The role of decoupled subsidies in agriculture providing ecosystem services

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Abstract

This paper proposes a new theoretical rationale for the possible incentive effect of decoupled subsidies. Using a multitasking agency model, we show that having recourse to mixed payment, by introducing decoupled payments, could raise farmer' incentives to provide non-contractible environmental services. This model is then empirically tested using French farm-level data. Our empirical results show that if "pay-for-performance" payments through environmental contracts impact positively and significantly the adoption of contractible services, e.g. permanent grass strip, they have no significant (or a negative) effect on the adoption of non-contractible environmental services, e.g. crop diversification or mixed farming practices. In contrast, mixed payment through decoupled subsidies helps balancing incentives for contractible and non-contractible environmental services.

1 Introduction

From a socio-environmental point a view, agriculture is by its very nature multitasking. The farmer is expected to produce food for society, but also preserves biological and landscape diversity. Both objectives may be conflicting since the dominant production mode in agriculture generates negative externalities on the environment that may reduce both biological and landscape diversity. Decades

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of production-coupled subsidies have led to a substantive increase in agricultural production and productivity, but also to a biased-technology toward chemical inputs (fertilizers and pesticides) that have harmful impact on environment (biological diversity) but also animal and human health (Duru et al., 2015). To balance this effect and try to internalize the negative externalities, some part of the subsidies became more conditioned and the farmer may get these subsidies only if he is committed in an environmental contract that: (i) specifies the adoption of environmental-friendly practices and inputs, (ii) and the payment is contingent to the adoption. However, farmers seem to be reluctant to these contingent or “pay-for-performance” contract, and this may explain why the adoption rate of environmental contracts is low (Espinoza-Goded et al., 2013). Indeed, at the EU-27 level, the share of utilised agricultural area under agri-environmental contracts amounts to almost 25% for the period 2007-2013 (European Network for Rural Development, 2014). The minimum participation level needed to ensure the expected environmental effects is not known. However, as many authors (e.g. Kuhfuss et al., 2015; Espinoza-Goded et al., 2013; Chistenssen et al., 2011; Ducos et al., 2007), we admit that an adoption rate of 25% is rather low.

The general literature on incentives recognizes that selective payment for performance leads to difficulties when the producer has to do different tasks or jobs (Bolton and Dewatripont, 2005). The problem of multitasking refers to the challenge of designing incentives to make appropriate effort across multiple tasks when performance of some tasks are is difficult to measure than others (Holmstrom and Milgrom, 1991). In agriculture, precise metrics for farmer actions that promote environmental quality are notoriously difficult to quantify. Furthermore, there are obviously many dimensions of quality for environmental services provided by agriculture and the farmer. Multitasking implies that the social planner or the Government (providing subsidies) should use pay-for-performance cautiously as long as environmental service is rewarded only partially or metrics are imperfect. In general, the less precise the measure of performance, the less pay-for-performance incentives should be used (Fares, 2009). The literature on the relationships between agriculture and the environment has been based for years on the concept of multi-functionality (OECD, 2001; Havlik et al, 2005), i.e. on the idea that there exist multiple commodity and non-commodity outputs ("goods" or "bads") that are jointly produced by agriculture. The traditional idea of multi-functionality and of jointness in production defines a rather passive role of farmers, since non-commodity outputs are produced no matter what decisions the farmer makes, as they are intimately related to agricultural activities. With idea of multi-functionality, the existing litterature provide no clear-cut conceptual guidance to investigate the incentive effects of decoupled subsidies on farmers' provision of ecosystem services. As such, our paper departs from the the passive idea of multi-functionality by using the multitasking approach of incentive contract (Holmstrom and Milgrom, 1991) to deal with the different (ecosystem) services that agriculture may provide. Indeed, the idea of multitasking defines a more active role for farmers, who chooses the amount of effort to be dedicated to each task, including the actions to promote environmental quality.

The simple model of agriculture multitasking developed in our paper suggests an additional implication: the problem of multitasking further strengthens the argument of mixed payment, i.e. introduction of partial decoupling subsidies from production in the farmer compensation scheme. Previous economic arguments for decoupled subsidies and mixed payment center on reducing farmer risk's aversion (Hennessy, 1998) or relaxing credit constraints (Goodwin and Mishra, 2006). We show that introducing decoupled subsidies may be socially efficient since they can balance incentives for effort across contractible and non-contractible environmental services. The relationship between both dimensions deserves attention, especially when new environmental instruments and contracts include measures of farmer performance in payment. Indeed, our main finding is that mixed payment, through decoupled subsidies, lessens distortions in effort allocation when pay-for-performance is imperfect, thus promoting non-contractible environmental services.

The link between pay-for-performance and mixed payment has not been shown in the previous literature on multitasking. Applying the idea of multitasking to agricultural contract between the Government and farmers, we show that moving away from coupled toward more decoupled subsidies (mixed payment) may promote effort on environmental non-contractible services. The theoretical proposition has been empirically tested using a French database and confirmed by the estimation of: (i) a reduced-form of the model (an extended seemingly unrelated regression (SUR) model), which accounts for continuous, dichotomic and polytomic decision variables, and (ii) a structural model.

The remaining sections are organized as follows. Section 2 reviews the related literature. Section 3 presents the theoretical model and in section 4 we test the empirical prediction of our theoretical framework on the incentive effect of mixed payment and decoupled subsidies. Section 5 brings some concluding remarks.

2 Related literature

Concerns about coherence between agricultural policies and the sustainability of the agriculture have motivated a large body of literature on the influence of agricultural supports on farmers' production decisions, particularly in terms of optimal input use, acreage decisions, agricultural production and environmental externalities. Today, production-related subsidies (also named coupled subsidies), decoupled subsidies, and agri-environmental payments represent the main forms of agricultural support granted to farmers (OECD, 2014). The coupled subsidies are given to maintain some specific crops in farming; the decoupled subsidies serve mainly to stabilize the farmer's revenue; and the agri-environmental payments are given to farmers who voluntarily subscribe to a program of environmentally-friendly farming practices. While the production specific payments (coupled subsidies) are known to induce distortions in production decisions (Young and Westcott, 2000), the effect of decoupled subsidies on production decisions is still under debate (Just and Kropp, 2013), and the uptake rate of the agri-environmental schemes remains relatively low (Guillem and Barnes, 2013; Espinosa-Goded et al., 2013).

Overall, initial research on decoupled subsidies supports that they do not provide incentives for production intensification (see Just and Kropp, 2013). They appear to be environmentally friendly since it is well known that intensification of agricultural production may lead to environmental damages such as biodiversity loss, water pollution, and land degradation. However, further research show that decoupled subsidies may increase production by reducing farmers' risk aversion to engaging in risky production activities (Hennessy, 1998, Sckokai and Moro, 2006; Féménia et al, 2010) and by relaxing credit constraints (Goodwin and Mishra, 2006; Ciaian and Swinnen 2009). In a more recent study, Just and Kropp (2013) argue that decoupled subsidies may be as production distorting as direct production subsidies. The reasoning is that, to be entitled to support, farmers are constrained to produce eligible crops even though the profits associated with these crops decline relative to the profits of non-eligible crops. This may create production distortions, because in this case producers are not encouraged to respond to market signals. Nevertheless, in a review of literature, Bhaskar and Beghin (2009) highlight that the effects of decoupled subsidies on production decisions are likely to be negligible. Additionally, Serra et al. (2011a) evidence that decoupled subsidies have only negligible impacts on farmer' production decisions. However, in what concerns farm productivity and technical efficiency, which can be seen as indicators of input optimal use, theoretical studies predict mixed impacts of decoupled subsidies (see Rizov et al, 2013; Kazukauskas et al., 2014; Serra et al. 2008; Kumbhakar and Lien, 2010). Although empirical results are in line with the theoretical predictions, the most common finding is a negative effect (see Minviel and Latruffe, 2014). In addition, some of the positive effects reported in the literature may result in artefactual modeling approaches (see Minviel and Latruffe, 2016). This suggests that, in essence, public subsidies involve non-optimal use of production factors.

As for acreage decisions, Goodwin and Mishra (2006) find a positive association between decoupled subsidies and acreage for grain productions. However, they mention that a more general evaluation of decoupled subsidies on acreage decisions has to include non-crop (pasture, fallow, and set-aside) use of farmland.

Regarding the issue of agri-environmental schemes, it is agreed that adoption of environmentally friendly farming practices (EFFP) is strongly driven by the environmental attitudes (environmental consciousness) and the ecological perceptions of the farmers (Wilson and Hart, 2000; Morris et al, 2002; Guillem and Barnes, 2013). However, the low adoption rate of agri-environmental contract can be explained by barriers to the adoption of environmentally-friendly practices, e.g. additional fixed costs and income foregone associated with these practices (Espinosa-Goded et al., 2013; Europa, 2015). In this view, the decoupled payments may potentially encourage EFFP since they serve mainly to flatten farmers' revenue. This coincides with the idea of Espinosa-Goded et al. (2013) who mention that lump sum payments would be efficient for the adoption of EFFP.

The previous discussion suggests that more theoretical and empirical work is needed to address the coherence between agricultural policies and the sustainability of agriculture. A limitation of the above literature is that the description of the strategic decisions of farmers is relatively poor. On the one hand, the productivity and efficiency analyzes are insightful as they reveal the extent to which public subsidies influence the optimal use of inputs. Nevertheless, in a socio-environmental perspective, the aggeagate measures of productivity and efficiency provide only partial insights for policy makers. For instance, they do not provide specific information on the influence of subsidies on the efficiency of land use and chemical input use, which may be relevant for policy makers. On the other hand, the models of acreage decisions ignore the fact that, given decoupled subsidies, farmers may adopt extensive production strategies by extending areas under cultivation while reducing chemical input use per unit area (Boussemart et al., 2011). In essence, one important issue, which is not explicitly addressed in the previous literature, is the multitasking nature of farmers' production decisions. That is why, our paper develops an agency multitasking model to address this issue.

3 The model

3.1 Set-up

In this section, we develop a simple model tailored to the agro-environmental setting. Consider the social planner or the Government (Ministry of Agriculture) who contracts with the farmer to provide multiple agricultural (ecosystem) services to society. Consumers are supposed to desire various ecosystem services - e.g. quantity and quality of food, less pesticide and fertilizer use, biological and landscape diversity preservation. Let Q represent the production of food outputs in quantitative terms, e_i the farmer's effort on environmental service i, and $V_i(Q, e_i)$ the social benefit from the production of food and the environmental service i. Assume that the food production level, as well as the farmer effort e_i on environmental service i, increases the social benefit $V_i(Q, e_i)$ at a decreasing rate. Assume also that environmental effort increases the marginal benefit of food production, i.e. $\partial^2 V_i(Q, e_i)/\partial Q \partial e_i > 0, \forall i$.

The social planner utility from ecosystem services is the sum of benefits from food production and each individual environmental service i, i.e. $V(Q,e) = \sum_i V_i$. Environmental service effort vector e generates a disutility $C(e)$ for the farmer, where $C(e)$ is increasing and convex in effort. Similarly, production of food generates a disutility $C(Q)$ for the farmer, where $C(Q)$ is increasing and convex in its argument. We suppose also that increasing one environmental effort increases the marginal cost of other efforts, i.e. $\partial^2 C/\partial e_i \partial e_j > 0, \forall j \neq i$.

Some farmer environmental efforts on providing ecosystem services may be contractible. For example, the Government may decide to offer an environmental contract with a "quality bonus" for specific ecosystem services that may improve quality of the environment, such as introducing permanent grass strip, fallow ... Suppose that the Government pays the farmer ν_j per verifiable unit of effort e_j, with $j \neq i$, and where ν_j can be seen as "pay-for-performance" or "bonus payment".

The revenue of the farmer is a three component compensation scheme. First, a market revenue from the output Q sold on the market at a price P. Without loss of generality we suppose that $P = 1$. Second, subsidies from a "production contract" with production coupled subsidies (αQ) with $0 < \alpha < 1$ and decoupled subsidies (or fixed payments) F. In Europe, the "production contract" refers to the first pillar of the Common Agricultural Policy (CAP). To ensure the participation of the farmer to the contract, if the Government decides to reduce coupled subsidies (αQ), it needs to increase the decoupled subsidies (F). Third, subsidies from an agri-environmental contract with payments for some specific effort in ecosystem services that may improve the environment ($\nu_i e_i$). Taking into account the production cost ($C(Q)$) and disutility of the environmental effort ($C(e)$), the profit Π of the farmer can be written as follows:

$$\Pi = F + (1+\alpha)Q - C(Q) + \sum_i \nu_i e_i - \sum_i C(e_i) \tag{1}$$

We suppose that the farmer cares about the social environmental concerns V, as well as his own profit Π from producing output and environmental services. His utility is then

$$U = U^0(\Pi) + \lambda V \tag{2}$$

The higher λ , the more "benevolent" the farmer is (see Daly and Giertz, 1972; Bergstrom, 1999). A farmer who equally values environmental concerns and his own profit would have λ equal to one. We assume that farmers do care about environmental concerns (McCann et al., 1997; Karali et al., 2014), although the level of "benevolence" could be quite limited. Let U^0 denote the private component of the farmer's altruistic utility function U, and assume that farmer's utility is strictly concave.

The Government is supposed to be able to specify a payment for each environmental service separately (e.g. a bonus for fallow practice and/or permanent grass strip). Dimensions of ecosystem performance that are not explicitly rewarded are implicitly assigned a "price" of zero ($\nu = 0$). That is, the effort distortions that arise in the model do not stem from inability to target ecosystem services incentives on particular services.

3.2 Incentives with one environmental service

We suppose that the Government maximizes the net social surplus subject to a budget constraint:

$$Max_{<Q,e>}\, W = W_C - T + W_F \quad s.t. \quad F + \alpha Q + \nu e \leq S \tag{3}$$

where W_C denotes consumers' surplus, T represents the taxes, and W_F denotes farmers' surplus, which are given by:

$$\begin{cases} W_C & = \lambda V\left(Q,\ e\right) - Q \\ T & = F + \alpha Q + \nu e \\ W_F & = \Pi = Q + F + \alpha Q + \nu e - C\left(Q\right) - C\left(e\right) \end{cases}$$

S denotes the total subsidy amount that can be spent by the Government. Substituting W_C, T and W_F in [3], the Government's program becomes:

$$Max_{<Q,e>} W = \lambda V\left(Q, e\right) - C\left(Q\right) - C\left(e\right) \quad s.t. \qquad F + \alpha Q + \nu e \leq S \tag{4}$$

The first order conditions (FOC) are given by:

$$\begin{cases} \lambda V_Q(Q^*, e^*) & = C'(Q^*) + \mu\alpha \\ \lambda V_e(Q^*, e^*) & = C'(e^*) + \mu\nu \end{cases} \tag{5}$$

where μ represents the strength of the budget constraint, Q^* and e^* denote the first-best levels of output and effort. Expression [5] indicates that the marginal value of the production Q, and the marginal value of the environmental service are higher than their respective marginal cost in the presence of "pay-for-performance" in environmental quality effort ν and high-powered production subsidies. This implies that the Government can promote environmental quality effort with high-powered pay-for-performance or with low-powered production subsidies, assuming that Q and e are substitutable.

But this can be done only if e is contractible. That is, when a production subsidies parameter α can be set appropriately to increase production output, while direct rewards for environmental service prevent production from adversely impacting environmental service. In contrast, suppose that the Government cannot reward environmental service effort (because e is non-contractible). Then it has only one instrument (α) to hit two targets (increasing production and environmental services). When Q and e are substitutable, the non-contractibility of environmental service presents a dilemma: a high production subsidy rate α ensures production quantity provision but not environmental effort; low α promotes environmental service but also low production quantity. A mixed form of payment is likely to be optimal, to balance production output with environmental service.

3.3 Incentives with two environmental services

Consider now a two-environmental service model, where the Government contracts with a farmer to provide two kinds of environmental services: service 1 and service 2. The contract includes a fixed payment F (decoupled subsidies), a share payment αQ (coupled subsidies), as well as incentive payments $\nu_1 e_1$ and $\nu_2 e_2$ to motivate efforts in environmental services 1 and 2. Then, the disutility of effort is $C(e) = C(e_1, e_2)$, where effort on service 1 competes for the farmer attention with effort on service 2, so that a higher level of one effort increases the marginal cost of the other. Denoting partial derivatives with a subscript, the assumptions are thus $\partial C(e_1, e_2)/\partial e_1 = C_1 > 0, \partial C(e_1, e_2)/\partial e_2 = C_2 > 0$, and $\partial^2 C(e_1, e_2)/\partial e_1^2 = C_{11} > 0, \partial^2 C(e_1, e_2)/\partial e_2^2 = C_{22} > 0$.

Similar to the case of one environmental service, the program of the Government is given by:

$$Max_{<Q,e_1,e_2>} W = \lambda V_1(Q, e_1) + \lambda V_2(Q, e_2) - C(Q) - C(e_1, e_2) \qquad s.t. \quad F + \alpha Q + \nu_1 e_1 + \nu_2 e_2 \leq S \tag{6}$$

The FOCs of the social welfare maximization for choice of production output and environmental service efforts are

$$\lambda \left[\frac{\partial V_1(Q, e_1)}{\partial Q} + \frac{\partial V_2(Q, e_2)}{\partial Q} \right] = C'(Q) + \mu\alpha \tag{7}$$

$$\lambda \left[\frac{\partial V_1(Q, e_1)}{\partial e_1} \right] = C_1(e_{1,}e_2) + \mu\nu_1 \tag{8}$$

$$\lambda \left[\frac{\partial V_2(Q, e_2)}{\partial e_2} \right] = C_2(e_1, e_2) + \mu\nu_2 \tag{9}$$

where μ represents the strength of the budget constraint.

Comparative statics (see appendix) show how the relationships between services lead to the multitasking problems and how mixed payment through decoupled subsidies can mitigate the adverse effects. First, increasing the share payment for production (coupled subsidies) induces the farmer to increase his production output ($\partial Q/\partial\alpha > 0$). Increasing incentive payment for the first environment service (ν_1) induces the farmer to exert more effort on that service ($\partial e_1/\partial\nu_1 > 0$) and to decrease effort on the other environmental service ($\partial e_2/\partial\nu_1 < 0$). That is, our model replicates standard results of the literature on multitasking (Holmstrom and Milgrom, 1991).

What has not been shown in the literature on multitasking, and the primary focus here, is the trade-off between pay-for-performance ($\nu_i > 0$) for some environmental service(s) and mixed-payment ($0 < \alpha < 1$). The following proposition articulates both results.

Proposition 1. *Suppose that the first environmental service is non-contractible (ν_1 is constrained to 0), whereas the second environmental service is contractible ($\nu_2 > 0$). We get two results:*

(i) classic multitasking effect: Incentive payments on the second service ($\nu_2 > 0$) causes the multitasking problem, i.e. the farmer reallocates effort from the first service ($\partial e_1/\partial \nu_2 < 0$) to the second service ($\partial e_2/\partial \nu_2 > 0$).

(ii) mixed-payment effect: Introducing mixed payment by decreasing the high-powered incentives for production, through decoupled subsidies, can restore some incentive for the first service ($\partial e_1/\partial \alpha < 0$). The underlying idea is that, as mentioned earlier, to ensure the farmer's participation to the contract, if coupled subsidies are reduced (by decreasing α), decoupled subsidies must be increased.

Proof. See appendix for the derivation of the results.

Proposition 1 implies that moving away from coupled subsidies toward more decoupled subsidies, i.e. mixed payment by decreasing α, reduces the multitasking problem. That is, it is possible to restore incentives for the non-contractible environmental service. In the example that we consider in the empirical application below, the permanent grass strip environmental service may be measurable, and thus contractible, while environmental service from mixed farming and crop diversification may be more difficult to measure (Meynard et al., 2013). Then, using high-powered pay-for-performance will distort farmer away form mixed farming or investment in crop diversification toward permanent grass strip service. Using mixed payment, by decreasing coupled subsidies and increasing the decoupled subsidies (F) reduces the distortion.

4 Empirical analysis

To test the empirical prediction of our Proposition 1, we use a farm-level database that collected from 2003 to 2011 information on : (i) French farmers' decisions on production and environmental practices; and (ii) different components of the public subsidies received by these farmers. After a brief presentation of the data and the two empirical models used (4.1), we discuss the results of the econometric results (4.2).

4.1 Data and econometric models

4.1.1 Data and variables

We use an unbalanced panel dataset for French farms located in the French region Meuse over two sub-periods of policy implementation: 2003-2005 and 2008-2011. This segmentation allows evaluating the incentive effect of decoupled payments as in a natural experiment framework. In the period covered by the current study, direct payments to producers have become dominant in the European Union (UE) CAP budget and the agri-environmental payments have been strengthened. That is, in the sub-period 2003-2005 all direct payments received by farmers were coupled to their production decisions (coupled payments) while in the sub-period 2008-2011 the major part of the direct payments has been decoupled from production (decoupled payments). Notice that, in France the implementation of the decoupled payment schemes started in 2006. However, in our data set, no information is available on decoupled payments for the years 2006 and 2007; that is why these years are excluded in our analysis. The total number of observations is 1,049 for the sub-period 2003-2005 and 1,592 for the sub-period 2008-2011.

The data set is provided by a regional accounting office and contains information on farm production structure, on farm financial results, and on agricultural subsidies. More precisely, it contains information on crop areas, crop production in monetary values and in physical quantities, implementation of permanent grass strip, total expenditures on pesticides, fertilizer use in monetary values and in physical quantities, work hours and workloads, coupled and decoupled payments, payment for permanent grassland, and the number of crops. It also contains information on variables that may influence production decisions such as farmer's age (Age), the legal status of the farms (individual or company farms) (Indiv), and farm's indebtedness (Debt). For estimation purposes, the dataset was complemented with output, fertilizer, pesticide, and labour prices. For the output, the fertilizer and the labour, the prices are computed by dividing monetary values by physical quantities used. Farmers produce several outputs and their prices are potentially correlated. To circumvent correlation issues in the estimation procedure, the output price used in the regression is a mean price computed from the individual prices. Since no information is available on physical quantities of pesticides, we cannot compute their prices. Hence, as in Serra et al. (2011b) and Laukkanen and Nauges (2014), we consider the pesticide price index as a proxy for pesticide price. A statistical summary for those variables is presented in table 1. All monetary values are expressed in 2003 constant Euros using the appropriate deflators.

Among the critical variables, we distinguish a set of decisions including production services such as chemical input use (Fert and Pest) in cropping to increase the agricultural yield and environmental services such as implementation of permanent grass strip (PG), crop diversity (NC), and mixed farming adoption (MF). The dependent variables in the reduced-form model below [10] concern therefore the use of chemical fertilizers ($Fert$) and pesticides ($Pest$), the implementation of permanent grass strip (PG), the number of diversified crops (NC), and mixed farming (MF). The dependent variables are related to decoupled payment (S_D), coupled payment (S_c), contract payment for permanent grassland (S_{pg}), but also fertilizer (W_f) and pesticide price (W_p), total farm area (L), the ratio of wheat area to total farm area (Sh_{wheat}), farmers' age (Age), a binary indicator for individual farms ($Indiv$) versus partnership farms, and farmers' indebtedness ($Debt$) measured as the ratio of farmers' debt and capital assets. The control variable Sh_{wheat} is used to account for some induced effects of wheat. Indeed, wheat is a very profitable crop and it is very demanding in fertilizer and pesticide. It may therefore influence the other choices of the farmers.

- Insert Table 1-

4.1.2 The reduced-form approach

We first test Proposition 1 prediction by having recourse to a reduced-form approach. That is, we estimate the impact of the compensation scheme (coupled and decoupled subsidies (S_C and S_D), and pay-for-(environmental) performance (S_{pg}) on the decision to adopt production services

($Fert$ and $Pest$) and contractible (PG) and non-contractible services (NC and MF). To do so, we estimate the following system of equations

$$
\begin{aligned}
Fert &= \alpha_0 + \alpha_1 S_D + \alpha_2 S_c + \alpha_3 S_{pg} + \alpha_4 X + \xi_1 \\
Pest &= \beta_0 + \beta_1 S_D + \beta_2 S_c + \beta_3 S_{pg} + \beta_4 X + \xi_2 \\
PG &= \gamma_0 + \gamma_1 S_D + \gamma_2 S_c + \gamma_3 S_{pg} + \gamma_4 X + \xi_3 \\
NC &= \delta_0 + \delta_1 S_D + \delta_2 S_c + \delta_3 S_{pg} + \delta_4 X + \xi_4 \\
MF &= \theta_0 + \theta_1 S_D + \theta_2 S_c + \theta_3 S_{pg} + \theta_4 X + \xi_5
\end{aligned}
\tag{10}
$$

where $X = \{W_F, W_P, L, Sh_{wheat}, Age, Indiv, Debt\}$ is the vector of other exogenous variables. In this setup, the system of equations [10] allows testing direct and indirect effects of different incentives on farmers' choices. For instance, the agri-environmental schemes serve mainly to engage farmers in specific environmentally-friendly farming practices such as implementation of permanent grass strip, but they may also contribute to the production of ecologically sound commodities by reducing fertilizer use at farm level, or by encouraging mixed farming. The decoupled payments may balance incentives toward extensive farming and thus induce production of non-contractible environmental services by reducing distortion toward contractible environmental service (permanent grass strip) chemical input use.

The system of equations [10], in which some of the dependent variables are continuous (Fert, Pest, PG) while others are ordered (NC) and binary (MF), can be estimated by the mixed-process maximum likelihood procedure introduced by Roodman (2011). This procedure can be seen as a seemingly unrelated regression (SUR) model (Zellner, 1962) with continuous and discrete variables. In behavioral analysis, the SUR model combines a set of equations related to a set of individual decisions, assuming that equation residual errors may be correlated for an individual given unobservable drivers that may influence his decisions. More precisely, the SUR method estimates simultaneously a set of equations which share a common error structure with non-zero covariance, so that the parameters of each single equation take into account information provided by the other equations (Cadavez and Henningsen, 2012). The term SUR is used in the sense that there is no reciprocal causation between endogenous variables and the error terms are assumed to be correlated across equations. Each equation of the SUR model could be consistently estimated separately; but a simultaneous estimation is generally more efficient since it uses information from full covariance structure of the model.

4.1.3 The structural-form approach

Besides the reduced-form approach, we also estimate a system of structural equations from expression [1]. To derive this system of equations, which concerns only the continuous variables, we follow Lacroix and Thomas (2011) who propose a profit function of the farmer which integrates the effects of coupled subsidies and Laukkanen and Nauges (2014) for the introduction of Agri-environmental payments. We complete this model by integrating the effect of decoupled subsidies on profit. As such the expression of the profit Π of the farmer can be rewritting as follows :

$$\Pi = \sum_{c} L_c(P_c Q_c + S_c) + L_{pg} S_{pg} - wx + S_D \tag{11}$$

Were L_c denotes land allocated to crop c; P_c stands for output production price; Q_c denotes output production per hectare; S_c and S_{pg} represent per hectare subsidy rates for crops and permanent grass strip (L_{pg}); x is vector of inputs and w represents their corresponding price; and S_D stands for the amount of decoupled payments. Maximizing the profit function [11] under the constraint of total land available, $L_c + L_{pg} = L$, yields optimal land, output, and input decisions. The equations related to these decisions can be derived by applying Hoteling's lemma to a dual profit function ($\prod(P_c, w, S_c, S_{pg}, S_D, L)$). To be theoretically valid, the profit function has to be convex in prices, linearly homogeneous in prices, monotonic increasing in output prices, monotonic decreasing in input prices. To impose these conditions as well as the constraint on the available total land, the dual profit function is modeled using the normalized quadratic form (Lau, 1976). As in Lacroix and Thomas (2011) and Laukkanen and Nauges (2014), the normalization is done by dividing the profit, prices and subsidies by the price of one input. For the purpose of our analysis, the inputs considered include fertilizer, pesticide, and labour; and the price of labour is used to normalize the profit function. Hence, the quadratic profit function is given by

$$\begin{aligned}
\bar{\Pi} = {} & \alpha_0 + \alpha_1 \bar{P}_c + \alpha_2 \bar{S}_c + \alpha_3 \bar{S}_{pg} + \alpha_4 \bar{S}_D + \alpha_5 \bar{W}_f + \alpha_6 \bar{W}_p + \alpha_7 \bar{P}_c \times \bar{S}_c \\
& + \alpha_8 \bar{P}_c \times \bar{S}_{pg} + \alpha_9 \bar{P}_c \times \bar{S}_D + \alpha_{10} \bar{P}_c \times \bar{W}_f + \alpha_{11} \bar{P}_c \times \bar{W}_p + \alpha_{12} \bar{S}_c \times \bar{W}_f \\
& + \alpha_{13} \bar{S}_c \times \bar{W}_p + \alpha_{14} \bar{S}_{pg} \times \bar{W}_f + \alpha_{15} \bar{S}_{pg} \times \bar{W}_p + \alpha_{16} \bar{S}_D \times \bar{W}_f \\
& + \alpha_{17} \bar{S}_D \times \bar{W}_p + 0.5\alpha_{18} \bar{P}_c^2 + 0.5\alpha_{19} \bar{S}_c^2 + 0.5\alpha_{20} \bar{S}_{pg}^2 + 0.5\alpha_{21} \bar{S}_D^2 \\
& + 0.5\alpha_{22} \bar{S}_c \times \bar{S}_{pg} + 0.5\alpha_{23} \bar{S}_c \times \bar{S}_D + 0.5\alpha_{24} \bar{S}_{pg} \times \bar{S}_D + 0.5\alpha_{25} \bar{W}_f^2 \\
& + 0.5\alpha_{26} \bar{W}_p^2 + 0.5\alpha_{27} \bar{W}_f \times \bar{W}_p + \alpha_{28} \bar{P}_c \times L + \alpha_{29} \bar{S}_c \times L + \alpha_{30} \bar{S}_{pg} \times L \\
& + \alpha_{31} \bar{W}_f \times L + \alpha_{32} \bar{W}_p \times L
\end{aligned} \tag{12}$$

Differentiating with respect to prices and unit of subsidies yields

$$L_c Q_c = \frac{\partial \bar{\Pi}}{\partial \bar{P}_c} = \alpha_1 + \alpha_7 \bar{S}_c + \alpha_8 \bar{S}_{pg} + \alpha_9 \bar{S}_D + \alpha_{10} \bar{W}_f + \alpha_{11} \bar{W}_p + \alpha_{12} \bar{P}_c + \alpha_{28} L \tag{13}$$

$$L_c = \frac{\partial \bar{\Pi}}{\partial \bar{S}_c} = \alpha_2 + \alpha_7 \bar{P}_c + \alpha_{12} \bar{W}_f + \alpha_{13} \bar{W}_p + \alpha_{19} \bar{S}_c + \alpha_{22} \bar{S}_{pg} + \alpha_{23} \bar{S}_D + \alpha_{29} L \tag{14}$$

$$L_{pg} = \frac{\partial \bar{\Pi}}{\partial \bar{S}_{pg}} = \alpha_3 + \alpha_8 \bar{P}_c + \alpha_{14} \bar{W}_f + \alpha_{15} \bar{W}_p + \alpha_{20} \bar{S}_{pg} + \alpha_{12} \bar{S}_c + \alpha_{23} \bar{S}_D + \alpha_{30} L \tag{15}$$

$$-x_f = \frac{\partial \bar{\Pi}}{\partial \bar{W}_f} = \alpha_5 + \alpha_{10} \bar{P}_c + \alpha_{12} \bar{S}_c + \alpha_{14} \bar{S}_{pg} + \alpha_{16} \bar{S}_D + \alpha_{25} \bar{W}_f + \alpha_{27} \bar{W}_p + \alpha_{31} L \tag{16}$$

$$-x_p = \frac{\partial \bar{\Pi}}{\partial \bar{W}_p} = \alpha_6 + \alpha_{11} \bar{P}_c + \alpha_{13} \bar{S}_c + \alpha_{15} \bar{S}_{pg} + \alpha_{17} \bar{S}_D + \alpha_{26} \bar{W}_p + \alpha_{27} \bar{W}_f + \alpha_{32} L \tag{17}$$

where $L_c Q_c$ denotes output supply, L_c stands for land allocated to crop production, L_{pg} represents land allocated to permanent grassland, x_f and x_p denote fertilizer and pesticide use respectively. The upper bar indicates normalized profit, price, and subsidy variables. For the purpose of our analysis, equations [12] to [17] form the system of structural equations to be estimated after appending a disturbance term to each equation. Moreover, following Lau and Yotopoulos (1971), Khan and Maki (1979), and Dupraz and Latruffe (2015), we include some contextual variables that condition the realization of the profit in the structural model. As in the expression [10], we consider the following contextual variables: the ratio of wheat area to total area (Sh_{wheat}), farmers' age (Age), a binary indicator for individual farms ($Indiv$) versus company or partnership farms, and farmers' indebtedness ($Debt$) measured as the ratio of farmers' debt and capital assets. It should be noticed that we do not take the derivative of profit with respect to decoupled payments; we do not apply the Hotelling's lemma with respect to decoupled payments. The decoupled payments appear in the derivative equations only because they were crossed with other variables in the quadratic profit function (12). This is in line with our theoretical model and can be further justified by the fact that the existing literature show that even under risk neutrality assumption, decoupled subsidies could influence famer behavior by alleviating credit constraints (see, Ciaian and Swinnen 2009; Latruffe et al. 2010).

The equations of the structural model are estimated simultaneously, while imposing the appropriate parameter constraints. As indicated before, the simultaneous estimation improves the efficiency of the parameters by accounting for correlation between errors across equations. It must be remarked that there exists no price for non-contractible environmental services. So we cannot apply Hotelling's lemma to them and thus they could not be included into the structural model.

- Insert Table 1 here -

4.2 Empirical results

The estimation results for the extended SUR model in [10] are reported in tables 2, while the estimates for the main equations of interest from the structural model are presented in table 3. We report results for the two sub-periods: 2003-2005 and 2008-2011; as previously stated, this allows evaluating the possible incentive effect of decoupled payments as in a natural experiment framework. Most of the regressors have a significant impact on farmer' decisions at the 1 or 5 percent level. As regard the main variables of interest and the correlation coefficients for the error terms by pair of equations (ρ_{ij}), the estimates from the reduced form and the structural form tell globally the same story and the results correspond closely to our theoretical predictions. This feature is very interesting since the structural model has been used to confirm some results provided by the reduced-form model (the extended SUR model).

The correlation coefficients for the error terms by pair of equations (ρ_{ij}) can be interpreted as the effects of unobservables on the corresponding dependent variables (Wooldridge, 2010). But, in a multitasking model the correlation coefficients may also be considered as indicators of jointness in the decision making process (Ahearn et al, 2006), or as indicators of complementarity (in cases of positive signs) or substitutability (in cases of negative signs) between pairs of equations (Baskaran et al, 2013). In our estimates, the high level of significance of this coefficient signals that several equations are highly interrelated and that the parameters of each single equation take into account information provided by the other equations (Cadavez and Henningsen, 2012).

In a multitasking perspective of production decisions, the signs of the correlation coefficients are globally as expected. For instance, the use of chemical inputs and implementation of permanent grassland appear to be negatively correlated. This suggests that the production service provided by chemical input use (fertilizer, pesticide) and the environmental service provided by permanent grass strip are substitute services. Our estimates on the correlation coefficients in table 3 confirm also the first part of our theoretical prediction in Proposition 1 (*classic multitasking effect*) since the contractible environmental service (permanent grass) and non-contractible ones (crop diversification and mixed farming) are substitutes.

Our main findings on the effect of subsidies also confirm the empirical predictions in proposition 1. Indeed, for contractible environmental service (permanent grass strip) payment for highlight the multitasking issue stated in proposition 1. First, as expected, tables 2 and 3 show that the estimates for contractible environmental service (permanent grass strip) contract payments are significantly positively associated with the choice of permanent grass strip practice. The positive effect holds in the two sub-periods of policy implementation, even though in the period 2003-2005 environmentally-friendly practices were not encouraged, given the coupled payment scheme. Second, the estimated coefficients for contractible environmental service (permanent grass strip) indicate that these payments do not imply an increase in non-contractible environmental services (crop diversification or mixed farming) nor a reduction of chemical input use.

In contrast, mixed payment, through decoupled subsidies, induce a significant and positive effect on non-contractible environmental services (crop diversification and mixed farming adoption) and a reduction in chemical input use. Moreover, our estimates indicate that decoupled payments impact also positively the implementation of permanent grassland. These results confirm partly our theoretical prediction in the sense that they suggest that decoupled payment helps to balance incentives for effort across ecosystem services (contractible and non-contractible) than high-powered incentives of the agri-environmental contracts. These results could also be related to the cross-compliance measures required to be eligible for decoupled payments, since as suggested by Jaraite and Kazukauskas (2012) cross-compliance measures could reinforce farmers incentives to adopt environmental-friendly practices.

Importantly, the decoupled subsidies are estimated to have also a significant negative impact on chemical input (fertilizer and pesticide) use. The decoupled direct payments are lump sum payments granted to farmers to stabilize their revenue, without production requirements. This may explain why they do not encourage intensive use of fertilizer and pesticide. The results are in line with those of Serra et al. (2006) and Kassoum and Lefer (2013), and those of Koundouri et al. (2009) from simulation exercises for fertilizer. But they contrast with Koundouri et al. (2009) and Peckham and Kropp (2012) simulation results for pesticides.

The estimates for coupled payments also confirm our proposition 1 prediction since they indicate that coupled payments influence positively the use of chemical input (fertilizer and pesticide) in the sub-period 2003-2005, while they have a nonsignificant effect on the choice of mixed farming in the sub-period 2003-2005. There is a slight difference on the impact on chemical input use in the period 2008-2011, since coupled payments have a positive impact only on fertilizer, while their impact on pesticide use is nonsignificant. Concerning the use of chemical inputs, our results are in line with Laukkanen and Nauges (2014).

Concerning the other (control) exogenous variables, the estimates in tables 2 and 3 provide some intuitive results. For instance, the farm scale (total farm area) is estimated to have a positive effect on chemical use and on establishment of permanent grass strip. In contrast, if debt influences positively the use of chemical inputs, it has a negative effect on the use of permanent grass strip. That is, indebted farmers tend to use more chemical input, and less environmental-friendly practices, to ensure their yield and avoid defaulting on debt obligations (Peckham and Kropp, 2012). As for individuals farms and the control variable Age, the results are inconclusive. The results from tables 2 and 3 also display that the share of land allocated to wheat is positively associated to the use of chemical inputs. The estimates from the structural model (table 3) indicate that land allocated to crop production is not influenced by output price in the period of the coupled subsidies (2003-2005) while a positive association is found in the period of the decoupled payments (2008-2011). These results signal that, in contrast to decoupled payments, coupled subsidies influence farmers production decisions without accounting for market prices.

- Insert Table 2 -

- Insert Table 3 -

5 Conclusion

In this paper we developed a theoretical model to study the possible incentive effect of decoupled subsidies. To the extent that some ecosystem services in agriculture cannot be written into an environmental contract, multitasking problems will always plague farmer performance measurement and thus reduce the development of such uncontractible services. We show that this dilemma of agricultural multitasking gives support in favor of mixed payment, through decoupled subsidies.

The traditional argument for incentive effect of decoupled subsidies runs as follows: using decoupled subsidies reduces the farmer's aversion toward risky activities (Hennessy, 1998; Sckokai and Moro, 2006; Féménia et al, 2010) or relaxes credit constraint (Goodwin and Mishra, 2006; Ciaian and Swinnen, 2009). Our paper adds the following argument: since pay-for-performance incentives are imperfect for rewarding some specific services, using mixed payment through decoupled subsidies helps to balance incentives for effort across ecosystem services. First, mixed payment can reduce the negative externalities of production (through pesticide and fertilizer use) by providing weaker incentives to produce. Second, when environmental services are non-contractible and costly to provide (crop diversification and mixed farming practices), pay-for-performance for contractible environmental services and mixed payment through decoupled subsidies should be used. This theoretical proposition has been empirically tested using a French database and confirmed by the estimation of a reduced-form model and a structural model.

In our paper we do not consider risk and uncertainty aspects, while these aspects could be vital for analyzing farmer' behavior (Chambers and Quiggin, 2000). They could also be salient determinants of the use of chemical inputs (fertilizer and pesticide), which are generally perceived as risk-increasing or risk-decreasing inputs (Horowitz and Lichtenberg, 1993; Rajsic et al, 2009; Ramaswami, 1992). A further research avenue is therefore to extend our theoretical model to account for risk and uncertainty, or to include an indicator of risk aversion (defined as the ratio of insurance cost to total expenditures) in our empirical model as in Goodwin and Mishra (2006).

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6 Appendix

Proof of proposition 1

This appendix derives the comparative static results describing how farmer's choices of output and effort respond to the payment incentives of the underlying compensation scheme for production output (αQ) and environmental services ($\nu_1 e_1$ and $\nu_2 e_2$). Recall that the regulator's objective consists in maximizing the social welfare under a budget constraint:

$$Max_{<Q,e>} W = \lambda V_1(Q, e_1) + \lambda V_2(Q, e_2) - C\,(Q) - C\,(e_1, e_2) \qquad s.t. \quad F + \alpha Q + \nu_1 e_1 + \nu_2 e_2 \leq S \quad (18)$$

The FOCs for choice of output and environmental efforts are given in the main text (equations 5.7 to 5.9). Strict concavity of regulator's utility implies that the Hessian matrix H is negative definite, where H is given by

$$H = \begin{bmatrix} \lambda V^1_{QQ} & 0 & \lambda V^1_{Qe} & 0 \\ 0 & \lambda V^2_{QQ} & 0 & \lambda V^2_{Qe} \\ \lambda V^1_{Qe} & 0 & \lambda V^1_{Qe} - C_{11} & -C_{12} \\ 0 & \lambda V^2_{Qe} & -C_{12} & \lambda V^1_{ee} - C_{22} \end{bmatrix}$$

where λV^1_{QQ} denotes $\frac{\partial^2 V_1}{\partial Q Q}$, λV^2_{Qe} denotes $\frac{\partial^2 V_1}{\partial Q e}$, and so forth.

We derive some inequalities that will be useful in the comparative statics. By assumption of concavity, the Hessian determinant is positive (fulfilling the second-order condition for maximization), and the principal minors alternate in sign. This implies that $\lambda V^2_{QQ}[\lambda V^1_{QQ}(\lambda V^1_{ee} - C_{11}) - [\lambda V^1_{Qe}]^2] < 0$. Since $V^2_{QQ} < 0$:

$$\lambda V^1_{QQ}(\lambda V^1_{ee} - C_{11}) - [\lambda V^1_{Qe}]^2 > 0. \qquad (19)$$

Similarly, since environmental services 1 and 2 are perfectly symmetric, we have:

$$\lambda V^2_{QQ}(\lambda V^2_{ee} - C_{22}) - (\lambda V^2_{Qe})^2 > 0 \qquad (20)$$

Moreover, the Hessian could also be written as:

$$H2 = \begin{bmatrix} \lambda V_{ee}^1 - C_{11} & -C_{12} & \lambda V_{Qe}^1 & 0 \\ -C_{12} & \lambda V_{ee}^2 - C_{22} & 0 & \lambda V_{Qe}^2 \\ \lambda V_{Qe}^1 & 0 & \lambda V_{QQ}^1 & 0 \\ 0 & \lambda V_{Qe}^2 & 0 & \lambda V_{ee}^2 \end{bmatrix}$$

It follows from concavity that the principal minors of H2 also alternate in sign, so that the following three inequalities hold:

$$[(\lambda V_{ee}^1 - C_{11})(\lambda V_{ee}^2 - C_{22}) - [C_{22}]^2 > 0 \tag{21}$$

$$\lambda V_{QQ}^1 \left[(\lambda V_{ee}^1 - C_{11})(\lambda V_{ee}^2 - C_{22}) - (C_{12})^2\right] - (\lambda V_{ee}^2 - C_{22})[\lambda V_{Qe}^1]^2 < 0 \tag{22}$$

$$\lambda V_{QQ}^2 \left[(\lambda V_{ee}^1 - C_{11})(\lambda V_{ee}^2 - C_{22}) - (C_{12})^2\right] - (\lambda V_{ee}^2 - C_{11})[\lambda V_{Qe}^2]^2 < 0 \tag{23}$$

by symmetry of services 1 and 2.

As regard the second part of proposition 1, consider the effect of introducing mixed payment by decreasing the share payment for production (α), through the increase of decoupled subsidies, on the farmer's choice of the first environmental service. From (20), we have

$$\frac{\partial e_1}{\partial \alpha} = \frac{-\lambda V_{Qe}^1 \left[\lambda V_{QQ}^2)(\lambda V_{ee}^2 - C_{22}) - (\lambda V_{Qe}^2)^2\right]}{|H|} < 0 \tag{24}$$

where the numerator is negative by (20) and the denominator is positive by strict concavity of $W(Q, e_1, e_2)$. The other comparative statics are derived analogously as follows:

$$\frac{\partial Q}{\partial \alpha} = \frac{\lambda V_{Qe}^1 \left[\lambda V_{Qe}^2)C_{12}\right]}{|H|} > 0 \tag{25}$$

$$\frac{\partial e_2}{\partial \alpha} = \frac{\lambda V_{Qe}^1 \left[\lambda V_{QQ}^2)(-C_{22})\right]}{|H|} > 0 \tag{26}$$

$$\frac{\partial Q}{\partial \nu_1} = \frac{\lambda V^1_{Qe}\left[(\lambda V^2_{QQ})(\lambda V^2_{ee} - C_{22}) - (\lambda V^2_{Qe})^2\right]}{|H|} > 0 \tag{27}$$

$$\frac{\partial e_1}{\partial \nu_1} = \frac{-\lambda V^1_{QQ}}{|H|} > 0 \tag{28}$$

$$\frac{\partial e_2}{\partial \nu_1} = \frac{\lambda V^1_{QQ}\left[\lambda V^2_{QQ})(-C_{22})\right]}{|H|} < 0 \tag{29}$$

Table 1: Brief summary statistics of the main variables used

Variable		2003-2005		2008-2011	
Name	Abreviation	Mean	SD	Mean	SD
Fertilizer input (Kg)	Fert	7,638	5,153	4,354	3,343
Pesticide input (Euros)	Pest	11,227	6,053	18,985	13,548
Permanent grassland (ha)	PG	55.57	33.71	61.01	42.64
Coupled payment (Euros)	Sc	43,734	19,780	5,236	6,870
Decoupled payment (Euros)	S_D	/	/	51,425	26,511
Payment for permanent grass strip (Euros)	S_{pg}	520.15	2,041	636.92	1,818
Total farm area (ha)	L	131.49	51.68	187.70	96.91
Land allocated to crop	L_c	75.91	42.56	126.68	86.66
Output price (Euros/tone)	P_c	173.44	31.41	132.66	27.90
share of area in wheat (%)	Sh_{wheat}	24	11	27	9
Fertilizer price (Euros/Kg)	W_F	0.54	0.15	0.89	0.24
Pesticide price (index)	W_P	1.01	0.01	1.07	0.02
Number of crops	NC	4.04	1.41	4.19	0.96
labour price (Euros/hour)		5.26	2.97	7.07	4.68
mixed farms (dummy)	MF	0.87	0.33	0.88	0.32
Profit (Euros)	$\prod$	121,937	55,551	122,996	81,783
Age (years)		40.46	9.52	44.24	8.58
Individual farm (dummy)	Indiv	0.38	0.48	0.21	0.40
Debt (debt to capital assets)	Debt	0.39	0.88	0.35	0.38
Number of observations		1,049		1,592	

Table 2: **Empirical Estimates of the extended SUR model**

	2003-2005					2008-2011				
	Fert (1)	Pest (2)	PG (3)	NC (4)	MF (5)	Fert (1)	Pest (2)	PG (3)	NC (4)	MF (5)
Fertilizer price	-7,317***	-4,956**	50.27***	1.85 ***	2.43 ***	-1,856**	5218 *	12.98	-1.31***	-0.07
	(1837)	(2270)	(12.82)	(0.65)	(0.81)	(734)	(3005)	(13.33)	(0.49)	(0.81)
Pesticide price	3,290 **	3,507**	-24.11***	-0.62	-1.66***	4,215***	-3,745	-77.45***	-0.29	-2.49 **
	(1208)	(1493)	(8.43)	(0.42)	(0.55)	(870)	(3540)	(15.71)	(0.58)	(0.96)
Decoupled	/	/	/	/	/	-0.08 ***	-0.11 **	0.003***	2.6E-05 ***	8E-05***
payment						(0.01)	(0.05)	(0.0002)	(8.7E-06)	(1.7E-05)
Coupled payment	4.08***	11.74***	-0.03***	0.004 ***	-5E-04	2.38**	5.67	-0.02 (0.02)	0.003 ***	1.9E-03
	(1.38)	(1.71)	(0.009)	(0.0005)	(7E-04)	(1.12)	(4.56)		(0.0007)	(1.2E-03)
Payment for PG	-3.68	-10.59	0.12 *	-0.008**	-0.009**	-0.13	-0.24	0.004***	-1.6E-04 ***	- 8.5E-05
	(10.00)	(12.36)	(0.07)	(0.03)	(0.004)	(0.08)	(0.32)	(0.001)	(5.3E-05)	(9.2E-05)
Total farm area	52.63***	76.15***	0.33 ***	0.008 ***	0.007 ***	31.03 ***	118.44***	0.12***	0.003 ***	-0.002***
	(1.95)	(2.40)	(0.01)	(0.0007)	(0.001)	(0.60)	(2.45)	(0.01)	(0.0004)	(0.0007)
Share wheat	26,923***	17,821***	-147.81	1.34 ***	-0.85 **	9,838***	36,896 ***	-215.22 ***	-0.05	-4.59***
	(859)	(1062)	*** (6.00)	(0.30)	(0.41)	(426)	(1732)	(7.68)	(0.28)	(0.45)
Age	0.43	42.45***	-0.13 *	0.009 ***	-0.006	23.13***	41.36 ***	-0.29***	0.0004	-0.0006
	(10.77)	(13.31)	(0.07)	(0.003)	(0.006)	(4.88)	(19.88)	(0.09)	(0.003)	(0.005)
Individual farms	822 ***	526 *	-2.95 *	0.16**	-0.25**	138	667 (455)	-2.18	-0.12 *	-0.17
	(231)	(294)	(1.66)	(0.08)	(0.12)	(112)		(2.02)	(0.07)	(0.11)
Debt	-99.60	266 **	-0.53	-0.05 (0.04)	-0.14 ***	2.53 **	2967 ***	-14.57 ***	-0.34 ***	-0.83 ***
	(107)	(132)	(0.75)		(0.04)	(106)	(431)	(1.91)	(0.07)	(0.11)
Intercept	-8,128***	-10,268***	55.19***	/	1.07***	-5,170 ***	-15,666***	106.35***	/	3.14 ***
	(732)	(905)	(5.11)		(0.38)	(286)	(1,164)	(5.16)		(0.33)
Number of Obs.			1,049					1,592		
ρ_{12}(Fert-Pest)			0.32 ***					0.48 ***		
ρ_{13}(Fert-PG)			-0.15 ***					-0.60 ***		
ρ_{14}(Fert-NC)			0.17 ***					-0.01		
ρ_{15} (Fert-MF)			0.05					-0.36 ***		
ρ_{23} (Pest-PG)			-0.61 ***					-0.50 ***		
ρ_{24} (Pest-NC)			0.48 ***					0.07 **		
ρ_{25} (Pest-MF)			-0.12 ***					-0.26***		
ρ_{34} (PG-NC)			-0.45 ***					-0.18 ***		
ρ_{35} (PG-MF)			-0.29 ***					- 0.61 ***		
ρ_{45} (NC-MF)			0.45 ***					0.31***		

* significance at 10%; ** significance at 5%; *** significance at 1%; Fert: fertilizer; Pest: Pesticide; PG: Permanent grassland; NC: number of crops; MF: Mixed farming; ρ_{ij}: correlation coefficient for each pair of equations

Table 3: Estimation results of the structural model

	2003-2005				2008-2011			
	Fert (1)	Pest (2)	PG (3)	Lc (4)	Fert (1)	Pest (2)	PG (3)	Lc (4)
Output price	6.63 (9.19)	-11.23	-0.27	-0.17	17.67 ***	36.20 *	-0.11	1.72 ***
		(12.41)	(0.17)	(0.11)	(5.68)	(21.04)	(0.09)	(0.54)
Fertilizer price	-5,080***	-1400	7.04 (9.62)	7.41*	-2,451 ***	1,856 *	-0.12	(13.63 ***
	(1646)	(1441)		(4.39)	(642)	(1016)	(0.08)	(4.68)
Pesticide price	-1,400	996.24	1.50	12.55 **	1856 *	-9,791 ***	-0.23	24.85
	(1441)	(2203)	(11.68)	(5.30)	(1016)	(2989)	(0.32)	(16.66)
Decoupled payment	/	/	/	/	-0.12 ***	- 0.10 **	0.002 ***	- 0.05 **
					(0.01)	(0.05)	(0.0003)	(0.02)
Coupled payment	7.44 *	12.55 **	0.12 (0.08)	0.09 *	13.63 ***	24.85	0.005	-0.06
	(4.39)	(5.30)		(0.05)	(4.68)	(16.66)	(0.01)	(0.56)
Payment for PG	7.04 (9.62)	1.50	0.29 *	0.12 (0.08)	-0.12 (0.08)	-0.23	0.05 **	0.05 (0.01)
		(11.68)	(0.18)			(0.32)	(0.02)	
Total farm area	52.47 ***	77.1 5***	0.30 ***	0.57 ***	30.16 ***	112.70 ***	0.19 ***	0.99***
	(1.96)	(2.52)	(0.05)	(0.03)	(0.61)	(2.36)	(0.01)	(0.08)
Share wheat	26,813 ***	18,013 ***	-153 *** (	125 ***	9395 ***	34,659 ***	-158 ***	371 ***
	(865)	(1113)	22.68)	(14.02)	(444)	(1721)	(11.60)	(66.65)
Individual farm	847 ***	836 ***	-4.98	11.51 ***	69.81	470 (455)	-2.15	-13.86
	(240)	(310)	(6.27)	(3.89)	(117.07)		(3.25)	518.17)
Age	-5.68	19.54	-0.07	0.07 (0.16)	16.65 ***	4.90	1.12 ***	4.23 ***
	(10.87)	(13.79)	(0.28)		(4.93)	(18.88)	(0.09)	(0.56)
Debt	-75.45	304**	-0.73	0.52 (1.78)	270.49 **	3,117 ***	-15.79 ***	13.36
	(108.07)	(139)	(2.86)		(110.82)	(430)	(3.08)	(17.44)
Intercept	-6,630 ***	-6,598 ***	51.21	-54.14***	-4,399	-11,532	2.35 ***	-365 ***
	(633)	(814)	(18.18)	(9.82)	(275)	***	(0.43)	(28.32)
						(1,054)		
Number of obs.	1,049				1,592			
ρ_{12}(Fert-Pest)	0.32 ***				0.48 ***			
ρ_{13} (Fert-PG)	- 0.15 ***				-0.56 ***			
ρ_{14} (Fert-Lc)	0.28 ***				0.29 ***			
ρ_{23} (Pest-PG)	-0.61 ***				-0.48 ***			
ρ_{24} (Pest-Lc)	0.73 ***				0.23 ***			
ρ_{34} (PG-Lc)	-0.82 ***				-0.14 ***			

* significance at 10%; ** significance at 5%; *** significance at 1%; Lc: land allocated to crop; Fert: fertilizer; Pest: Pesticide; PG: Permanent grassland; ρ_{ij}: correlation coefficient for each pair of equations