments even if they don't involve environmental considerations in the provision of their payments.*

Even though the FC and UN regime involve indifferent levels of secondary production choices on input usage, cultivated and set-aside land $\left(\mathbf{t}_{ij}^{x}, t^{c}, t^{nc}\right)$, the initial regime involves higher level of labor usage treatment $\left(t^{\ell}\right)$ rendering it environmentally superior in terms of treatments.[27] Such an finding is reasonable given the fact that crop yields that are positively affected by undertaken training or advisory services. Hence, a farmer operating within a CAP regime characterized by payments linked with production level (i.e. FC) is encouraged to undertake higher level of labor usage treatment so that to achieve both the attainment of the land quality performance standard and the increase of received amount of coupled payments crop yields. Nevertheless, when the full coupling regime is being extended with RD payments then it involves higher level of all kind of treatments.

In the same context the extended full coupling (EFC) and extended partial decoupling regime (EPD) is indifferent in terms of $\left(\mathbf{t}_{ij}^{x}, t^{c}, t^{nc}\right)$ treatments to the extended full decoupling regime (EFD) and rural development regime (RD), while they involve higher level of treatment on labor usage both under the absence and presence of environmental considerations.

It can be also supported that CAP regimes involving production subsidies are associated with higher level of treatment t^{ℓ} compared to CAP regimes involving either Pillar I and / or Pillar II payments that are decoupled from the production level - especially in the absence of environmental requirements.[28] It is noticeable that even though the extended full decoupling regime (EFD) and the rural development regime (RD) involve higher level of the rest secondary production choices $\left(\mathbf{t}_{ij}^{x}, t^{c}, t^{nc}\right)$ compared to the partially decoupling regime (PD) regime, the later regime involves higher level of labor usage treatment $\left(t^{\ell}\right)$.[29] Hence the relative performance of the partic-

[27] It holds $\Delta(t^{x})_{2}^{1}, \Delta(t^{c})_{2}^{1}, \Delta(t^{nc})_{2}^{1} = 0$ and $\Delta(t^{\ell})_{2}^{1} < 0$.

[28] It can be seen in the table (4) that the FC, EFC and PD, EPD regimes involve higher level of treatments on labor usage compared to the FD, EFD and RD regime.

[29] It holds $\Delta(t^{x})_{7a}^{3a}, \Delta(t^{c})_{7a}^{3a}, \Delta(t^{nc})_{7a}^{3a} < 0$, while $\Delta(t^{\ell})_{7a}^{3a} > 0$. Moreover, it holds $\Delta(t^{x})_{8a}^{3a}, \Delta(t^{c})_{8a}^{3a}, \Delta(t^{nc})_{8a}^{3a} < 0$, while $\Delta(t^{\ell})_{8a}^{3a} > 0$.

ular CAP regimes in terms of secondary production choices is quite ambiguous.

Finally, it is logical to expect that within a given CAP regime the incorporation of farming standards induces farmers to undertake higher level of all kind treatments. The same occurs when the given regime is being extended with RD payments both the absence and presence of environmental consideration with the only exception that the level of labor usage treatment is unaffected.

Remark 18 *After summing up the findings of the tables (1) to (4) it can be clearly inferred that the distinction between main and secondary production choices impedes an explicit conclusion about the "ideal" CAP regime in environmental terms. However, relative to the rest CAP regimes the old regime involves higher input and labor usage, along with lower employment of treatments on input usage, cultivated land and set-asided land, while on the other hand it exhibits variform behavior in terms set-aside decision and undertaken treatment on labor usage.*

Remark 19 *Furthermore, it can be clearly inferred that the incorporation of both environmental considerations and / or RD payments enhances environmental performance of a given CAP regime, in the sense that input and labor usage has been restricted while set-aside decision and all the secondary production choices have been enhanced, justifying the decision of Commission to modify to this direction the communal agricultural policy.*

3.4.1 Assessment of the Alternative Behavioral Rules

The optimality conditions under the two alternative behavioral rules are also compared to assess a rule describing their relative performance in terms of production choices. Let:

$$
\begin{aligned}
\pi_x^D(\hat{x}) &= \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x^e}\beta_i\left(1-\hat{t}_i^x\right)\left\{\left[\sigma_1^c\hat{L}^c+\tilde{R}D\right]p\gamma-\lambda_1\right\} \\
\pi_{b^f}^D(\hat{b}^f) &= \frac{\partial Q_i}{\partial e_i}\beta_i\left\{\frac{\partial e_i}{\partial L_c^e}\left(1-\hat{t}_i^x\right)-\frac{\partial e_i}{\partial L_{nc}^e}\left(1+\hat{t}_i^{nc}\right)\right\}\left\{\lambda_1-\left[\sigma_1^c\hat{L}^c+\tilde{R}D\right]p\gamma\right\} \\
&\quad -\lambda_2+p\gamma\left[\sigma_1\left(\bar{Q}_i-Q_i\right)-\sigma_2\left\{\left(\bar{L}-\tilde{L}^c\right)-2\left(\bar{L}-\hat{L}^c\right)\right\}\right] \\
\pi_\ell^D(\hat{\ell}) &= \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial \ell_e^e}\beta_i\left(1-\hat{t}_i^\ell\right)\left\{\left[\sigma_1\hat{L}^c+\tilde{R}D\right]p\gamma-\lambda_1\right\} \\
\pi_{t^x}^D(\hat{t}^x) &= rs^x\left\{1-p\gamma\left(\bar{Q}_i-Q_i\right)\right\}-\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x^e}\beta_i\hat{x}\left\{\left[\sigma_1\hat{L}^c+\tilde{R}D\right]p\gamma-\lambda_1\right\} \\
\pi_{t^\ell}^D(\hat{t}^\ell) &= -\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial \ell_e^e}\beta_i\hat{x}\left\{\left[\sigma_1\hat{L}^c+\tilde{R}D\right]p\gamma-\lambda_1\right\}
\end{aligned}
$$

In the absence of an enforcement mechanism, in the sense that either $p=0$ or $\gamma=0$, or even under the presence of a lax enforcement mechanism it holds:

$$
\begin{aligned}
&\pi_{x_{ij}}^D(\hat{x}_{ij}), \pi_\ell^D(\hat{\ell})>0 \quad \text{involving} \quad \hat{x}_{ij}<\check{x}_{ij} \quad \text{and } \hat{\ell}<\check{\ell} \\
&\pi_{b^f}^D(\hat{b}^f), \pi_{t^\ell}^D(\hat{t}^\ell)<0 \quad \text{involving} \quad \hat{b}^f>\check{b}^f \quad \text{and } \hat{t}^\ell>\check{t}^\ell
\end{aligned}
$$

implying that the deviating rule involves higher usage of inputs, labor and land, while less treatment on labor usage.

On the other hand, the relative performance of the two behavioral rules in terms of treatment on inputs, cultivated and set-asided land respectively is uncertain since:

$$
\pi_{t^x}^D(\hat{t}_{ij}^x)=r_j s^x+\lambda_1\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x^e}\beta_i\hat{x}_{ij}\lesseqqgtr 0
$$

implying that the deviating rule can involve higher treatment if the marginal benefit in terms of provided subsidy (s^x) is higher than the marginal cost in terms of compliance with the land quality constraint $\left(\lambda_1\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x^e}\beta_i\hat{x}_{ij}\right)$.

3.5 Optimal Regulation under the Rural Development CAP Regime

In the context of optimal regulation the purpose of the social planner is to define the socially optimal equilibrium values for the main production choices $\left(\tilde{\mathbf{x}}_i^{SP}, \tilde{b}_{SP}^f, \tilde{\ell}_{SP}\right)$ and secondary production choices $\left(\tilde{\mathbf{t}}_{SP}^x, \tilde{t}_{SP}^c, \tilde{t}_{SP}^{nc}, \tilde{t}_{SP}^\ell\right)$ for each farmer i, so that the net social benefit from agricultural activities is being maximized and thus the first-best level of aggregate land quality Q_{SP}^T is obtained.

Under the modification of the farm model obtained by the incorporation of the rural development CAP measures, the social planner's maximization problem (2.14) can be redefined:

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

to include the aggregate labour costs (*i.e.* $\mathbf{v}\ell = \sum_{i=1}^n v\ell_i$) and the aggregate costs associated with secondary production choices, that is

$$\mathbf{TC} = \sum_{i=1}^n \left(\sum_{j=1}^m \mathbf{r}_j \mathbf{t}_{ij}^x + \kappa t_i^{nc} + c t_i^c + d t_i^\ell \right) \tag{3.19}$$

. These are elements that in the previous definition of the social planner's problem under the market policy CAP regime were ignored.

The associated Kuhn-Tucker necessary conditions by which social optimum equilibrium values of individual farmer's production choices are being assessed are given as:

$$FOC_x^{SP} : P\frac{\partial f(\mathbf{x}, L^c)}{\partial x_{ij}} - w + \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}, L^c)}{\partial x_{ij}^e}\beta_i\left(1 - t_i^x\right) = 0 \tag{3.20}$$

if $\tilde{x}_{ij}^{SP} > 0$

or $\dfrac{\partial SW}{\partial x} < 0 \qquad$ if $\tilde{x}_{ij}^{SP} = 0$

$$FOC_{bf}^{SP} : -P\frac{\partial f(\mathbf{x}, L^c)}{\partial L^c} - \tag{3.21}$$

$$\frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\left[\frac{\partial e_i}{\partial L_e^c}\beta_i\left(1 - t_i^c\right) - \frac{\partial e_i}{\partial L_e^{nc}}\beta_i\left(1 + t_i^{nc}\right)\right] \text{ if } \tilde{b}_{SP}^f > 0$$

or $\dfrac{\partial SW}{\partial b^f} < 0 \qquad$ if $\tilde{b}_{SP}^f = 0$

$$FOC_\ell^{SP} : P\frac{\partial f(\cdot)}{\partial \ell_y^e}\left(1 + t_i^\ell\right) - v + \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}, L^c)}{\partial \ell_e^e}\beta_i\left(1 - t_i^\ell\right) \tag{3.22}$$

if $\tilde{\ell}_{SP} > 0$, or $\dfrac{\partial SW}{\partial b^f} < 0 \qquad$ if $\tilde{\ell}_{SP} = 0$

$$FOC_{t_{ij}^x}^{SP} : -r - \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}, L^c)}{\partial x_{ij}^e}\beta_i x_{ij} = 0 \tag{3.23}$$

if $\tilde{t}_{SP}^x > 0$

or $\dfrac{\partial SW}{\partial b^f} < 0 \qquad$ if $\tilde{t}_{SP}^x = 0$

$$FOC_{t^c}^{SP} : -c - \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}, L^c)}{\partial L_e^c}\beta_i L^c = 0 \qquad \text{if } \tilde{t}_{SP}^c > 0 \tag{3.24}$$

or $\dfrac{\partial SW}{\partial b^f} < 0 \qquad$ if $\tilde{t}_{SP}^c = 0$

$$FOC_{t^{nc}}^{SP} : -k - \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}, L^c)}{\partial L_e^{nc}}\beta_i\left(\bar{L} - L^c\right) = 0 \quad \text{if } \tilde{t}_{SP}^{nc} > 0 \tag{3.25}$$

or $\dfrac{\partial SW}{\partial b^f} < 0 \qquad$ if $\tilde{t}_{SP}^{nc} = 0$

$$FOC_{t^\ell}^{SP} : P\frac{\partial f(\cdot)}{\partial \ell_y^e}\ell - d - \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}, L^c)}{\partial \ell_e^e}\beta_i \ell = 0 \quad \text{if } \tilde{t}_{SP}^\ell > 0 \tag{3.26}$$

or $\dfrac{\partial SW}{\partial b^f} < 0 \qquad$ if $\tilde{t}_{SP}^\ell = 0$

It is evident that the socially optimal equilibrium values of the main and secondary production choices are defined as a function of the product's market price (P), the input and labor purchase price

(w, v) along with the per unit costs of treatments (r, c, κ, d).

According to the condition (3.20) and (3.22) the $j = 1, ..., m$ inputs and labor must be employed up to the point that the associated marginal costs from their market purchase and the land quality deterioration are equated with the associated marginal market revenues respectively. In the same context, condition (3.21) equates marginal revenues from the enhancement of aggregate land quality with marginal costs in terms of foregone market revenues due to the shrink of cultivated land area. Finally, conditions (3.23) to (3.25) define the social optimum values of the given treatments that equate marginal revenues from the reduction of social damage with marginal costs from their market purchase, while according to the condition (3.26) labor is being treated up to the point that marginal revenues from production and aggregate land quality enhancement are set equal to the marginal costs from the purchase of the given production choice in the competitive market.

3.5.1 Optimal CMOs and Rural Development CAP Measures in a Static Context

Given the large set of production choices, the simultaneous assessment of the socially optimum CAP measures both under the common market organizations and the rural development CAP regime is technically demanding. Henceforth, to facilitate and simplify analysis the farmer $i's$ set of production choices is restricted to three choice variables, two main production choices and one secondary production choice, while the rest choices are treated as fixed. Given the identical structure of the maximization problems (3.3) and (3.4) under the different production subsets, the analysis is undertaken only for a subset and the findings are generalized for the rest subcases of production choices.

Assume thus that the farmer's set of choice variables involve solely the decision of a single input (x_{ij}) and land usage $\left(b_i^f\right)$, along with the decision of the treatment $\left(t_{ij}^x\right)$ on the usage of the x_{ij} input. The optimality conditions of the deviating farmer and the social planner are restricted to three expressions that define a system the solution of which provides the form of the CMOs and / or Pillar II CAP instruments that induce the initial agent to adopt the socially optimal production choices $\left(\tilde{x}_i^{SP}, \tilde{b}_{SP}^f, \tilde{t}_{SP}^x\right)$. Given the fact that the number of externalities is less than the number of instruments introduces a further source of interdependence in the definition of the optimal CAP instruments, involving that the defined system allows the simultaneous definition only of three CAP measures for fixed values of the rest CAP measures.

Hence, the system defined by the optimality condition for the deviating farmer and the social planner is given by:[30]

$$
\begin{aligned}
& P(1+s)\check{\alpha}_1 + \left[\sigma_1 \check{L}^c + \tilde{R}D\right] p\gamma\check{\beta}_1\beta_i\left(1-\check{t}^x\right) = && (3.27)\\
& P\alpha_1^{SP} + \delta_1\beta_i\left(1-\tilde{t}_{SP}^x\right) && \\
& \alpha_2^{SP}\left[\sigma_2\left\{1-p\gamma B\right\} - \sigma_1\left\{1-p\gamma A\right\} + \right. && (3.28)\\
& \left.\left[\sigma_1\check{L}^c + \tilde{R}D\right] p\gamma\beta_i\left(\check{\beta}_2\left(1-\check{t}^c\right) - \check{\beta}_3\left(1+\check{t}^{nc}\right)\right)\right] = && \\
& (1+s)\check{\alpha}_2\beta_i\left[\delta_3\left(1+\tilde{t}_{SP}^{nc}\right) - \delta_2\left(1-\tilde{t}_{SP}^c\right)\right] && \\
& \left[\sigma_1\check{L}^c + \tilde{R}D\right] p\gamma\check{\beta}_1\beta_i\tilde{x}^{SP} + rs^x\left\{1-p\gamma A\right\} - rs^x && (3.29)\\
= \; & \delta_1\beta_i\tilde{x}^{SP} &&
\end{aligned}
$$

allowing also the determination of the type of correlation between the elements of the Mid-term CAP reform.

Given the large number of combinations of optimal CAP measures that can be assessed by the system (3.27) to (3.29), emphasis is given on three representative CAP pairs including: (i) production subsidy, land-usage direct payment and subsidy for input usage treatment, (ii) production subsidy, set-aside direct payment and subsidy for input usage treatment, along with the pair involving (iii) production subsidy, subsidy for input usage treatment and cross-compliance term.

In particular, the following socially optimal CAP pairs have been assessed:

- 1^{st} optimal CAP pair: $\tilde{s}, \tilde{\sigma}_1, \tilde{s}^x$

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[30] Let $\alpha_1^{SP}, \alpha_2^{SP}$ 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 $\delta_1, \delta_2, \delta_3$ denote the impact of social optimum choices on social damage. It needs to be made clear that: $\check{\beta}_3 = \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}, L^c)}{\partial L^c}$ ... and $\delta_3 = \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}^{SP}, L_{SP}^c)}{\partial L^c}$ that both expressions are positive and represent the impact of set-aside decision on the individual land quality index and social damage respectively.

In a static context the expressions of the socially optimum coupled payment ($\tilde{s}$), land-usage direct payment ($\tilde{\sigma}_1$) and rural development subsidy for input usage treatment ($\tilde{s}^x$) are given by:[31]

$$\tilde{s} = \tag{3.30}$$
$$\frac{1}{P\breve{\alpha}_1}\left[P\left(\alpha_1^{SP}-\breve{\alpha}_1\right)+\delta_1\beta_i\left(1-t_{SP}^x\right)-\left(\tilde{\sigma}_1\check{L}^c+\tilde{R}D\right)p\gamma\breve{\beta}_1\beta_i\left(1-\check{t}^x\right)\right]$$

$$\tilde{\sigma}_1 = \tag{3.31}$$
$$\left[\breve{\alpha}_2\Delta\left\{\frac{1}{P\breve{\alpha}_1}\left[P\left(\alpha_1^{SP}-\breve{\alpha}_1\right)+\delta_1\beta_i\left(1-t_{SP}^x\right)-\tilde{R}Dp\gamma\breve{\beta}_1\beta_i\left(1-\check{t}^x\right)\right]-1\right\}\right.$$
$$\left.-\alpha_2^{SP}\left[\sigma_2\left\{1-p\gamma B\right\}+\tilde{R}Dp\gamma\beta_i\Gamma\right]\right]\Big/$$
$$\left[\alpha_2^{SP}\left\{\check{L}^c p\gamma\beta_i\Gamma-(1-p\gamma A)\right\}+\frac{\breve{\alpha}_2}{P\breve{\alpha}_1}\Delta\check{L}^c p\gamma\beta_i\breve{\beta}_1\left(1-\check{t}^x\right)\right]$$

$$\tilde{s}^x = \tag{3.32}$$
$$\check{L}^c p\gamma\breve{\beta}_1\beta_i\breve{x}\alpha_2^{SP}\left[\frac{\breve{\alpha}_2}{P\breve{\alpha}_1}\Delta\left[P\left(\alpha_1^{SP}-\breve{\alpha}_1\right)+\delta_1\beta_i\left(1-t_{SP}^x\right)-\sigma_2\left\{1-p\gamma B\right\}\right]-\right.$$
$$\left.E\delta_1\beta_i\tilde{x}^{SP}\right]/$$
$$p\gamma\left[\check{L}^c p\gamma\breve{\beta}_1\beta_i\breve{x}r\check{t}^x\left(\frac{\breve{\alpha}_2}{P\breve{\alpha}_1}\breve{\beta}_1\beta_i\left(1-\check{t}^x\right)+\alpha_2^{SP}\Gamma\right)-Er\left(\check{t}^x\breve{\beta}_1\beta_i\breve{x}-A\right)\right]$$

It is worth mentioning that under the non-enforcement of the environmental consideration (*i.e.* p or $\gamma=0$) the expression (3.32) of the rural development subsidy for input usage treatment $\tilde{s}^x$ can not be defined. It is evident that:

Remark 20 *Under certain conditions an intervention CAP regime characterized by fully or partially coupled payments can be the socially optimal choice, while a transition to a regime characterized solely by rural development subsidies as involved by the Mid-term Review is socially suboptimal.*

The rural development CAP regime is the optimum type of policy intervention if (3.30) and (3.31) are both zero and (3.32) is nonzero and positive expression.

Even though the given structure of CAP as described by Agenda

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[31] Where $\Delta=\delta_3\left(1+\tilde{t}_{SP}^{nc}\right)-\delta_2\left(1-\tilde{t}_{SP}^{c}\right)$, $\Gamma=\left(\breve{\beta}_2\left(1-\check{t}^c\right)-\breve{\beta}_3\left(1+\check{t}^{nc}\right)\right)$ and $E=\alpha_2^{SP}\left[1-p\gamma(A-\check{L}^c\Gamma)\right]+\frac{\breve{\alpha}_2}{P\breve{\alpha}_1}\Delta\check{L}^c p\gamma\beta_i\breve{\beta}_1\left(1-\check{t}^x\right)$

2000 reform involves only the provision of subsidies on crop yields, land usage and established input usage treatments, the assessed optimum expression of the given CMOs and Pillar II CAP measures may involve the opposite. This implies that the maximization of the social welfare criterion requires that farmers are imposed charges instead of being provided subsidies on the given production choices. However, if such a scenario occurs the attainment of the first-best aggregate quality target is infeasible given the fact that such charges are not involved in Agenda 2000 structure.

The estimation of the total derivatives of the expressions (3.30) to (3.32) with respect to the rest CAP measures provides an insight regarding the type of interdependencies between the elements of the optimal CAP pair and the rest CAP measures, so that if a CAP measure is being modified then the optimal CAP pair is altered to the analogous direction in order to retain farmer's production choices at the social optimum level. Analysis indicated that there is associated uncertainty about the type of correlation between the optimum pair $(\tilde{s}, \tilde{\sigma}_1, \tilde{s}^x)$ and the rest CAP measures, which can be defined only under restrictive assumptions. The only evident type of correlation is the one relating the optimum rural development subsidy on input usage treatment $\tilde{s}^x$ and the optimum CMOs coupled $(\tilde{s})$ and decoupled payment $(\tilde{\sigma}_1)$. In particular, it holds:

$$\begin{aligned}\frac{d\tilde{s}}{d\tilde{s}^x} &= -\frac{1}{P\breve{\alpha}_1}p\gamma\breve{\beta}_1\beta_i\left(1-\breve{t}^x\right) \text{ and}\\ \frac{d\tilde{\sigma}_1}{d\tilde{s}^x} &= -\frac{\breve{\alpha}_2 r\breve{t}^x p\gamma\beta_i}{E}\left\{\frac{1}{P\breve{\alpha}_1}\Delta\breve{\beta}_1\left(1-\breve{t}^x\right)+\alpha_2^{SP}\Gamma\right\}\end{aligned}$$

indicating that if the provided value of the rural development $\tilde{s}^x$ is altered then the optimum coupled payment $\tilde{s}$ needs to be modified to the analogous direction, while the optimum land-usage direct payment to the opposite direction.

- 2^{nd} optimal CAP pair: $\tilde{s}, \tilde{\sigma}_2, \tilde{s}^x$

The expression of the socially optimum coupled payment $\tilde{s}$ is similar to the previous expression with the only modification that it is no longer a function of the optimum land-usage direct payment $(\tilde{\sigma}_1)$. On the other hand, the expression of the optimum rural development subsidy for input usage treatment $\tilde{s}^x$ is quite modified and along with the expression of the optimum set-aside direct payment is given by:

$$\tilde{\sigma}_2 = \tag{3.33}$$
$$-\frac{\alpha_2^{SP}\left\{\left(\sigma_1 \check{L}^c + \tilde{R}D\right)p\gamma\Gamma - \sigma_1\left(1 - p\gamma A\right)\right\} - (1+\tilde{s})\check{\alpha}_2\Delta}{1 - p\gamma B}$$

$$\tilde{s}^x = \frac{\delta_1\beta_i\tilde{x}^{SP} - \sigma_1\check{L}^c p\gamma\check{x}\check{\beta}_1\beta_i}{rp\gamma\left(\check{t}^x\check{x}\check{\beta}_1\beta_i -\right)} \tag{3.34}$$

The type of the optimum CAP measures involved by the expressions (3.33) and (3.34) is uncertain given the fact that their sigh cannot be clearly inferred. Therefore, the socially optimum CAP regime can require either nonintervention if and the three expressions are simultaneously equal to zero,[32] intervention via a partially decoupled regime if solely (3.34) is zero, or intervention though an extended partially decoupled regime with rural development subsidies if all expressions are nonzero. In the special case that the optimal pair $(\tilde{s}, \tilde{\sigma}_2, \tilde{s}^x)$ involves charges on the given production choices the attainment of the first-best aggregate land quality infeasible given the fact that such kind of penalties are not foreseen in the CAP regime.

- 3^{rd} optimal CAP pair: $\tilde{s}, \tilde{s}^x, \tilde{\gamma}$

Given that the expression of the socially optimum coupled payment $\tilde{s}$ is given similarly to the expression (3.30), the rest elements of the particular optimal CAP pair given by the expressions:[33]

[32] This also involves that the rest CAP measures: land usage premium, subsidy on set-asided and cultivated land, along with the subsidy on labor usage, are zero.

[33] Where $\Lambda = \left\{\check{\alpha}_2\Delta + \frac{1}{P\check{\alpha}_1}\left(P\left(\alpha_1^{SP} - \check{\alpha}_1\right) + \delta_1\beta_i\left(1 - t^x_{SP}\right)\right) - \frac{\check{t}^x\delta_1\beta_i\tilde{x}^{SP}}{\check{t}^x\check{x}\check{\beta}_1\beta_i - A}\left[\alpha_2^{SP}\Gamma + \frac{1}{P\check{\alpha}_1}\check{\beta}_1\beta_i\left(1 - \check{t}^x\right)\right]\right\}.$

$$\tilde{s}^x = \tag{3.35}$$
$$\left\{\delta_1\beta_i\tilde{x}^{SP}P\left\{\sigma_1\check{L}^c\left[\alpha_2^{SP}\Gamma+\frac{1}{P\check{\alpha}_1}\check{\beta}_1\beta_i\left(1-\check{t}^x\right)\right]+(\sigma_1 A-\sigma_2 B)\right\}\right.$$
$$\left.-\sigma_1\check{L}^c p\Lambda\check{\beta}_1\beta_i\check{x}\right\}\div$$
$$r\left(\check{t}^x\check{x}\check{\beta}_1\beta_i-A\right)\left\{\sigma_1\check{L}^c\left[\alpha_2^{SP}\Gamma+\frac{1}{P\check{\alpha}_1}\check{\beta}_1\beta_i\left(1-\check{t}^x\right)\right]+(\sigma_1 A-\sigma_2 B)\right\}$$

$$\tilde{\gamma}=\left\{\check{\alpha}_2\Delta+\frac{1}{P\check{\alpha}_1}\left(P\left(\alpha_1^{SP}-\check{\alpha}_1\right)+\delta_1\beta_i\left(1-t_{SP}^x\right)\right)-\right. \tag{3.36}$$
$$\left.\frac{\check{t}^x\delta_1\beta_i\tilde{x}^{SP}}{\check{t}^x\check{x}\check{\beta}_1\beta_i-A}\left[\alpha_2^{SP}\Gamma+\frac{1}{P\check{\alpha}_1}\check{\beta}_1\beta_i\left(1-\check{t}^x\right)\right]\right\}\div$$
$$P\left\{\sigma_1\check{L}^c\left[\alpha_2^{SP}\Gamma+\frac{1}{P\check{\alpha}_1}\check{\beta}_1\beta_i\left(1-\check{t}^x\right)\right]+(\sigma_1 A-\sigma_2 B)\right\}$$

The fact that the sign of the expression (3.36) is ambiguous can imply either that the nonenforcement of environmental consideration in the event of detected deviating behavior is socially optimal (*i.e.* $\tilde{\gamma}=0$) if the expression is zero, or that further financial assistance should be provided to detected deviating farmers (*i.e.* $\tilde{\gamma}<0$) if the expression is negative.

It is worth reminding that if the first-best aggregate quality target is to be attained then both CMOs and rural development CAP measures need to be differentiated among European farmers given their heterogeneity. However, such an intervention policy that is adaptable to the individual characteristics of farmers is not feasible in practice not only due to both the enormous informational or / and administrative requirements it involves, but also due to the legal limitation regarding the available set of instruments of the communal agricultural policy.

3.5.2 Optimal CMOs and Rural Development CAP Measures in a Dynamic and Evolutionary Context

The problem of the social planner can also be defined in a dynamic context in order to define the optimal path of both main and secondary production choices $\mathbf{x}_i^{SP}$ and $\mathbf{b}_{SP}^f$ for each $i=1,...,n$ individual farmer so that to maximize the current value of the net social benefit from agricultural activities subject to the evolution of aggregate land quality as described by (2.27). The maximization problem is:

$$\max_{\mathbf{x}_{ij},L_i^c,\ell,\mathbf{t}_{ij}^x,t_i^c,t_i^{nc},t_i^\ell} \int_0^\infty e^{-rt}\left[\int_0^{\sum y} F(u)du - \mathbf{w_j x} - \mathbf{v}\ell - \mathbf{TC} - D(Z)\right] dt$$
$$st. \quad \dot{Q}^T = b\left(Q^T\right) - g(\mathbf{x}, \mathbf{L}^C)$$

Under the assumption that individual farmers are myopic and after following the standardized procedure a system defined by the static optimality conditions of the deviating farmer and the dynamic optimality conditions of the social planner is assessed. The solution of the system provides the expressions of the dynamic socially optimum CAP measures. Given the fact that the structure of the assessed system is analogous to the static system (3.27) to (3.29), with the only exception that an additional term is introduced containing the Hamiltonian multiplier (μ) that represents the dynamic shadow value of the aggregate land quality Q^T. Hence the expressions of the dynamic socially optimum CAP measures are identical to the static optimal expressions.

By employing the evolutionary framework described in the previous part of the report, the type and range of values of both the given CMOs and rural development CAP measures can be assessed, providing policy implications about the proper design of the communal agricultural policy so that the majority or even the totality of farmers within a given geographical region are induced over time to adopt the compliant behavioral rule.

Under the generalized CAP regime containing both Pillar I and Pillar II measures, the evolution of the compliant behavioral rule is given by the following replicator dynamic equation:

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

The divergence $\left(\pi_i^C - \pi_i^{NC}\right)$ between the payoff of the compliant and deviating strategy can be decomposed into the following elements:

- $P(1+s)\Delta_{NC}^{C}(f(\cdot))$: the divergence of the two strategies in terms of market revenues and coupled payments.
- $w\Delta_{NC}^{C}(x)+v\Delta_{NC}^{C}(\ell)+\Delta_{NC}^{C}(TC^o)$: the divergence of purchase costs of input and land usage, as well as the establishment and maintenance costs of treatments under the two behavioral rules.
- $(\sigma_1-\sigma_2)\,\Delta_{NC}^{C}(L_i^c)$: the divergence of the two behavioral rules in terms of direct payments.
- $\Delta_{NC}^{C}(RD)$: the divergence of the two behavioral rules in terms of provided rural development subsidies.
- $p\gamma\left[\left(\sigma_1\check{L}^c+\tilde{R}D\right)\left(\bar{Q}_i-Q_i^{NC}\right)+\sigma_2\left(\bar{L}_i-\check{L}^c\right)\left(\check{L}^c-\tilde{L}^c\right)\right]$: the amount of decoupled payments and rural development subsidies removed by the farmer i if found into deviation from the environmental considerations incorporated in direct payments regime.

Given the identical structure of the replicator dynamic equation under the extended partially decoupled regime (EPD) compared to the associated replicator equation (2.31) under the presence solely of CMOs payments, the analysis is not repeated. It is just inferred that under the assumption that both compliant and deviating farmers are myopic and "hard wired" to their strategy the critical rural development subsidy $\ddot{s}^{x}$ setting the profit divergence $\left(\pi_i^C-\pi_i^{NC}\right)$ equal to zero is given by the expression:

$$
\begin{aligned}
\ddot{s}^{x} = {} & [w\Delta_{NC}^{C}(x)+v\Delta_{NC}^{C}(\ell)+\Delta_{NC}^{C}(TC^o)- \\
& P(1+s)\Delta_{NC}^{C}(f(x,L_i^c,(1+t^{\ell})\ell)) \\
& -(\sigma_1-\sigma_2)\,\Delta_{NC}^{C}(L_i^c)- \\
& \sigma_2 p\gamma\left(\bar{L}_i-\check{L}^c\right)\left(\check{L}^c-\tilde{L}^c\right)-\Delta_{NC}^{C}(RD-rs^xt^x) \\
& -p\gamma\left(\sigma_1\check{L}^c+\left(\tilde{R}D-rs^xt^x\right)\right)\left(\bar{Q}_i-Q_i^{NC}\right)\Big]\div \\
& \left[rt^x\left(1+p\gamma\left(\bar{Q}_i-Q_i^{NC}\right)\right)\right]
\end{aligned}
\tag{3.37}
$$

The fact that the sign of the expression (3.37) is uncertain implies that the attainment of the target of full compliance may not be feasible. This can be the case if the critical rural development payment $\ddot{s}^{x}$ involves a penalty on established input usage treatment, instrument that however is not foreseen by the current CAP structure.

Part II

Estimating Individual Nitrate Leaching in Agricultural Non-Point-Source Pollution: The Entropy Approach, Theory and a Case Study

4

The Maximum Entropy Approach

4.1 Introduction

In developing effective information processing rules we are restricted, in many instances, by the fact that the underlying surveyed sample is incomplete or incorrectly specified. This is a usual problem encountered in economics and social sciences in general are non-experimental and the data generation is restricted. In these cases, the passively generated data that are available in applied economic practice are limited, partial, aggregated and usually incomplete. Under these constraints, achieving a tractable econometric model may not be possible and conventional econometric techniques may fail to determine a unique solution. When this occur, we define the problem as ill-posed, ill-determined or logically indeterminate. As Jaynes (1984) has noted, when ill-posed problems arise, creative assumptions or prior information are used to induce a well-posed problem that is amenable to solution by one of the existing formulations in the traditional econometrics textbooks. However, this working route may equally lead to erroneous interpretations and conclusions about the real economic phenomena. Although in a traditional sense we do not know about a situation we would like the principle or formalism we are using to give us the best conclusions possible based on the data at hand. One potential candidate is the entropy formalism which is used to measure information acquisition and estimate unobservable parameters from undersized sample. Both of these uses rely on the seminal work of Shannon (1948) who first introduced the entropy formalism as a measure of the expected information contained in a noisy message.[1] Later on Jaynes (1984) and Kullback (1959) expanded Shannon's information entropy developing methods to be used in problems of statistical inference.

[1] Actually the entropy concept has a rich history dating back to Boltzman (in the 1870's) as well as Maxwell and Gibbs and related work by Bernoulli and Laplace.

For example in real economic activities we can observe on an individual or some other aggregate basis, data on inputs and outputs but we cannot observe the corresponding marginal products or the output elasticities of utilized inputs. Therefore, in order to recover the unknown parameters of interest, we are faced with an inverse problem that may be formalized in the following way. We observe the outcome of an economic activity (i.e., output produced) denoted by $\mathbf{y}$. However, our interest is the unknown and unobserved variable (i.e., output elasticity) $\boldsymbol{\beta}$ which may be a number, vector or function. Since we cannot measure $\boldsymbol{\beta}$ directly, in order to recover it we must use indirect measurements on the observables. In this context consider the following finite, discrete linear inverse problem of the form:

$$\mathbf{y} = \mathbf{x}\boldsymbol{\beta} = \mathbf{x}\mathbf{p} \tag{4.1}$$

where, $\mathbf{y} = \{y_1, ..., y_T\}^{'}$ is a $T-$dimensional vector of observations on output, $\boldsymbol{\beta}$ is the $K-$dimensional vector of unobservable unknowns, $\mathbf{x}$ is a known non-invertible (TxK) linear operator with $K > T$ from which we want to determine the unknown and unobservable frequencies that represent the data generating process. Hence, out of all the probability distributions that satisfy relation (4.1) and fulfill the conditions $\sum_{k=1}^{K} p_k = 1 \ \forall p_k \geq 0$, we need to recover unambiguous probabilities p_k. Given that the data points are less than the number of unknowns, in its present form the problem is ill-posed and the basis of assigning a probability is, at this point unresolved.

In situations like these, Shannon ideas can be used to resolve the problem. Shannon wanted some basis to measure the uncertainty in the mind of someone about to receive a noisy message.[2] Since it is traditional to use probability as a measure to uncertainty we have about the occurrence of a single event, Shannon used the axiomatic method to define a unique function to measure uncertainty of a collection of events. Suppose there are K possible outcomes for some future event and the discrete probability distribution $\{p_1, ..., p_K\}$ can be used to explain outcomes as in our example above. Intuitively, if we assume that a particular outcome is very likely to happen we will

[2] Shannon's (1948) work stemmed from the need to code / decode noisy messages as part of the WWII information transfer problem. A discussion of the axioms underlying maximum entropy formalism can be found in Theil (1967).

not be surprised if it happens. Alternatively, if a future event has a low probability and it occurs, we might well be surprised by its occurrence. In information theory it is assumed that the information contained in an observation is inversely proportional to its probability. Letting $\mathbf{x}$ be a random variable with possible outcome values x_k, $k = 1, ..., K$ and probabilities p_k such that $\sum_{k=1}^{K} p_k = 1$, Shannon defined the entropy of the distribution probabilities $\mathbf{p} = \{p_1, ..., p_K\}^{'}$ as the measure

$$H(\mathbf{p}) = -\sum_{k=1}^{K} p_k \ln p_k = -\mathbf{p}^{'} \ln \mathbf{p} \tag{4.2}$$

where $\mathbf{0} \cdot \ln(\mathbf{0}) = \mathbf{0}$. This is the minus expectation of the logarithms of the probabilities which is a measure of uncertainty or missing information in Shannon's original thoughts. When $p_k = 0\ \forall k$ then $H(\mathbf{p}) = 0$. On the other hand, it reaches a maximum when $p_1 = p_2 = ... = p_k = 1/K$ or in other words when the probabilities are uniform which follows from the "*principle of insufficient reason*". If it happens to be the case that the expected information generated by an event is zero, this means that the prior distribution is degenerate and the only possible outcome occurs with certainty. The Shannon measure of entropy can therefore be viewed as a distance measure between the discrete uniform distribution and the distribution degenerating $\mathbf{p}$.

Based on the work of Shannon, Jaynes (1957a, b) proposed a means by which to recover the unknown probabilities, $\mathbf{p}$. In particular, Jaynes argued that if particular moments (means, variances, skew ness etc) of the probability distribution generating the data were viewed as constraints on the entropy measure $H(\mathbf{p})$, usually two or more feasible distributions could be found. In other words, under what Jaynes called the *maximum entropy* (ME) principle, one chooses the distribution for which the information (i.e., data) is just sufficient to determine the probability assignment. Hence, maximizing the Shannon's entropy measure subject to the limited, aggregated data in (4.1), we obtain the frequency distribution of p_k that can be realized in the greatest number of ways consistent with what we know. Thus if one is asked which particular set of relative frequencies we consider the best approximation for the p_k, it seems reasonable to follow Jaynes and favor the one that could have been generated in the greatest number of ways consistent with what we know from the data at hand. This means that we choose the $\mathbf{p}$ that maximizes

$$\max_{\mathbf{p}} H(\mathbf{p}) = -\sum_{k=1}^{K} p_k \ln p_k = -\mathbf{p}^{'} \ln \mathbf{p} \tag{6.3a}$$

subject to *moment-consistency* constraints

$$\mathbf{y} = \mathbf{xp} \tag{6.3b}$$

and the *adding up-normalization* constraint

$$\mathbf{p}^{'}\mathbf{i} = 1 \tag{6.3c}$$

where $\mathbf{i}$ is an $(Kx1)$ vector of ones and $ln\mathbf{p}$ is a $(Kx1)$ vector. Hence, the problem has been converted from one of deductive mathematics to one of inference where one seek to make best predictions possible from the information that we have. Through the use of the maximum entropy principle we have a basis for using or transforming the data into a distribution of probabilities describing our state of knowledge. Thus, in the maximum entropy approach we take into account not only the data, but also the relevant information about the multiplicity of all the different outcomes.[3]

The Lagrangian function of the above maximization problem can be formalized as:

$$L = -\mathbf{p}^{'} \ln \mathbf{p} + \boldsymbol{\lambda}^{'}(\mathbf{y} - \mathbf{xp}) + \mu \left(1 - \mathbf{p}^{'}\mathbf{i}\right) \tag{6.4}$$

with the optimality conditions given by:

$$\frac{\partial L}{\partial \mathbf{p}} = -\ln \mathbf{p} - \mathbf{i} - \mathbf{x}^{'}\hat{\boldsymbol{\lambda}} - \hat{\mu} = 0 \tag{6.5a}$$

$$\frac{\partial L}{\partial \boldsymbol{\lambda}} = \mathbf{y} - \mathbf{x}^{'}\hat{\mathbf{p}} = 0 \tag{6.5b}$$

$$\frac{\partial L}{\partial \mu} = 1 - \hat{\mathbf{p}}^{'}\mathbf{i} = 0 \tag{6.5c}$$

---

[3] Axiomatic arguments for the justification of the ME principle have been made by Shore and Johnson (1980), Jaynes (1984), Skilling (1989) and Csiszar (1991). Golan et al., 1996 provide an in-depth analysis for the relevant concepts.

$>$From the above optimality conditions we can solve for $\hat{\mathbf{p}}$, in terms of $\hat{\boldsymbol{\lambda}}$ to get the following solutions:

$$\hat{\mathbf{p}} = \exp\left[-\frac{\mathbf{x}'\hat{\boldsymbol{\lambda}}}{\boldsymbol{\Omega}\left(\hat{\boldsymbol{\lambda}}\right)}\right] \tag{6.6a}$$

where

$$\boldsymbol{\Omega}\left(\hat{\boldsymbol{\lambda}}\right) = \sum_{k=1}^{K} \exp\left(-\mathbf{x}'\hat{\boldsymbol{\lambda}}\right) \tag{6.6b}$$

is the normalization factor that converts the relative probabilities into absolute probabilities known as the *partition matrix.* The $\hat{\boldsymbol{\lambda}}$ is the $(Tx1)$ vector of the Lagrange multipliers on the constraints in (6.3b) which are determined by the T simultaneous equations:

$$y_t = \left(\frac{\partial}{\partial \lambda_t}\right) \ln \boldsymbol{\Omega} \qquad for \qquad 1 \leq t \leq T \tag{6.7}$$

Similar to all optimization problems, the Lagrange multipliers reflect the change in the objective value as a result of a marginal change in the constraint set. That is the Lagrange multipliers are just the partial derivatives of $max\,\{H\}$ with respect to y_t, and as such are *marginal entropies.* However, for the ME formalism, the Lagrange multipliers have more meaningful economic interpretation that changes from problem to problem. For instance in estimating the size distribution of firms, a common application of ME formalism in economics, the multipliers are used to determine the scale properties of the industry. Generally speaking, the λ's reflect the more traditional notion of relative contribution of each data point-constraint to the optimal objective value. Consequently the multipliers reflect the information content of each constraint in (6.3b). for instance if $\lambda_t = 0$ implies that the t^{th} constraint is redundant and has no informational value and, as such, does not reduce the maximum entropy level or the level of uncertainty.

In this characterization of the ME formalism, which is designed to solve pure ill-posed or ill-determined problems, it should be noted that all possible states are assumed equally likely and no prior assumptions or constraints are imposed on the data set. That is, we seek a distribution of probabilities $\mathbf{p}$ that only describes what we know. Maximizing the entropy subject to no data constraints (i.e., without 6.3b and 6.3c) yields a uniform distribution. The constraints restrict the initial missing information and the ME formalism seeks a solution that maximizes the missing information contained in the data. As formulated, the traditional ME formalism is a non-linear inversion procedure for solving inverse problems where the object to be recovered is known to be positive. By letting the discrete covariate to tend to infinity, a continuous probability distribution formulation of the entropy formalism can be formulated.

In order to measure the information content in a system and the importance of contribution of each piece of data or constraints in reducing uncertainty, Golan (1994) and Soofi (1992; 1994) introduced the *normalized-entropy measure*. In the simple ME formulation, the maximum level of uncertainty results when moment constraints in (6.3b) are not enforced and the distribution of the probabilities over the K different states is uniform. As we add each piece of effective data, a departure from the uniform distribution results and implies a reduction of uncertainty. The proportion of the remaining total uncertainty is measured by the normalized entropy:

$$S(\hat{\mathbf{p}}) = \left(-\sum_{k=1}^{K} \hat{\mathbf{p}}_k \ln \hat{\mathbf{p}}_k \right) \Big/ \ln K \tag{6.8}$$

where $S(\hat{\mathbf{p}}) \in [0, 1]$ and where $\ln K$ represents maximum uncertainty. A value $S(\hat{\mathbf{p}}) = 0$ implies no uncertainty, that is $p_k = 0$, for some k and for all $j \neq k$. On the other hand, when $S(\hat{\mathbf{p}}) = 1$ implies perfect certainty of the outcomes, that is, $p_k = 1 \ \forall k$. An analog measure $1 - S(\hat{\mathbf{p}})$, called the information index, serves to measure the reduction in uncertainty. Since $S(\hat{\mathbf{p}})$ is a relative measure of uncertainty, it can be utilized to compare different cases or scenarios. For instance it can be used to compare the information embodied in data set once we add or delete a data point. Specifically, if the normalized entropy measure after the deletion of one data point is greater than that with the complete information set, it means that the excluded piece of information provide us a better more informed set of recovered probabilities and reduces the uncertainty about the unknown recovered vector of parameters $\boldsymbol{\beta}$.

It is possible to generalize further the definition of entropy by allowing the possibility that the information that is received does not guarantee that a particular event has occurred. We can think of this as being non-sample information or conceptual knowledge exists and relates to the properties of the system. If we have this kind of information about the unknown probabilities, **p**, this can be expressed in terms of a prior probability distribution vector, **q**. The prior probability distribution can help to improve the accuracy of the estimates we derive from the data for **p** using maximum entropy. Following Kullback (1959), when non-sample information is incorporated yields the principle of cross-entropy (CE). Theil (1967) referred to this form of non-sample information as an indirect message. In contrast to the maximum entropy pure inverse problem framework, in this instance, the objective may be reformulated to minimize the entropy distance between the data in the form of **p** and the prior beliefs **q**. That is, the underlying principle is that of probabilistic distance or divergence between the two. Following Good (1963), one minimizes the cross-entropy between the probabilities that are consistent with the information in the data and the prior information **q**. The objective is to find out of all the distributions of probabilities satisfying the constraints, the one closest to **q**. This leads to the cross entropy between **p** and **q** to be defined as follows:

$$\min_{\mathbf{p}} I(\mathbf{p};\mathbf{q}) = \sum_{k=1}^{K} p_k \ln\left(\frac{p_k}{q_k}\right) = -\mathbf{p}^{'} \ln \mathbf{p} - \mathbf{p}^{'} \ln \mathbf{q} \tag{6.9}$$

subject to the consistency and normalization constraints in (6.3b) and (6.3c), respectively. As before the probability vector **p** is recovered by forming the Lagrangean function and the associated optimality conditions defined in a similar way with (6.5a) though (6.5c). Solving the system of $T + K + 1$ equations yields $\hat{\mathbf{p}}$, $\hat{\boldsymbol{\lambda}}$, and $\hat{\boldsymbol{\mu}}$. The formal solution, equivalent to (6.6a) and (6.6b), that combines the information from the data and the prior is given by:

$$\hat{\mathbf{p}} = \frac{\mathbf{q}^{'} \exp\left(\mathbf{x}^{'}\hat{\boldsymbol{\lambda}}\right)}{\boldsymbol{\Omega}\left(\hat{\boldsymbol{\lambda}}\right)} \tag{6.10a}$$

where

$$\mathbf{\Omega}\left(\hat{\boldsymbol{\lambda}}\right)=\sum_{k=1}^{K} q_k \exp\left(-\mathbf{x}'\hat{\boldsymbol{\lambda}}\right) \tag{6.10b}$$

is again the partition function. If the prior information is consistent with the data then zero information is gained from the data. For values other than zero it means that the non-sample data are providing additional information. It has been noted by Zellner (1988) that there is a close relationship between cross entropy and Bayes in that both are information processing rules that are able to transform prior beliefs and sample information into posterior information.[4] Also the cross entropy specification in relation (6.9) above is equivalent to that in (6.3a) when there is no non-sample information, thus maximum entropy is a special case of cross entropy.

4.2 The Generalized Maximum and Cross Entropy Principles

Although the ideas of maximum and cross entropy have entered the economic and econometric literature there are difficulties in employing the concepts in their traditional form. Both theoretical and applied applications of the entropy formalism in economics have been limited because of technical difficulties. First, the moment conditions in the constraint set in (6.3b) are assumed to be exact and the stated entropy methods do not specifically account for the presence of disturbances. Secondly, the unknown quantities must have some properties of a probability distribution if the Shannon measure of entropy is to be meaningful. In order to cope with the above limitations of the entropy formalism, Judge and Golan (1992) generalized maximum entropy by expressing the unknown parameters and disturbances of the standard econometric problem in terms of discrete probability distributions. To explain how generalized maximum entropy (GME) works, consider the standard regression representation of the following form:

[4] See Lee and Judge (1996), Golan et al., (1996) and Mittelhammer and Cardell (1997) on the nature of the relationship between cross entropy and Bayes.

$$\mathbf{y} = \mathbf{x}\boldsymbol{\beta} + \boldsymbol{\varepsilon} \tag{6.11}$$

where again $\mathbf{y}$ is a $(Tx1)$ vector, $\mathbf{x}$ is the (TxK) non-invertible design matrix, both of which are observed, $\boldsymbol{\beta}$ is a $(Kx1)$ vector of unknowns with $K > T$, and $\boldsymbol{\varepsilon}$ is a $(Tx1)$ vector of disturbances. In order to overcome the difficulties of the maximum and cross entropy, Judge and Gollan (1992), showed that in many cases it was possible to bound $\boldsymbol{\beta}$ and $\boldsymbol{\varepsilon}$, and that these bounds could be used to construct a finite and discrete support for both $\boldsymbol{\beta}$ and $\boldsymbol{\varepsilon}$.

Judge and Golan (1992) proceed by assuming that each β_k in the matrix of coordinates that reflects the unknown and unobservable coefficients, can be viewed as a discrete random variable with a compact support.[5] In other words, for each β_k it is assumed that there exists a discrete probability distribution that is defined over the parameter space $[0,1]$ by a set of equally distanced discrete points $\mathbf{z} = \{z_1, ..., z_M\}^{'}$ with corresponding probabilities with $\tilde{\mathbf{p}} = \mathbf{p}\,\{y_{k1}, ..., p_{kM}\}^{'}$ with $2 \leq M \leq \infty$. M is defined here to be the number of elements in the support. If z_{kl} and z_{Km} are sensible lower and upper bounds on the support then β_k can be expressed as a convex combination of the bounds. This means that there will exist a $p_k \in [0,1]$, and this will hold true for all β_k. Similarly ε_t can be viewed as a discrete random variable with compact support and $2 \leq J \leq \infty$ possible outcomes, where J is the number of support elements. In this reformulation the classical regression model in (6.11) may be rewritten as:

$$\mathbf{y} = \mathbf{x}\boldsymbol{\beta} + \boldsymbol{\varepsilon} = \mathbf{xzp} + \mathbf{vw} \tag{6.12}$$

where $\mathbf{z}$ is a $(KxKM)$ matrix of known support values for $\boldsymbol{\beta}$, $\mathbf{p}$ is a KM vector of unknown probabilities and M is the number of support points. Similarly, $\mathbf{v}$ is a $(TxTJ)$ matrix of unknown support values for $\boldsymbol{\varepsilon}$ and $\mathbf{w}$ is a vector of probability weights $(TJx1)$ such that $w_t \gg 0$ and $w_t^{'}\mathbf{s}_J = 1$ for each t where $\mathbf{s}_J$ is a vector of ones and J is the number of support values chosen for each error w_t. Using this reparameterization it is possible to reformulate the standard

[5] A criticism of ME has been the need to employ discrete probability distributions. Efforts to employ continuous probability distributions are considered by Kitamura and Stutzer (1997).

linear regression model as a generalized maximum entropy (GME) as follows:

$$\max_{\mathbf{p},\mathbf{w}} H(\mathbf{p},\mathbf{w}) = -\sum_{m=1}^{M}\sum_{k=1}^{K} p_{km}\ln p_{km} - \sum_{j=1}^{J}\sum_{t=1}^{T} p_{tj}\ln w_{tj} \quad (6.13a)$$

subject to *moment-consistency* constraints

$$\mathbf{y} = \mathbf{xzp} + \mathbf{vw} \quad (6.13b)$$

and the *adding up-normalization* constraint

$$\sum_{k=1}^{K} p_{km} = 1\ \forall m \qquad \textit{and} \qquad \sum_{t=1}^{T} w_{tj} = 1\ \forall j \quad (6.13c)$$

By forming the Lagrangean and deriving the optimality conditions, estimates of $\boldsymbol{\beta}$ can be obtained containing the least amount of information whilst satisfying the data and constraint set. In relation (6.13a) it is assumed that all $\mathbf{p}$ and $\mathbf{w}$ are equally likely to occur. In making this assumption the objective function is equivalent to the sum of Shannon entropies on the parameter and error distribution and it is this specific case that Judge and Golan (1992) refer to as GME. The endpoints of the probability supports can be either symmetric or asymmetric depending upon the problem under consideration. For the error term it is normal to use a symmetric representation centered on zero assuming a discrete uniform distribution.

With the support space of $\mathbf{z}$, it is necessary to ensure that support contains the true value of $\boldsymbol{\beta}$. If the support is too narrow the true value of β might be outside the support. Golan et al., (1996) explain in detail that wide bounds may be used without extreme consequences if prior information is minimal so as to ensure that our estimate of $\mathbf{z}$ contains the true β. In other words, the impact of the data on the estimates increases relative to the support boundary values. There is also the choice of M and J, the number of elements in the supports, that remains to be resolved. In general M and J are determined more by computational time rather than accuracy of estimation. However, by increasing the number of points in the support and maintaining equal distances between them, the variance of the uniform distribution decreases. The down side of this is that it leads to an increase in computational burden.

It is possible within the above generalization of the maximum entropy to incorporate easily non sample prior information. This might simply take the form of specifying the upper/lower bounds on a support case. This leads to a generalization of the cross entropy principle.[6] In this case the optimization problem in (**??**), assuming that our model does not have disturbances, takes the form:

$$\min_{\mathbf{p}} I(\mathbf{p};\mathbf{q}) = \sum_{k=1}^{K}\sum_{m=1}^{M} p_{km}\ln p_{km} - \sum_{k=1}^{K}\sum_{m=1}^{M} p_{km}\ln q_{qm} \quad (6.14a)$$

subject to the moment consistency constraint

$$y_t = \sum_{k=1}^{K}\sum_{m=1}^{M} x_{tk}z_m p_{km} \; t = 1,...,T;\;\; m = 1,...,M \quad (6.14b)$$

and adding up-normalizing constraints

$$\sum_{k=1}^{K}\sum_{m=1}^{M} z_m p_{km} = 1 \quad (6.14c)$$

$$\sum_{m=1}^{M} p_{km} = 1 \;\forall m \quad (6.14d)$$

The Lagrangean function is given by

$$\begin{aligned} L \;=\; & \sum_{k=1}^{K}\sum_{m=1}^{M} p_{km}\ln\left(\frac{p_{km}}{q_{km}}\right) + \sum_{t=1}^{T}\lambda_t\left(y_t - \sum_{k=1}^{K}\sum_{m=1}^{M} x_{tk}z_m p_{km}\right) \quad (6.15) \\ & + \mu\left(1 - \sum_{k=1}^{K}\sum_{m=1}^{M} z_m p_{km}\right) + \sum_{k=1}^{K}\gamma_k\left(1 - \sum_{m=1}^{M} p_{km}\right) \end{aligned}$$

[6] In the case that we have prior information about $\boldsymbol{\beta}$ in terms of a continuous probability distribution function, the problem is transformed into a standard Bayesian analysis.

from which the optimality conditions are derived as

$$\frac{\partial L}{\partial p_{km}} = \ln\left(\frac{p_{km}}{q_{km}}\right) + 1 - \sum_{t=1}^{T} \hat{\lambda}_t x_{tk} z_m - \hat{\mu} z_m - \hat{\gamma}_k = 0 \ \forall k, m \tag{6.16a}$$

$$\frac{\partial L}{\partial \boldsymbol{\lambda}_t} = y_t - \sum_{k=1}^{K} \sum_{m=1}^{M} x_{tk} z_m \hat{p}_{km} = 0 \ \forall t \tag{6.16b}$$

$$\frac{\partial L}{\partial \mu} = 1 - \sum_{k=1}^{K} \sum_{m=1}^{M} z_m \hat{p}_{km} = 0 \tag{6.16c}$$

$$\frac{\partial L}{\partial \gamma_k} = 1 - \sum_{m=1}^{M} \hat{p}_{km} = 0 \ \forall k \tag{6.16d}$$

Solving the above system of $KM + K + T + 1$ equations and parameters yields

$$\hat{p}_{km} = \frac{q_{km}}{\Omega_k\left(\hat{\lambda}_t, \hat{\mu}\right)} \exp\left(\sum_{t=1}^{T} \hat{\lambda}_t x_{tk} z_m + \hat{\mu} z_m\right) \tag{6.17a}$$

with

$$\Omega_k\left(\hat{\lambda}_t, \hat{\mu}\right) = \sum_{m=1}^{M} q_{km} \exp\left(\sum_{t=1}^{T} \hat{\lambda}_t x_{tk} z_m + \hat{\mu} z_m\right) \tag{6.17b}$$

being again the partition matrix.

The generalized cross entropy (GCE) formulation, which is our basis for the case study, minimizes the entropy measure between prior assessments of a parameter and the estimated value. If generalized cross entropy yields a value greater than zero then the sample data have yielded a gain in information and learning can be assumed to have occurred. With repeated samples, generalized cross entropy is a form of shrinkage rule so that the constructed probability approaches the true probability as the sample size approaches infinity. As would be expected if the correct prior information is available and it is employed within the estimation process, this improves accuracy of the estimation. Interestingly enough, incorrect prior information does not significantly impact upon the accuracy of estimation. In general generalized entropy measures behave like other shrinkage estimators, the variance of the estimator is less than the variance of sample-based rules like least squares or maximum likelihood, but the use of prior information introduces bias. This bias is typically offset by variance reductions, so the mean squared error of the estimator is smaller than sample-based mean squared error.

4.3 Estimating Individual Nitrate Leaching Levels

There are only few studies appearing in the literature utilizing generalized entropy formalism to state space modeling like it is the case of NPS pollution problem. Golan et al., (1996b) using a dynamic discrete time model provide estimates of the unknown parameters of the state and observation equations and the unknown values of the state variable using a generalized maximum entropy approach. In a similar manner Fernandez (1997) utilize also a generalized entropy approach to estimate inverse control problem with time-series data. Still she is focused on a PS pollution where the sequential updating potential of the entropy principle does not apply. Vickner et al., (1998) developed a dynamic economic model including control variables for both nitrogen fertilizers and irrigation water to analyze interseasonal corn production and nitrate leaching in the presence of irrigation system uniformity. Miller and Plantiga (1999) used a maximum entropy approach to recover a parametric model of county-level land use shares as a function of decision variables such as output process, input costs and land quality. Subsequently, they develop a land use model to study the impact of changes in decision variables on soil erosion or other environmental outcomes. On the other hand, Singh and Krstanovic (1987) and Kaplan et al., (2003) estimate sediment yield using a generalized cross entropy approach and time-series data under an updating scheme. Under certain approach can be adopted in the case of a single cross-section of data like our case of nitrate pollution initiated from agricultural activities in Ierapetra Valley, Crete. The NPS pollution model presented below is based heavily on the results presented by the last two papers.

The total nitrate runoff that reach the underground aquifer depends exclusively on the agricultural activity held in the are and therefore on the individual farmer's leaching levels. Thus,

$$Q^N = \sum_{j=1}^{J} q_j^N \tag{6.18}$$

where Q^N is the total nitrate runoff in the aquifer and q_j^N is the nitrate leaching level of farmer j with $j = 1, ..., J$ being the total number of farms in the valley. Regulator observe only the total amount of nitrates in the underground aquifer but not individual levels. Instead regulator has subjective expectations about individual nitrate leaching levels based on prior information that he may have. We may denote regulator's expectations by a vector

$$\bar{\mathbf{q}}_j^N = \left\{ \bar{q}_j^N, ..., \bar{q}_J^N \right\}' \tag{6.19}$$

where $\bar{q}_j^N$ is the unobservable individual leaching levels. Following Singh and Krstanovic (1997) and Kaplan et al., (2003) we may assume a linear relationship between individual leaching levels and fertilizer use by farmer j, that is,

$$Q^N = \sum_{j=1}^{J} \bar{q}_j^N = \sum_{j=1}^{J} g_i \left\{ E\left[a_j\right], x_j^N \right\} \tag{6.20}$$

where the total nitrate pollution generated by each farmer j is a function of individual fertilizer use and the individual stochastic loading factor $E\left[a_j\right]$ with E being the expectation operator as regulator only forms subjective expectations about individual runoff. The problem encountered above is that we do not observe individual loading factors so that to be able to determine NPS pollution levels. The only we can do is to form expectations about them. Though we can simplify these by adopting entropy formalism to obtain close estimates of a_j. We can assume that for each a_j there exists a discrete probability distribution supported by a set of equally distance discrete points denoted by z with corresponding probabilities denoted by p. Then by defining the lower and upper bounds of the support values, a_j can be expressed as a convex combination of these bounds.

Let a_{kj} be thek^{th} state of the nature for the j^{th} farmer and be the probability that farmer j belongs to the k^{th} state of nature, i.e., $a_j = a_{kj}$. In order to simplify things we assume that $k = 2$, that is we have only two states of nature, namely, good and bad practicing farmers.[7] This means that if p^a_{1j} denotes the probability that the farmer j is a good practicing farmer, then $p^a_{2j} = 1 - p^a_{1j}$ is the probability that farmer j is a bad practicing farmer. Then according to the above assumption it holds that $a_j = p^a_{kj} a_{kj}$. Further, we may reasonably assume that the evolution of individual loading factors, a_{kj}, can be expressed as a function of the variables affecting individual nitrate runoff, i.e.,

$$\frac{\partial a_{kj}}{\partial t} = l_j \left(w_j, L_j - R_j, H_j, RNF_j, SQ_j \right) a_{kj} \tag{6.21}$$

where, w_j is the applied irrigation water by farmer j, $L_j - R_j$ is the actual land utilized in agricultural production, H_j is farm's human capital (education level, experience etc), RNF_j is the annual rainfall in the area and, SQ_j specific soil quality.[8]

We defined p^a_{kj} to be the post-data probability that farmer j belongs to the state k (good or bad practicing farmer). This probability is updated by information gathering effort (or monitoring effort) applied by the regulator every period. Hence, the state equations of motion for the probabilities are given by:

$$\frac{\partial p^a_{kj}}{\partial t} = h_j \left(m_t, p^a_{kj} \right) \ \forall j \tag{6.22}$$

where m_t denotes the monitoring effort applied by regulator at time t that provides information about the individual loading factor. Accordingly the total runoff uncertainty about the known sources (i.e., farmers) is measured with the normalized information entropy metric (see relation 6.8 in the previous section) over all leaching distributions as:

$$A\left(p^a\right) = -\frac{\sum_{j=1}^{J} \sum_{k=1}^{2} p^a_{kj} \ln p^a_{kj}}{J \ln(2)} \tag{6.23}$$

[7] This assumption enables to reduce the number of state equations in he optimal control problem from J^*k only to J.

[8] One may think of several other factors affecting individual stochastic nitrate loading factor. However, our choice has been determined by data availability.

Assuming a discrete time formulation, the state equation of stochastic loading factor at every year t can be written as (Kaplan et al., 2003):

$$E\left[a_{jt}\right]=E\left[a_{jt-1}\right]\left\{h_j\left(m_t\right)+l_j\left(w_j,\left(L_j-R_j\right),H_j,RNF_j,SQ_j\right)\right\}+v_j \tag{6.24}$$

for every j farmer and with β being the unknown parameters. If only a cross-section of data is available and assuming that data on monitoring costs does not exists, as it is in our case study, relation (6.24) may be rewritten as:

$$E\left[a_j\right]=l_j\left(w_j,\left(L_j-R_j\right),H_j,RNF_j,SQ_j\right)+v_j \tag{6.25}$$

which is our basis for estimation. Then following again Singh and Krstanovic (1997) and Kaplan et al., (2003) we may assume that regulator's expectations on individual nitrate runoff follow an exponential functional specification, i.e.,

$$\ln \bar{q}_j^N=E\left[a_j\right]\ln x_j^N+\omega_j \tag{6.26}$$

again for every j farmer. The above relationship is naturally subject to the constraint of total leaching into the aquifer, i.e., $Q^N=\sum_{j=1}^{J}\bar{q}_j^N$. Both error terms appended in relations (6.25) and (6.26) are assumed to be *iid* with zero mean and constant variances V and Ω, respectively.

To estimate probability distributions for the random model parameters, the following reparameterization from the parameter space to probability space is made in accordance with the generalized entropy formalism (see relation 6.12 in the previous section):

$$E\left[a_j\right] = \sum_{k=1}^{2} p_{kj}^{a} z_{kj}^{a} \ \forall j \tag{6.27a}$$

$$l_j\left(\cdot\right) = \beta_{1j} w_j + \beta_{2j}\left(L_j - R_j\right) + \beta_{3j} H_j + \beta_{4j} RNF_j + \beta_{5j} SQ_j \ \forall j \tag{6.27b}$$

$$\beta_m = \sum_{k=1}^{2} p_{kj}^{m} z_{kj}^{m} \ \forall j \tag{6.27c}$$

$$\omega_j = \sum_{k=1}^{2} p_{kj}^{\omega} z_{kj}^{\omega} \ \forall j \tag{6.27d}$$

$$v_j = \sum_{k=1}^{2} p_{kj}^{v} z_{kj}^{v} \ \forall j \tag{6.27e}$$

$$\sum_{k=1}^{2} p_{kj}^{a} = \sum_{k=1}^{2} p_{kj}^{m} = \sum_{k=1}^{2} p_{kj}^{\omega} = \sum_{k=1}^{2} p_{kj}^{v} = 1 \ \forall j, m \tag{6.27f}$$

where $z\prime s$ are the support values for the respective probability distributions that represents the constraints on the probability space. We assume that the support values are analogous to the states of the nature (i.e., good and bad practicing farming) and thus have the same subscript to denote the various support values.

Given the above, in the single period under consideration the generalized cross entropy specification of the objective function is given by:

$$\begin{aligned}\min_{p} I(\mathbf{p};\tilde{\mathbf{p}}) \quad = \quad & \sum_{k=1}^{2} p_{kj}^{a} \ln\left(\frac{p_{kj}^{a}}{\tilde{p}_{kj}^{a}}\right) + \sum_{k=1}^{2}\sum_{m=1}^{5} p_{kj}^{m} \ln\left(\frac{p_{kj}^{m}}{\tilde{p}_{kj}^{m}}\right) \qquad (6.28\text{a}) \\ & + \sum_{k=1}^{2} p_{kj}^{\omega} \ln p_{kj}^{\omega} + \sum_{k=1}^{2} p_{kj}^{v} \ln p_{kj}^{v} \ \forall j\end{aligned}$$

subject to

$$\sum_{k=1}^{2} p_{kjt}^{a} z_{kjt}^{a} = \sum_{m=1}^{5} \sum_{k=1}^{2} p_{kj}^{m} z_{kj}^{m} x_{kj}^{m} + \sum_{k=1}^{2} p_{kj}^{v} z_{kj}^{v} \ \forall j \tag{6.28b}$$

$$\ln \bar{q}_{j}^{N} = \left(\sum_{k=1}^{2} p_{kjt}^{a} z_{kjt}^{a} \right) \ln x_{j}^{N} + \sum_{k=1}^{2} p_{kj}^{\omega} z_{kj}^{\omega} \ \forall j \tag{6.28c}$$

$$Q^{N} = \sum_{j=1}^{J} \bar{q}_{j}^{N} \tag{6.28d}$$

$$\sum_{k=1}^{2} p_{kj}^{a} = \sum_{k=1}^{2} p_{kj}^{m} = \sum_{k=1}^{2} p_{kj}^{\omega} = \sum_{k=1}^{2} p_{kj}^{v} = 1 \ \forall j, m \tag{6.28e}$$

where the restriction in (6.28b) was obtained by substituting (6.27b), (6.27c) and (6.27e) into relation (6.25), the restriction in (6.28c) by substituting relation (6.27d) into relation (6.26) and $\tilde{\mathbf{p}}$ is the vector of the prior probabilities. This specification of the entropy objective is a mixture of generalized maximum and cross entropy measures as the error terms in (6.28b) and (6.28c) does not have a prior probability. We further assume that the prior probabilities are uniformly distributed which implies that any state of nature is as likely as any other and thus the probabilities will be equal to $1/K$ (i.e., 0.5) where K is the number of support values or the number of different states of the nature.

The total number of support values is eight (8) and their choice was based on the prior beliefs we have that are imposed into the model. Specifically, the support values for z^a range from -0.5 to 0.5 implying that exogenous factors may have both a negative and positive impact on individual nitrate leaching. Concerning the farm-specific characteristics included in (6.28b) we have assume that for all except human capital variables (education, experience) the associated support values range between 0.0 and 1.5 as all of them (irrigation water use, utilized agricultural area, rainfall, and favored soil quality) affect positively individual nitrate leaching. For the two human capital variables the associated range of their support values is between -2.0 and 0.0 as both affect negatively the nitrate runoff. According to human capital theory, these variables, are associated with the resource allocation skills of farm operators (Schultz 1972; Huffman 1977). A farmer with a high level of resource allocation skills will make more accurate predictions of fertilizer use and will thus make more efficient decisions.

The choice of the support values for the two error terms appearing in relations (6.25) and (6.26) is more complicated as the error bounds influence the estimated parameters. The higher the bounds of the support values the more likely the possibility that the posterior distributions are closer to the prior choice. In order to explore the possible bias in the entropy estimates of the parameter and therefore of individual nitrate leaching levels, we utilize two sets of support values for both error terms. One high, $z^v, z^\omega \in [-20, 20]$ and one low $z^v, z^\omega \in [-2, 2]$. Under these assumptions the solution of the above optimization problem can be carried out using any commercial software (i.e., GAMS, Gauss, LIMDEP, Shazam, Matlab) using any of the available non-linear optimization algorithms. In the present context we utilized Gauss version 3.2.23 and Newton-Ralphson algorithm to obtain estimates of the individual loading factor. Then using individual fertilizer use it is possible to calculate individual nitrate leaching levels using relation (6.26).

4.4 Data Description

The data used in this study come from a broader survey of the structural characteristics of the agricultural sector on the Greek island of Crete, financed by the Regional Directorate of Crete. The sample consists of 265 randomly selected multi-output farms located in the Ierapetra Valley during the 1999-00 cropping season. Detailed information about production patterns, input use, average yields, gross revenues, and structural characteristics of the surveyed farms were obtained via questionnaire-based, field interviews. Summary statistics for these variables are reported in Table 1. Greenhouse farms in the sample are producing four different vegetables namely, cucumbers, tomatoes, eggplants and peppers. On the average farms are producing 20,387 kgs of vegetables, the 32.8% of which are cucumbers, the 33.4% tomatoes, the 13.7% eggplants and the rest 20.1% peppers. The average farm size is 5 stremmas (1 stremma equals 0.1 ha) for which 504 working hours are required annually. On the average farms are using 1,962 kgs of chemical fertilizers (mainly enriched in nitrogen) and 164 m^3 of water for irrigation purposes. The average age of the owner is 49 years varying from a minimum of 23 to a maximum of 85. On the average Cretan farmers are having 8 years of formal education while they are visited four times annually by private or public extension agents. The 25.4% of the cultivated land under greenhouses is rented, while each farms is fragmented into 3 plots on the average. Finally, the 47.4% of the cultivated area is on sandy soils which exhibit high nitrate leaching capacity, the 13.6% on lime stones, the 21.2% on marls and the 17.8% on dolomites. The required data of nitrate pollution in the aquifers were obtained from the local water authorities of Ierapetra and refer to the same year that the survey was conducted. On the average, the nitrate pollution on the aquifer is quite high approaching the 15 mg/lt with minimum and maximum value of 8.8 and19.7 mg/lt, respectively. The total water consumption during the cropping season of the survey was approximately 2.2 bn m^3, while the buffer stock was 1.5 bn m^3.

4.5 Estimation of the Crop Farm Production Model

For the purposes of the present project, the underlying production function for Cretan greenhouse farms was approximated by the following quadratic form:

$$y_i = \beta_0 + \sum_{j=1}^{m} \beta_j x_{ji} + 0.5 \sum_{j=1}^{m} \sum_{k=1}^{m} \beta_{jk} x_{ji} x_{ki} + \beta_N N_i + 0;.5 \left(\beta_{NN} N_i^2 + \sum_{j=1}^{m} \beta_{jN} x_{ji} N_i \right)$$

where $i = 1, ..., n$ is the number of farms in the sample, $j, k = 1, ..., m$ are the productive inputs used by farms, N is the quantity of nitrates in aquifer and β are the parameters to be estimated. The dependent variable is the annual vegetable production measured in kilograms. The aggregate inputs included as explanatory variables were: (a) total labor, comprising hired (permanent and casual) family and contract labor, measured in working hours. It included all farm activities such as plowing, fertilization, chemical spraying, harvesting, irrigation, transportation, administration and other services; (b) land, including only the share of farm's land devoted to vegetable cultivation measured in stremmas (one stremma equals 0.1 ha); (c) fertilizers, including nitrogenous and complex measured in kilograms; (d) total water used for plant irrigation, measured in m^3; (e) the total amount of nitrates in the aquifer measured in mgs. The local water authorities undertake each year several measurements which are not the same across the valley. Given these measurement we assigned to each farm the level of nitrate pollution which is closest to it.

Aggregation over the various components of the above input and output categories (except for land input) was conducted using *Divisia* indices with cost or revenue shares serving as weights. To avoid problems associated with units of measurement, all variables were converted into indices, with the basis for normalization being the representative greenhouse farm. The choice of the representative farm was based on the smallest deviation of the variables (i.e., output and input levels) from the sample means.

The estimated parameters of the quadratic production function using a simple OLS are presented in Table 2. The estimated first-order parameters (β_j) are having the anticipated (positive) sign and magnitude (being between zero and one), and the bordered Hessian matrix of the first- and second-order partial derivatives is negative semi-definite indicating that regularity conditions hold at the point of approximation (representative farm). That is, marginal productivities are positive and diminishing and the production function is locally quasi-concave. The estimated adjusted *R-squared* was found to be 0.7623 indicating a satisfactory fit of the quadratic production function above. Hypotheses concerning the structure of the production technology were performed and examined using the conventional likelihood-ratio test.[9] First the hypothesis that the production technology of Cretan greenhouse farms exhibit constant returns-to-scale $\left(i.e.\ \sum_j \beta_j = 1 \frown \sum_k \beta_{jk} = 0\ \forall j,k\right)$ was rejected at the 5% significance level (the LR-test was 45.87 considerably higher than the respective value of the chi-squared distribution). Next, the hypothesis that the production technology is approximated by the traditional Cobb-Douglas functional form $\left(i.e.\ \beta_{jk} = 0\ \forall j,k\right)$ is also rejected at the same level of significance (the LR-test was found to be 68.9). Finally, the hypothesis of input homotheticity $\left(i.e.\ \sum_k \beta_{jk} = 0\ \forall k\right)$ is rejected as the LR-test was found to be 32.89, well above the corresponding critical value at the 5% significance level.

[9] The LR-test statistic is calculated as $LR = -2\left[\ln(\theta^*) - \ln(\theta)\right]$ where * denotes estimates from the unrestricted model.

4.6 Entropy Results

The maximum entropy results are reported in Tables 3 and 4 and Figures 1 and 2. Figures 1a and 1b illustrate the entropy information acquired under the two different error support values. Recall that the normalized information entropy of one represents complete uncertainty and normalized information entropy of zero represents certainty. As it is shown from these two figures, uncertainty is reduced as the amount of fertilizer use increases, while on the other hand, when the error bounds are set at the lower value the certainty acquired is increased. In other words, in high levels of fertilizer use the information acquired is improved particularly when the support bounds for both error terms are set at low values, i.e., $z^v, z^\omega \in [-2, 2]$. Finally, the information acquired from the normalized entropy exhibit more rapid burst with the low bounds of the error term.

Accordingly figures 2a and 2b present the estimates of nitrate loading factors according to fertilizer use. The relative magnitude of these parameters more or less appears to be consistent across the different support values ranges with a greater difference observed for the lower error bounds. However, in both cases the estimated nitrate loading factors increase with fertilizer use exhibiting a relative consistency with the observed data. Under the high error bounds the estimated nitrate loading factors exhibit a relative stability with an increasing trend though. This implies that large farms are using excessively chemical fertilizers in their farm production and therefore monitoring and abatement efforts should be directed to those farms that have difficulties in optimizing fertilizer application behavior. Given that the cost of monitoring the whole farm population is considerable high, policy measures to that direction may have significant environmental implications. Overall, the results for both support values of the error bounds suggest that the level of aggregation of the nitrate concentration affects the manager's ability to acquire information and produce more predictable results and therefore greater precision in their policy response to mitigate environmental degradation due to nitrate pollution of groundwater resources.

The estimated individual nitrate leaching levels computed using individual loading factors and relation (6.26), under both the high and the low error bound, are reported in Table 3 in a form of a frequency distribution with a 0.05 mg/lt range. On the average, farms in the sample during the year of survey polluted the underground aquifer by 0.27 mg of nitrate per liter of water under the high error bound, and by 0.22 mg/lt under the low error bound. However, the variation across farms is high ranging from a low of 0.02 mg/lt to a high of 0.47 mg /lt under the low error bound, and from 0.04 mg/lt to 0.46 mg/lt under the high support values for the error terms. Overall the variation is higher under the low values of the error support range as the standard deviation of individual leaching levels is almost doubled compared with the estimate obtained from the high range of error bounds (0.10 and 0.05 mg/lt, respectively). The majority (approximately the 70% under the low error bound and 80% under the high error bound) of the surveyed farms exhibit nitrate leaching levels between 0.15 and 0.30 mg per lt of underground water.

Finally, the estimated individual loading factors obtained from relation (6.27a) are presented also in a form of frequency distribution within a 0.1 range in Table 4. Using the low support values for the error terms in relations (6.27d) and (6.27e) the mean estimated loading factor is 1.341 ranging from a minimum of 1.093 to a maximum of 1.820. the standard deviation of the individual loading factors is relatively low, only 0.132. In fact almost the 86% of the sampled farms have an estimated loading factor within the 1.2 and 1.5 range. On the other hand, when the higher range of the support values for the error terms is used, the variation of individual loading factors is lower as it is the case with nitrate leaching levels presented previously. Specifically, the mean individual loading factor was found to be 1.432 ranging from a minimum of 1.132 to a maximum of 1.798. Approximately the 91% of the farms exhibit estimates of loading factor within the 1.2 and 1.5 range.

The variables most likely affecting individual nitrate leaching levels are farm's human capital, utilized agricultural area and the soil characteristics. The relevant parameters obtained from relation (6.28b) change much from the prior expected values for these particular variables. This deviation suggests that the information contained in the data set was sufficient to validate a priori expectations concerning the effect of human capital and soil variables. The lack of variation with respect to the parameters associated with the rest two variables (irrigation water use, average annual rainfall in the area) included in relation (6.28b) may be the outcome of the limited observation and variation in the explanatory variables. In general policy makers aimed to reduce nitrate pollution to the aquifer should derive measures directed towards the improvement of farms human capital and hence their know how concerning the appropriate levels of chemical fertilizer use.

Table 1. Summary Statistics of the Variables

Variable	Mean	Max	Min	Stdev
Economic Data:				
Output (kgs)	20,387	59,640	2,100	11,393
Cucumbers (%)	32.8			
Tomatoes (%)	33.4			
Eggplants (%)	13.7			
Peppers (%)	20.1			
Area (stremmas)	5	20	1	4
Labour (working hours)	504	1,077	37	271
Fertilizers (kgs)	1,962	8,266	346	1,483
Water (m3)	164	880	25	155
Revenues (€/stremma)	11,878	24,728	4,631	3,436
Cost (€/stremma)	8,315	15,604	4,104	1,762
Profits (€/stremma)	3,563	13,272	847	2,436
Nitrates in the Aquifer (mg/lt)	14.9	19.7	8.8	4.1
Household Characteristics:				
Extension Visits (no)	4	29	0	6
Age (years)	49	85	23	14
Education (years)	8	20	3	4
Specialization (Herfindhal index)	0.627	0.952	0.500	0.106
Fragmentation (no of plots)	3	7	1	2
Land Tenancy (% of rented land)	0.254	0.855	0.000	0.192
Soil Type (% of Farm Land)				
Sandy	47.4			
Limestone	13.6			
Marls	21.2			
Dolomites	17.8			
No of observations	265			

Table 2. Parameter Estimates of the Quadratic Production Function

Parameter	Estimate	Std Error	Parameter	Estimate	Std Error
β_0	0.8655	(0.0986)*	β_{LW}	-0.0425	(0.0237)**
β_A	0.2570	(0.0599)*	β_{LL}	-0.1659	(0.0905)**
β_L	0.2699	(0.0785)*	β_{FW}	0.0270	(0.0137)**
β_F	0.1415	(0.0446)*	β_{FF}	-0.0257	(0.0286)
β_W	0.0896	(0.0485)**	β_{WW}	-0.0215	(0.0215)
β_{AF}	-0.0065	(0.0625)	β_N	0.2270	(0.1025)**
β_{AW}	0.0855	(0.0500)**	β_{NN}	-0.0969	(0.1021)
β_{AA}	-0.0086	(0.0046)**	β_{NF}	0.0472	(0.0202)**
β_{LF}	-0.0653	(0.0755)	β_{NW}	0.0159	(0.0102)
$\bar{R}^2$	0.7623				

Note: A stands for area, L stands for labour, F for fertilizers, W for water, N for total nitrates in the aquifer. * (**) indicate statistical significance at the 5 (1)% level.

Table 3. Frequency Distribution of Individual Nitrate Leaching

Nitrate Leaching	$z^v, z^\omega \in [-2, 2]$		$z^v, z^\omega \in [-20, 20]$	
(mg/lt)	No of Farms	(%)	No of Farms	(%)
0.05	3	(1.1)	1	(0.4)
0.10	21	(7.9)	14	(5.3)
0.15	66	(24.9)	53	(20.0)
0.20	37	(14.0)	48	(18.1)
0.25	45	(17.0)	66	(24.9)
0.30	39	(14.7)	47	(17.7)
0.35	23	(8.7)	16	(6.0)
0.40	21	(7.9)	14	(5.3)
0.45	7	(2.6)	5	(1.9)
0.50	3	(1.1)	1	(0.4)
N	265		265	
Mean	0.22		0.27	
Maximum	0.47		0.46	
Minimum	0.02		0.04	
StDeviation	0.10		0.05	

Table 4. Frequency Distribution of Individual Loading Factors.

Loading Factor	$z^v, z^\omega \in [-2, 2]$ No of Farms	(%)	$z^v, z^\omega \in [-20, 20]$ No of Farms	(%)
1	0	(0.0)	0	(0.0)
1.1	2	(0.8)	1	(0.4)
1.2	29	(10.9)	19	(7.2)
1.3	83	(31.3)	74	(27.9)
1.4	78	(29.4)	89	(33.6)
1.5	42	(15.8)	60	(22.6)
1.6	21	(7.9)	16	(6.0)
1.7	6	(2.3)	4	(1.5)
1.8	3	(1.1)	2	(0.8)
1.9	1	(0.4)	0	(0.0)
2	0	(0.0)	0	(0.0)
N	265		265	
Mean	1.341		1.432	
Maximum	1.820		1.798	
Minimum	1.093		1.132	
StDeviation	0.132		0.092	

Figure 1a. Estimated Normalized Entropy when .
Figure 1b. Estimated Normalized Entropy when .
Figure 2a. Estimated Nitrate Loading Factors when .
Figure 2b. Estimated Nitrate Loading Factors when .

5

Policy Design in a Dynamic Agricultural System with Nitrate Leaching

5.1 Introduction

In this part we explicitly use the optimal control framework to analyze an agricultural production system which uses fertilizers and water from an aquifer with renewable resource characteristics and generated harmful nitrate leaching. We explicitly introduce CAP type policy instruments in the form of, subsidies, payment granted on the basis of cultivated land, and land-set-aside premiums. By modeling the dynamic system describing the evolution of water stock and the accumulation of nitrates, we solve for the optimal input use for a regulator that seeks to maximize the value of agricultural production less environmental costs due to nitrate leaching, subject to the water and nitrate dynamics. Treating the policy instruments as parameters we derive the optimal paths for nitrate accumulation and fertilizers use as well as a policy function which relates the stock of nitrates to the optimal fertilizers use. This approach combined with the maximum entropy approach of the previous chapter can be used to analyze policy impacts in agricultural nonpoint source pollution problems after transforming them through the maximum entropy approach to point source pollution problems.

Using the data of the previous case study we demonstrate the applicability of our methodology, which can be readily applied to any EU region given data availability.

5.2 Modelling the Productive System and Policy Impacts

We consider a strictly concave quadratic agricultural production function with stock effects from nitrate accumulation, N.

$$f(\mathbf{x},N) = \boldsymbol{\beta}'\mathbf{x} + \frac{1}{2}\mathbf{x}'\mathbf{B}\mathbf{x} + \beta_N N + \frac{1}{2}\beta_{NN}N^2$$

where $\mathbf{x} = (x_1, ..., x_J)$ is a vector of $j = 1, ..., J$ inputs $\boldsymbol{\beta}$ is a corresponding vector of parameters, $\mathbf{B}$ is a symmetric matrix of parameters for the quadratic terms, and the terms β_N. and β_{NN} reflect stock effects from the nitrates N accumulated in an aquifer, which is used to irrigate the agricultural production system.

Let $\mathbf{c} = (c_1, ..., c_J)$ be a vector of input costs, $G(N)$ an increasing and convex damage function due to nitrate accumulation and $h(W)$ a concave benefit function associated with benefits generated by the water stock.

We adopt the following specifications

$$\begin{aligned} G(N) &= \frac{1}{2}gN^2 \\ h(W) &= vW^z \ , 0 < z < 1 \end{aligned}$$

The evolution of the water stock is determined by the differential equation

$$\dot{W} = fl - \sum_{i=1}^{n} w_j - \delta W \ , \ W(0) = W_0 \tag{5.1}$$

where fl denotes net water inflows, w_j water used by farmer $i = 1, ..., n$ and δ is a coefficient of water losses.

The evolution of the nitrate accumulation is determined by the differential equation

$$\dot{N} = \sum_{i=1}^{n} a_i F_i - bN \ , \ N(0) = N_0 \tag{5.2}$$

where F_i denotes fertilizers used by farmer $i = 1, ..., n$, a_i is the farmer's i loading factor estimated by the entropy method, and b is a coefficient associated with natural nitrate losses in the aquifer.

The regulators problem for the cased analyzed can be stated as

$$\max_{\{A(t),R(t),L(t),F(t),w(t)\}} \int_0^\infty e^{-\rho t} \left[\sum_{i=1}^{n} [p(1+s) f_i((A_i - R_i), L_i, F_i, w_i) - \right.$$
$$\left. c_A(1-s_A) A_i - c_L L_i - c_F F_i - c_w w_i + s_R R_i] - g(N) + h(W) \right] dt \quad or$$
$$\max_{\{A(t),R(t),L(t),F(t),w(t)\}} \int_0^\infty e^{-\rho t} B((A_i - R_i), L_i, F_i, w_i, N, W)$$

subject to (5.1), (5.2) and initial conditions on W and N, where:

- p output price and $s \geq 0$ subsidy
- A_i cultivated land by farmer i, and R_i land-set-aside by farmer i
- L_i labor input
- F_i fertilizers used
- w_i water used for irrigation
- c_A, c_L, c_F, c_w input prices
- s_A payments granted on the basis of cultivated land
- s_R land-set-aside premium

Thus, a CAP type agricultural policy is incorporated in the three parameters (s, s_A, s_R). Other policies regarding labor, fertilizer or water use can be incorporated in a similar way the cost parameters (c_L, c_F, c_w).

Using Pontryagin's maximum principle the solution to the problem is characterized by the following system of algebraic and differential equations, where we omit subscript i to simplify notation. We assume interior solutions and we define the current value Hamiltonian function as:

$$H = B((A_i - R_i), L_i, F_i, w_i, N, W) + \lambda_N \left[\sum_{i=1}^{n} a_i F_i - bN \right] + \lambda_W \left[fl - \sum_{i=1}^{n} w_j - \delta W \right]$$

$$p\,(1+s)\,\frac{\partial f}{\partial A}=c_A\,(1-s_A) \tag{5.3}$$

$$p\,(1+s)\,\frac{\partial f}{\partial R}=c_R \tag{5.4}$$

$$p\,(1+s)\,\frac{\partial f}{\partial L}=c_L \tag{5.5}$$

$$p\,(1+s)\,\frac{\partial f}{\partial F}=c_F-\lambda_N a_i\ ,\ \ \frac{\partial w}{\partial \lambda_N}=-\frac{1}{p\,(1+s)\,f_{FF}}>0 \tag{5.6}$$

$$p\,(1+s)\,\frac{\partial f}{\partial w}=c_w+\lambda_W\ , \tag{5.7}$$

$$\frac{\partial w}{\partial \lambda_W}=\frac{1}{p\,(1+s)\,f_{ww}}<0\ ,\ \ \frac{\partial w}{\partial \lambda_N}=-\frac{1}{p\,(1+s)\,f_{FF}}>0 \tag{5.8}$$

$$\dot{\lambda}_N=\rho\lambda_N-\frac{\partial H}{\partial N} \tag{5.9}$$

$$\dot{\lambda}_W=\rho\lambda_W-\frac{\partial H}{\partial W} \tag{5.10}$$

(5.1), (5.2)

and appropriate transversality conditions at infinity (5.11)

System, (5.3)-(5.7) is linear due to the quadratic structure of the production function, so solutions for the controls can be directly obtained as functions os the parameters of the problem. The modified Hamiltonian Dynamic system (MHDS) obtained from (5.1), (5.2) and (5.10), (5.11) is defined as

$$\dot{W} = fl-\sum_{i=1}^{n} w_i^*\left(s,c_A\,(1-s_A)\,,c_L,c_F,c_w,s_R;\lambda_W\right)-\delta W \tag{5.12}$$

$$\dot{\lambda}_W = (\rho+\delta)\,\lambda_W-zvW^{z-1} \tag{5.13}$$

$$\dot{N} = \sum_{i=1}^{n} a_i F_i^*\left(s,c_A\,(1-s_A)\,,c_L,c_F,c_w,s_R;\lambda_N\right)-bN \tag{5.14}$$

$$\dot{\lambda}_N = (\rho+\delta)\,\lambda_N-\beta_N-(\beta_{NN}-g)\,N \tag{5.15}$$

where

$$w_i^*\left(s,c_A\,(1-s_A)\,,c_L,c_F,c_w,s_R;\lambda_W\right),F_i^*\left(s,c_A\,(1-s_A)\,,c_L,c_F,c_w,s_R;\lambda_N\right) \tag{5.16}$$

are the optimal choices for irrigation water and fertilizers as function of cost and policy parameters and the shadow values of the water stock λ_W and nitrates stock λ_N respectively

It can be seen that due to the linear-quadratic structure of the problem the MHDS consists of two uncoupled subsystems the water sub-system (5.12)-(5.13) and the nitrates subsystem (5.14)-(5.15).

The steady states are obtained by setting $\dot{W} = \dot{\lambda}_W = \dot{N} = \dot{\lambda}_N = 0$, as solutions of:

$$W^* = \frac{fl - \sum_{i=1}^{n} w_i^* \left(s, c_A \left(1 - s_A\right), c_L, c_F, c_w, s_R; \lambda_W\right)}{\delta} \tag{5.17}$$

$$\lambda_W^* = \frac{zv \left(W^*\right)^{z-1}}{(\rho + \delta)} \tag{5.18}$$

$$N^* = \frac{\sum_{i=1}^{n} a_i F_i^* \left(s, c_A \left(1 - s_A\right), c_L, c_F, c_w, s_R; \lambda_N\right)}{b} \tag{5.19}$$

$$\lambda_N^* = \frac{-\beta_N - \left(\beta_{NN} + g\right) N^*}{(\rho + b)} \tag{5.20}$$

It is clear that steady state comparative statics with respect to to policy parameters can be easily obtained from (5.17)-(5.20). For example the derivatives

$$\frac{\partial W^*}{\partial s}, \frac{\partial W^*}{\partial s_A}, \frac{\partial W^*}{\partial s_R}, \frac{\partial N^*}{\partial s}, \frac{\partial N^*}{\partial s_A}, \frac{\partial N^*}{\partial s_R}$$

reflect the impact of price support, land payments and land-set-aside premium on the steady state water and nitrates stock.

The time paths for the water and nitrate stock and their corresponding shadow values can be obtained by solving the uncoupled water sub-system (5.12)-(5.13) and nitrates subsystem (5.14)-(5.15), using initial conditions and transversality conditions.

The Jacobian matrix of (5.12)-(5.13) at the steady state is

$$J_W = \begin{pmatrix} -\delta & -\frac{\partial w^*}{\partial \lambda_W} \\ -z\left(z-1\right) vW & \rho + \delta \end{pmatrix}$$

with trace$(J_W) = \rho > 0$ and $\det J_W = -\delta\left(\rho + \delta\right) - z\left(z-1\right) vW \frac{\partial w^*}{\partial \lambda_W} < 0$. Therefore the steady state is a saddle point. The solution for the stable paths is determined by the solution of the water sub-system (5.12)-(5.13) with initial value $W(0) = W_0$ for the water stock and terminal values $\left(W^*, \lambda_W^*\right)$. Because the system is nonlinear in W it may be solved numerically using the multiple shooting method.

The Jacobian matrix of (5.14)-(5.15) at the steady state is

$$J_N = \begin{pmatrix} -b & \frac{\partial F^*}{\partial \lambda_N} \\ -\left(\beta_{NN} - g\right) & \rho + b \end{pmatrix}$$

with trace$(J_W) = \rho > 0$ and $\det J_W = (\beta_{NN} - g) \frac{\partial F^*}{\partial \lambda_N} < 0$. Therefore the steady state is a saddle point. The solution for the stable paths is determined by the solution of the nitrates sub-system (5.12)-(5.13) with initial value $N(0) = N_0$ for the water stock and terminal values (W^*, λ_W^*). The linearity of the system and the transversality conditions at infinity

$$\lim_{t \to 0} e^{-\rho t} N(t) = 0, \lim_{t \to 0} e^{-\rho t} N(t) \lambda_N(t) = 0$$

result in the following explicitly solution

$$\begin{aligned} N^*(t) &= C_N e^{\lambda_2 t} + N^* \\ \lambda_N^*(t) &= C_{\lambda_N} e^{\lambda_2 t} + \lambda_N^* \end{aligned}$$

where λ_2 is the negative eigenvalue of the Jacobian matrix J_N, and the constants C_N, C_{λ_N} correspond to the eigenvector of the eigenvalue λ_2.

5.3 An Application to the Ierapetra Valley

In this part we consider a step-wise approach for an application of the above methodology.

1. We set the policy instruments to zero that is $(s, s_A, s_R) = 0$ and we calibrate a strictly concave quadratic production function

$$f(\mathbf{x}, N) = \boldsymbol{\beta}' \mathbf{x} + \frac{1}{2} \mathbf{x}' \mathbf{B} \mathbf{x} + \beta_N N + \frac{1}{2} \beta_{NN} N^2$$

   where matrix $\mathbf{B}$ is diagonal, that is 'no cross effects' are assumed. The parameters are chosen such that for the actual average prices for land (A), labour (L), fertilizer use (F) and water use (w), profit maximization will imply the observed average input use for the above inputs with no land set aside $(R = 0)$.

2. In the model of the productive system we use the concept of a representative producer that uses average values. We use an individual average leaching $a = 0.014496912$ of kgs of nitrate leaching per kgs of fertilizer used by the representative farmer. This is a simplification in order to apply the methodology. The

problem can be solved for different groups of farmers, where the average leaching in each group corresponds to results of table 3 of the previous chapter. Production functions in this case could be the corresponding group production functions, or an average production function. The final choice depending on data availability. The use of group production functions will provide 'finer' results.

3. Using the total nitrates in the aquifer $N = 14926.3$ kgs as an uncontrolled steady state when $a = 0.014496912$, the implied $b = 0.014531389$. We also use $\delta = 0.2$ for water losses from the aquifer

4. We assume values $g = 1$, $v = 1$, $z = 0.8$ for the functions $g(N)$ and $h(W)$ respectively.

5. We assume that the value of land is fixed at average value of $A = 53$ stremas. Thus regarding land as fixed, the choice variable is the land-to be set aside as a function of the premium s_R. By solving the first order conditions (5.3)-(5.7) we obtain

   $R \approx 0, L = 503.889, F = -6.48786(-2339.76 - 0.0144969\lambda_N),$
   $w = -3.33333(-50.9225 + \lambda_W)$

   by setting $s_R \neq 0$ we obtain the optimal short-run input use as function of the premium s_R and the shadow values

   $R = -16.6667(0.055 - s_R), L = 503.889, F = -6.48786(-2339.76 - 0.0144969\lambda_N),$

   $w = -3.33333(-50.9225 + \lambda_W).$

6. The MHDS corresponding to the solution for $s_R \neq 0$ is

$$
\begin{aligned}
\dot{W} &= 500 + 3.33333(-50.9225 + \lambda_W) - 0.2W \\
\dot{\lambda}_W &= 0.23\lambda_W - 0.2W^{-0.8} \\
\dot{N} &= -0.0940539(-2339.76 - 0.0144969\lambda_N) - 0.0145314N \\
\dot{\lambda}_N &= 0.0445314\lambda_N - 3(0.226985 - 0.2N) + N
\end{aligned}
$$

with a steady state

$$W^* = 1651.33, N^* = 3464.73, \lambda_W^* = 0.00231758, \lambda_N^* = -124472.$$

7. For the linear nitrates sub-system the Jacobian matrix is

$$J_N = \begin{pmatrix} -0.0145314 & 0.00136349 \\ 1.6 & 0.0445314 \end{pmatrix}$$

with eigenvalues and corresponding eigenvectors

$$\begin{aligned} \lambda_1 &= 0.0702602, \quad (v_{11}, v_{12}) = (-0.0160784, -0.999871) \\ \lambda_2 &= -0.0402602, \quad (v_{21}, v_{22}) = (-0.0529205, 0.998599) \end{aligned}$$

The transversality condition at infinity implies that the solution paths converging to the steady state correspond to the negative eigenvalue and they are

$$\begin{aligned} N(t) &= -0.0529205Ce^{-0.0402602t} + N^* \\ \lambda_N(t) &= 0.998599Ce^{-0.0402602t} + \lambda_N^* \end{aligned}$$

it is clear that C can be defined by an initial conditions on nitrate accumulation $N(0) = N_0$. Then the optimal path for fertilizers use is defined as

$$F^*(t) = -6.48786(-2339.76 - 0.0144969\lambda_N(t)) \quad (5.21)$$

8. Using

$$\frac{N(t) - N^*}{\lambda_N(t) - \lambda_N^*} = -\frac{0.0529205}{0.998599}$$

and solving (5.21) for $\lambda_N(t)$ as a function of $F^*(t)$ to obtain $\lambda_N(t) = G(F^*(t))$ we obtain the inverse policy function

$$N(t) = -\frac{0.0529205}{0.998599}(G(F^*(t)) - \lambda_N^*) + N^*$$

that relates the optimal fertilizer application with the optimal nitrates concentration.

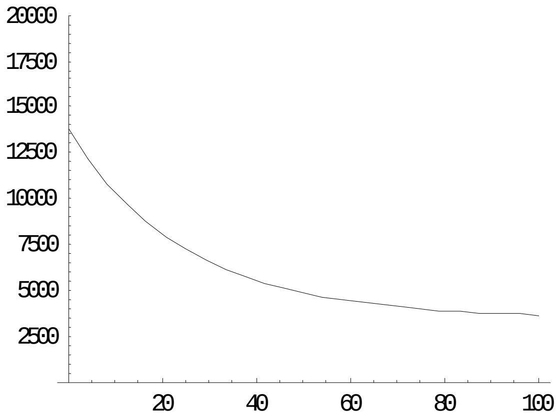
9. Using $N(0) = 14926.3$ we obtain $C = -194198.1$ and the optimal paths are:

$$\begin{aligned} N(t) &= 10277.66e^{-0.0402602t} + 3464.73 \\ \lambda_N(t) &= -193926e^{-0.0402602t} - 124472 \\ F^*(t) &= (3472.96 + 18239.5e^{-0.0402602t}) \end{aligned}$$

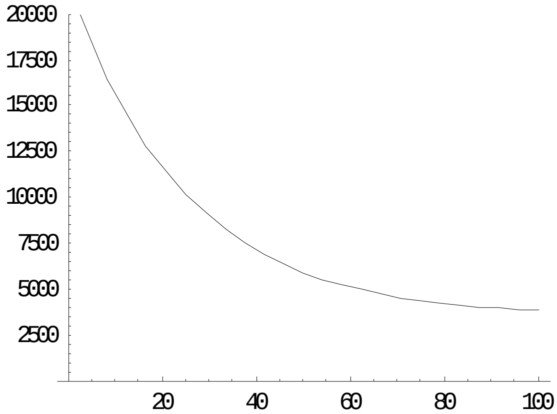
10. The policy function is then obtained as:

$$\frac{N(t) - 3464.73}{-161397. + 10.6322F(t) - 124472} = -\frac{0.0529205}{0.998599}$$
$$F = 33036.2 - 1.77478N$$

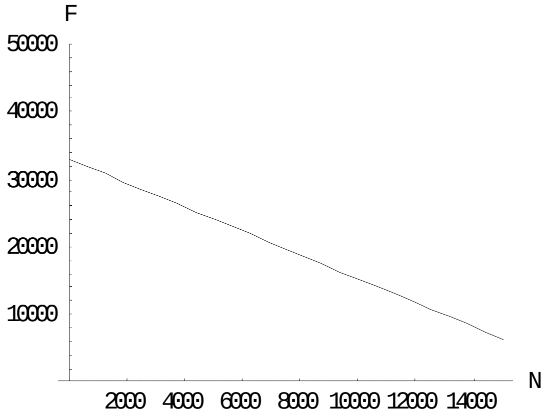
11. The optimal paths for nitrate accumulation and fertilizer use along with the optimal policy function are shown in the figures below.



Nitrate Accumulation



Fertilizer Path



Policy Function

Part III

Conclusions

The Common Agricultural Policy (CAP) measures can be included among the factors found responsible for the unbalance in the agricultural-environment relationship. As a response reformers integrated environmental goals into agricultural policy, leading to Agenda 2000 CAP reform that is considered to be pioneering from an environmental aspect due to the gradual reduction or elimination of production subsidies (decoupling), the introduction of the principle of cross-compliance of payments and the promotion of Pillar II measures. The first part of this deliverable provides a detailed, theoretical analysis of this new CAP regime, regarding its impacts on environment and its long term evolution.

In the **first chapter of part I** a conceptual, theoretical model of farming behavior was developed that embodies the basic reforms of communal agricultural policy for the common market organizations (CMOs). The generalized nature of the developed model allows the assessment of the environmental impacts, in terms of farmer's production choices, of the various CMOs CAP regimes such as the old regime of fully coupled payments, the partial and full decoupling regime. The policy effectiveness of Agenda 2000 CAP reform is evaluated by discussing the problem of the optimal regulation both in a static and dynamic context. The type of socially optimal Pillar I CAP instruments, along with type of interdependence characterizing them are assessed in a static context, while the long-run viability of the Agenda 2000 CAP reform is examined by employing the conceptual framework of replicator dynamics.

Our analysis suggest that the final impact of Agenda 2000 main reforms (i.e. direct payment regime and the cross-compliance enforcement mechanism) on the full set farmers' production choices is ambiguous. There is no doubt that the provision of direct payments, as well as the introduction of farming constraints will restrain input usage compared to the an unregulated regime or to the old full coupling regimes, however, their final impact on land-set-aside is uncertain due to the fact that they are associated with alternative and conflicting land usages. Our theoretical analysis provides no unambiguous conclusions that the transition from the full coupling regime to the regime of partially or fully decoupled payments will in fact induce all farmers to enhance their environmental performance. Our theoretical model provides however the necessary conceptual framework which can be used as a basis for applied work that can provide estimation of the relevant impacts.

The fact that intervention via decoupled payments is environmentally preferable to intervention via a combination of coupled and decoupled payments, under both the absence and presence of farming standards, supports the Commission's decision to proceed in the full cancellation of coupled payments. The analysis of optimal regulation, when external environmental damages are explicitly introduced, suggests that, for attaining the socially optimal CMOs CAP measures in both a static and dynamic context, it may be required on purely normative grounds, to potentially impose on farmers charges on some aspects of farming activity: crop yields, land-usage and / or set-aside-land, which however are not foreseen in the given structure of the communal agricultural. Finally, it needs to be pointed out that even if such measures were foreseen by the current structure of CAP the attainment of first-best level of aggregate land quality would require both nonuniform and time-flexible CMOs CAP measures, which are practically infeasible due to the high informational or / and administrative requirements they involve.

Summarizing, on positive grounds Agenda 2000 CAP reform seems to constitute an improvement over the previous regime, while on normative grounds it may be regarded as not achieving a first-best when environmental damages are explicitly included in a social welfare function. This might suggest a direction for future reforms.

In the **second chapter of Part I** the developed, conceptual model of farming activity was extended to embody the second pillar payments provided on a voluntary basis by the communal agricultural policy. The distinction between main and secondary production choices allowed us to examine the relative environmental performance of the various CAP regimes - full coupling, partial and full decoupling - when with Pillar II measures are extended in terms of production choices which are distinguished into two categories: main and secondary production choices. The policy effectiveness, along with the long-run viability of the generalized Agenda 2000 CAP regime involving both CMOs and RD payments, is assessed by discussing the problem of optimal regulation both in a static and dynamic context, as well as by employing the evolutionary conceptual framework of replicator dynamics.

Analysis indicated that after the extension of farmer's production choice set by secondary production choices dedicated exclusively to the emission abatement, the relative environmental performance of the various regimes of CAP payments cannot be clearly inferred. Hence, 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 finally to the intervention regime involving solely the provision of second pillar payments (i.e. Mid-term review), induces simultaneous restriction the use of main production choices and enhancement of the equilibrium value of secondary production choices. However, it is evident that the incorporation of rural development measures in the set of payments of a given CAP regime (i.e. full coupling) enhances the environmental performance of farmers even though the optimality analysis indicated that the provision of such subsidies may not always be socially optimal. Static and dynamic optimality analysis indicated that under certain circumstances the socially optimal intervention regime may involve certain charges imposed on main and / or secondary production choices.

As indicated in analysis of Part I the attainment of the first-best solution in terms of both individual and aggregate land quality requires nonuniform CAP policy measures. European farmers do not share the same farm characteristics, implying that each homogeneous group European farmer should be liable for a different set and type of both static and dynamic CAP measures. Even though achieving a first-best has enormous informational requirements and its attainment might not be technically feasible, the definition of individually designed performance standards, coupled and decoupled Pillar I measures, as well as rural development measures, in the present CAP requires the knowledge of emission flows associated with individual farmers or groups of homogeneous farmers.

This task which is not trivial as has become apparent by the extensive literature of non point source pollution problems is accomplished in the second part of this deliverable.

In the **first chapter of part II** a generalized maximum entropy approach was developed and applied in a case study, providing explicit results regarding the individual nitrates leaching of 265 randomly selected multi-output farms located in the Ierapetra Valley during the 1999-2000 cropping season. Given that the cost of monitoring the whole farm population is considerable high, monitoring and abatement efforts should be directed to those farms that have difficulties in optimizing fertilizer application behavior and therefore CAP policy measures tailor made towards this direction, may have significant environmental implications. Finally, analysis indicated that for the given data set, the variables most likely affecting individual nitrate leaching levels are farm's human capital, utilized agricultural area and the soil characteristics. Hence, policy makers aimed to reduce nitrate pollution to the aquifer should derive measures directed towards these factors.

The entropy approach developed in this deliverable can be used to provide a new way for the study of policy issues related to nitrate leaching and the CAP in particular. It can be used to help fine-tune policies and to infer violations of compliance by individuals or certain homogeneous groups, without excessive monitoring costs. Also, in a more general context, the entropy approach can be used to analyze at an applied level nonpoint source agricultural pollution problems an area of current academic research. The method can be easily adopted to any EU region given data availability.

Finally, in **Chapter 7** we explicitly use the optimal control framework to analyze an agricultural production system which uses fertilizers and water from an aquifer with renewable resource characteristics and generates harmful nitrate leaching. CAP type policy instruments, in the form of, subsidies, payment granted on the basis of cultivated land, and land-set-aside premiums are explicitly introduced. The optimal input use for a regulator that seeks to maximize the value of agricultural production less environmental costs due to nitrate leaching, subject to the water and nitrate dynamics is determined. Treating the policy instruments as parameters we derive the optimal paths for nitrate accumulation and fertilizers use as well as a policy function which relates the stock of nitrates to the optimal fertilizers use. The methodology is applied to data of the case study of chapter 6 and the optimal policy is explicitly determined. This approach combined with the maximum entropy approach of the previous of chapter 6, can be used to analyze policy design and policy impacts in agricultural nonpoint source pollution problems after transforming them through the maximum entropy approach to point source pollution problems. The methodology developed in this chapter can easily adopted to any EU region given data availability.

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