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Sylvain Chabé-Ferret and Anca Voia

Toulouse School of Economics

Are Grassland Conservation Programs a Cost-Effective Way to Fight Climate Change? Evidence from France*

Sylvain Chabé-Ferret†
Anca Voia‡

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Abstract

Grassland, especially when extensively managed and when replacing cropland, stores carbon in the ground. As a result, Grassland Conservation Programs, that pay farmers for maintaining grassland cover, might be an effective way to combat climate change, if they succeed in triggering an increase in grassland cover at the expense of cropland for a reasonable amount of money. In this paper, we use a natural experiment to estimate the cost-effectiveness of the French Grassland Conservation Program, the largest of such programs in the world. We exploit a change in the eligibility requirements for the program that generated a sizable increase in the proportion of participants in the areas most affected by the reform. We find that the expansion of the program lead to a small increase in grassland area, mainly at the expense of croplands, which implies that the program expansion increased carbon storage. We also find that the elasticity of grassland provision is low, and that, as a result, the program has large windfall gains. To compute the benefit-cost ratio of the program, we combine our results with similar estimates from the literature using meta-analysis tools and we introduce the resulting parameter in a model of carbon storage in grassland. We find that, for a carbon price of 24 Euros/tCO_2eq, the climate benefits of the program are equal to 7±3% of its costs. When taking into account the other benefits brought about by grassland, we find the benefits of the program to be equal to 44±15% of its costs. We estimate that the program would break even for a carbon price of 194±122 Euros/tCO_2eq.

Keywords: Payment for Ecosystem Services, Grassland, Natural Experiment, Treatment Effect.
JEL: Q15, Q18, Q24, Q28, Q57.

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†Toulouse School of Economics, INRAE, University of Toulouse Capitole, Toulouse, France. Corresponding author: sylvain.chabe-ferret@tse-fr.eu.

‡Toulouse School of Economics, University of Toulouse Capitole, Toulouse, France.

1 Introduction

Fighting climate change is one of the most important challenges facing mankind. Comparing the cost-effectiveness of the various options available to decrease the emissions of greenhouse gases is critical for succeeding in this endeavor. In this paper, we estimate the benefit-cost ratio of one such option: Grassland Conservation Programs. Grassland, especially when extensively managed and when replacing cropland, stores carbon in the soil (Soussana et al., 2004). It also reduces water pollution (Agouridis et al., 2005) and increases biodiversity (Bretagnolle et al., 2012). As a result, Grassland Conservation Programs, that pay voluntary farmers for maintaining grassland cover, might be an effective way to protect the environment and to combat climate change. The key for these programs to be cost-effective is to trigger an increase in grassland cover at the expense of cropland for a reasonable amount of money. To this day, it is still unknown whether Grassland Conservation Programs trigger sufficient changes in grassland cover so as to be cost-effective ways to fight climate change and to improve the environment.

A key input to compute the benefit-cost ratio of a Grassland Conservation Program is its additionality (Chabé-Ferret and Subervie, 2013): how many additional hectares of grassland have been implanted or maintained thanks to the program. Additionality in turn depends on the elasticity of the supply of grassland. The more elastic (i.e. responsive to prices) the supply of grassland, the more cost-effective the program. In the limit, if the supply of grassland is fully inelastic, the program ends up paying farmers for doing nothing differently from what they would have done without any payment, and the effectiveness of the program is null.

Estimating additionality is no easy task because usual comparisons are very likely to be biased by confounding factors (Chabé-Ferret and Subervie, 2012). Comparing contracting farmers to non contracting farmers might overestimate the impact of the program. Indeed, contracting farmers take up the program not by chance but because they have lower costs of supplying grassland, and thus would have had a larger area of grassland than nonparticipants even in the absence of the program. The characteristics that make contracting farmers supply more grassland even in the absence of the program thus confound the effect of the program. Most of these characteristics are difficult to measure in usual datasets: the opportunity cost of grassland is mostly related to land quality, a difficult parameter to observe and summarize. The change of grassland area of contracting farmers after the implementation of the program might also be confounded by simultaneous changes in prices or in other policies.

In this paper, we estimate the benefit-cost ratio of the French Grassland Conservation Program, the largest Grassland Conservation Program in the world, using a natural experiment to solve for counfounding bias.[1] The natural experiment that we exploit is a change in the eligibility requirements to the French Grassland Conservation Program that happened in 2000. Before 2000, contracting farmers had to have a ratio of grassland to agricultural usable area higher than 75% in order to be eligible to receive the payments. In 2000, new contracts were introduced that did not include this eligibility criteria. In the areas most affected by the reform, the proportion of beneficiaries of the Grassland Conservation Program doubled, increasing from 10% to 20%, while it remained stable around 15% in areas unaffected by the reform. Our identification strategy uses the change in grassland cover in areas where the proportion of beneficiaries remained constant as a counterfactual for the change in grassland area that would have occured in treated areas in the absence of the reform. In a theoretical model, we show that this comparison identifies the effect of the program on farmers that entered after the 2000 reform under plausible assumptions. The main assumption that we are making is that treated and control areas do not differ in their changes in grassland area absent the reform (an assumption generally called the Parallel Trends Assumption). We find support for the Parallel Trends Assumption in our pre-reform data. To account for possible effects of the program on non contracting farmers, we conduct our analysis at the commune level.[2] Contracting farmers might indeed decide to buy, rent or exchange grassland with non-contracting farmers, a phenomenon called "leakage effect". In the presence of leakage effects, the program might not add a single hectare of grassland in a commune but still appear to increase the area in grassland at the level of the individual participating farm. Working with commune-level data preserves our analysis from this issue.

Our results show that grassland cover increases in the communes most affected by the reform, and that this increase comes mostly at the expense of cropland. As a consequence, the 2000 reform helped store carbon in the ground, which suggests that the program brings positive environmental benefits. Unfortunately, the changes in grassland cover that we find are small compared to their monetary cost. The loosening of the eligibility criteria in 2000 lead to a substantial inflow of money in affected communes (around 5,000$\pm$513 euro over five years, or an increase of 42.46$\pm$6.21%), but to a comparatively small

[1] Natural experiments leverage quasi-experimental variation in exposure to a policy in order to neutralize the effect of confounding factors (Chabé-Ferret and Subervie 2012, Dominici et al., 2014).

[2] Communes are the smallest administrative unit in France. There are approximately 36,000 communes in France. The average size of a French commune is around 7 sq.mile, which is a little less than half of the average size of a US Census Block Group. Leakage effects, that act through the functioning of the land market, are likely to be the most important at the commune level.

increase in grassland area (3.73±7.31 hectares per commune, or an increase of 0.76±1.49%). We thus estimate that the elasticity of the supply of grassland is low (around 0.02±0.04), meaning that an increase in prices by 10% would only increase the supply of grassland by 0.2%.

To compute the benefit-cost ratio of the program, we combine our additionality estimates to estimates of how carbon storage changes when grassland is converted into cropland. With a Social Cost of Carbon of 24 Euros/tCO_2eq, we estimate that the value of CO_2 emissions avoided thanks to the program is equal to 12±24% of its costs. When taking into account the other benefits brought about by grassland, we find the benefits of the program to be equal to 72±141% of its costs. We estimate that the program's benefits would equal its costs for a Social Cost of Carbon of 80±389 Euros/tCO_2eq. Our estimates are not precise enough to decide whether the benefits of the French Grassland Conservation Program are superior to their costs. To increase the precision of our estimates, we combine our results with similar estimates of the impact of the French Grassland Conservation Program using meta-analysis tools. Chabé-Ferret and Subervie (2009) use DID-matching to estimate the additionality of the Grassland Conservation Program in 2005. Gallic and Marcus (2019) use a change in the eligibility rules of the French Grassland Conservation Program in 2015 in order to estimate its additionality. Both papers find results very similar to ours (even if somewhat smaller on the additionality side), despite using individual level data and different identification strategies. Combining their results with ours using a meta-regression, we find that the climate benefits of the program are equal to 7±3% of its costs, its total environmental benefits to 44±15% of its costs and that it would break even for a carbon price of 194±122 Euros/tCO_2eq.

Overall, our results suggest that the increase in the number of beneficiaires of the French Grassland Conservation Program that resulted from the relaxation of the eligibility requirements in 2000 did not provide environmental benefits large enough to cover the costs of the reform. Although our results are by nature local and thus valid only for the group of farmers affected by the 2000 reform, they suggest that the French Grassland Conservation Program, and by extension Grassland Conservation Programs in general, are probably not cost-effective ways to fight climate change. There are indeed good reasons to believe that the areas most affected by the 2000 reform are the ones where grassland cover was more at risk of conversion into cropland. The share of grassland was already low and decreasing and cropland was expanding. It is thus likely that additionality is lower in the zones that benefitted from the program prior to the reform. Results in Gallic and Marcus (2019) that cover different areas than the ones we do here find very similar results to ours. Similar programs elsewhere in Europe and in the US will probably be characterized by similar levels of additionality and thus reach similar benefot-cost ratios. Similar programs might have better benefit-cost ratios if they have larger additionality or if grassland stores more carbon than in France. But it seems unlikely that Grassland Conservation Programs can achieve similar climate benefits and benefit-cost ratios to the ones of Forest Conservation Programs. Indeed, forests store similar quantities of carbon in the ground as grassland does, but also, unlike grassland, store carbon above ground. Unless the elasticity of forest provision is much smaller than that of grassland, Forest Conservation Programs will have better benefit-cost ratios than grassland. Recent estimates suggest that the climate benefits of Forest Conservation Programs exceed their costs by a factor of two (Jayachadran et al., 2017; Simonet et al. 2018). A recent meta-analysis finds more modest climate benefits of Forest Conservation Programs, around 53±38% of their costs, and estimate that they would break even for a carbon price of 100 USD/tCO_2eq (Chabé-Ferret and Voia, 2021). Even with these more modest estimates, Forest Conservation Programs thus appear to be more promising that Grassland Conservation Programs to fight climate change. Nevertheless, if and when the Social Cost of Carbon reaches 200 Euros/tCO_2eq, Grassland Conservation Programs will become cost-effective, according to our estimates.

Our paper contributes to several literatures. First, we contribute to the literature estimating the additionality of Payments for Ecosystem Services by using a natural experiment. Most of the previous evaluations of the the additionality of Payments for Ecosystem Services use observational methods, namely a combination of matching with difference-in-differences (DID) (see e.g. Chabé-Ferret and Subervie (2013)). Of the few studies of the impacts of Payments for Ecosystem Services that rely on natural experiments, most evaluate rather small scale programs. Kuhfuss and Subervie (2018) look at the additionality of the French Payments for Ecosystem Services aimed at pesticide reduction in the Languedoc-Roussillon region using the exogenous variation in the timing of the implementation of the program as a natural experiment. Simonet et al. (2018) use the introduction of a Brazilian forest conservation program to estimate its additional effects in the Para state. Apart from our paper, only Alix-Garcia et al. (2012, 2015) and Gallic and Marcus (2019) use a natural experiment to evaluate a nationwide Payment for Ecosystem Services Program (the Mexican Forest Conservation Program and the French Grassland Conservation Program respectively).[3] Second, we contribute to the evaluation of the additionality of Grassland Conservation Programs. Very few evaluations focus on Grassland Conservation Programs,

[3]It is interesting to note that Gallic and Marcus came to their idea for their paper after seeing a presentation of an earlier version of our own work. We see this cross-pollination as a testament to how reasearch can influence work done by policy-makers.

although they are a major component of the EU Payments for Ecosystem Services. Arata and Sckokai (2016) identify a statistically significant increase in the share of grassland for participant farmers in all EU Payments for Ecosystem Services in five member states. Pufahl and Weiss (2009) apply a DID-matching approach to a non-representative subsample of German farms to show that the whole EU program of Payments for Ecosystem Services is likely to increase both the grassland area and the area under cultivation. Only Chabé-Ferret and Subervie (2009) and Gallic and Marcus (2019) perform a similar estimate to the one we are trying to achieve. Third, we clarify the causal effect parameters we can identify with our natural experiment, using a theoretical model of participation in a environmental subsidy program characterized by a notch (Kleven and Waseem, 2013) that is removed after some date. Our approach delineates conditions under which one can use DID to identify the effect of such a reform. Our model extends the one in Chabé-Ferret and Subervie (2013) to account for the existence of bunching at the eligibilty threshold and encompasses the use of data on aggregated units such as communes as a way to eschew the problems posed by leakage effects. Pollinger (2021) develops an alternative approach to compute the benefit-cost ratio of an environmental program characterized by a kinked incentive, based on a density discountinuity estimator. Fourth, we combine our estimates with similar estimates from Chabé-Ferret and Subervie (2009) and Gallic and Marcus (2019) in a meta-analysis to obtain more precise estimates of the benefit-cost ratio of the French Grassland Conservation Program. Meta-analysis are increasingly used to synthetize estimates from a broad range of literature. Chabé-Ferret and Voia (2021) for example conduct an extensive meta-analysis of the additionality estimates of Forest Conservation Programs (as do Samii et al. (2014) and Snilsveit et al. (2019)). Fifth, we combine our additionality estimates with estimates from the agronomic literature on the dynamics of carbon storage after grassland is converted to cropland. We derive closed form solutions for the climate and environmental benefits of a program affecting land use changes that are of separate usefulness. We include uncertainty estimates on the parameters of the dynamics of carbon storage into our benefit-cost ratios estimates using the Delta method. Sixth, we contribute to the literature estimating the most cost-effective ways to fight climate change. Jayachadran et al. (2017) estimate the benefit-cost ratio of a Forest Conservation Program. Chabé-Ferret and Voia (2021) derive the benefit-cost ratio of Forest Conservation Programs using a meta-analysis. Christensen et al. (2021) decompose the discrepancy between the impacts of weatherization programs predicted by theoretical models and their realized benefits. A complete comparison of the benefit-cost ratios of all the policy options for fighting climate change is still out of reach, but we hope that this paper, along with others cited here, gets us closer to that goal.

Gillingham and Stock (2018) provide estimates of the cost of actions that can be taken to fight climate change but do not include Grassland Conservation Programs nor an explicit meta-analysis.

The remainder of the paper is structured as follows: Section 2 describes the French Grassland Conservation Program; Section 3 exposes our empirical strategy; Section 4 introduces the data used in this paper; Section 5 presents the results and the robustness checks; Section 6 presents the cost-benefit analysis; Section 7 concludes.

2 The French Grassland Conservation Program

The French Grassland Conservation program is the largest grassland conservation program in the world. Over the period 2003-2007, a yearly budget of around 350 million euro was allocated to subsidize 4.6 million hectares of grassland, covering 60% of the total grassland area in France (CNASEA, 2008). The program was created in 1993 as part of a broader set of Payments for Environmental Services introduced in the European Union as accompanying measures of the 1992 Common Agricultural Policy (CAP) reform. Subsidies for grassland conservation were included in the agri-environmental programs of several European countries, such as the German Cultural Landscape Program (KULAP), the Austrian Agri-environmental Program (OPUL), the United Kingdom's Environmental Stewardship Scheme or the Irish Rural Environment Protection Scheme (REPS) (Institut de l'Elevage, 2007). The yearly budget allocated to these programs varies from 100 million euro for the German KULAP to 283 million euro for the Austrian OPUL. Similarly, in the United States grassland conservation measures were in place since 2002 through the Grassland Reserve Program[4], with a funding of 38 million dollars yearly (USDA-NRCS, 2010).

The timelime of the French Grassland Conservation Program is presented in Figure 1, while a detailed description of the eligibility requirements is given in Figure 2. The French Grassland Conservation Program is part of a broader set of Payments for Ecosystem Services introduced in the European Union as accompanying measures of the 1992 CAP reform. Payments for Ecosystem Services are voluntary agreements between a seller (a landowner) and a buyer (the Government or private users) in which a payment is given conditional on an environmental service being adequately provided (Alston et al., 2013). The payment is computed so as to compensate the landowner for the average compliance costs and for the forgone farming revenue associated with the adoption of greener practices or so as to reflect the value of the environmental service provided. In general, a Payments

[4]Since 2014 the program is called the Conservation Reserve Program-Grasslands

for Ecosystem Services program targets at least one of the four environmental services among carbon sequestration, watershed services, biodiversity and scenic beauty. Since 2000, Payments for Ecosystem Services have become a core instrument of EU agricultural policies as part of the second pillar of the CAP.

The French Grassland Conservation Program was created in 1993 with the goal of stopping the decrease in grassland cover (from 43% of the agricultural area in 1970 to 36% in 1988 and only 27% in 2010). It was first called ″Prime au Maintien des Systemes d'Elevage Extensifs″ (PMSEE). PMSEE was a five-year contract during which farmers committed to keep the grassland on the same plots. In exchange, they were paid 35 to 46 euro per hectare of grassland if they met two criteria: *(i)* a specialization rate (share of permanent and temporary grassland in the total usable agricultural area) higher than 75% and *(ii)* a loading ratio (density of livestock units (LU) per hectare of forage area) below 1.4. In 1998, PMSEE was renewed for another five years and an eligibility requirement related to the use of fertilisers was introduced: farmers were not allowed to exceed 70 kilograms of nitrogen per hectare of grassland. PMSEE was replaced in 2003 by a new extensive grazing scheme called ″Prime Herbagère Agro-Environnementale″ (PHAE). The eligibility criteria for PHAE were similar to those for PMSEE with three main exceptions. First, the thresholds for eligibility in terms of share of grassland and density of livestock units varied at department[5] level. Some departments kept the same thresholds as for PMSEE, while others chose a threshold for the specialization rate smaller than 75%, but never smaller than 50%. Also, some departments set the loading ratio higher than 1.4 LU/ha, but never larger than 1.8. Second, additional requirements were introduced, especially in order to limit the use of phytosanitary products and fertilizers on the plots. Finally, the payments were increased to 76 euro per hectare of conserved grassland.

PMSEE and PHAE were two national programs that specifically target grassland conservation. However, starting in 2000, France launched an ambitious new Payments for Ecosystem Services program as part of the National Plan for Rural Development (NPRD). It was first called ″Contrat Territorial d'Exploitation″ (CTE) and was replaced in 2003 by ″Contrat d'Agriculture Durable″ (CAD). Among all the new Payments for Ecosystem Services that this program instituted, two broad categories were actually subsidies to grassland conservation: the measures 19 and 20. The measure 19 subsidized the maintenance of grassland opening where it was colonized by scrubs and trees, while the measure 20 subsidized extensive grassland management through mowing and/or pasture. The eligibility requirements for measures 19 and 20 were mainly that fertilization was limited on

[5] There are 95 departments in France.

the field (in general, below 60 kilograms of nitrogen per hectare of grassland). The main difference is that measures 19 and 20 did not have any requirements on the specialization rate. As a consequence, these measures were taken also by farmers who were in general not eligible for PMSEE or PHAE due to a small share of grassland. Thus, measures 19 and 20 generated a new influx of farmers into the French Grassland Conservation Program.

3 Empirical Strategy

In this section, we delineate our empirical strategy. In order to do so, we first present a simple model of how farmers react to the incentives triggered by the grassland program before and after the 2000 reform. We then detail the sources of identification of our parameter estimates. Finally, we present our econometric strategy.

3.1 Farmers' reaction to the Grassland Conservation Program

We posit that there is a continuum of farmers of unit size characterized by their technical effectiveness at generating income from grassland θ. θ is distributed according to the cumulative distribution function F_θ over the interval $\left[\underline{\theta}, \overline{\theta}\right]$. Returns from grassland are given by the function $R(q, \theta)$ where $q \in [0, 1]$ is the share of the total area of the farm allocated to grassland. R is a continuous, twice differentiable function of both arguments. It is concave, with $R_{qq} < 0$, $R_\theta > 0$ and $R_{q,\theta} > 0$. Before 2000, farmers' response to the program can be described as follows:[6]

$$\max_q R(q, \theta) + tq\mathbb{1}[q \geq \bar{q}]. \tag{1}$$

In this optimization problem, when farmers cross the $\bar{q}$ threshold, they receive a compensation for all of their additional units of grassland beyond $\bar{q}$ but also for all the $\bar{q}$ inframarginal units as well. This large discontinuity in the incentives faced by the farmers around $\bar{q}$ is called a notch (Kleven and Waseem, 2013). The optimal response by farmers include some bunching at $\bar{q}$. In order to understand why, let us solve the farmers' problem as presented in equation (1).

Let us first define $\pi(t, \theta) = \max_q R(q, \theta) + tq$ as the farmers' problem without the participation constraint. π is increasing in both t and θ.[7] The interior solution for the optimal supply of grassland without the notch constraint is $q(t, \theta)$ and is defined as the

[6] $\mathbb{1}[A]$ is equal to one if A is true and to zero otherwise.

[7] By the enveloppe theorem, $\pi_t = q \geq 0$. We also have that $\pi_\theta = R_\theta > 0$.

solution to the first order equation $R_q(q,\theta) + t = 0$. By the implicit function theorem, $q(t,\theta)$ exists, is unique and is increasing in θ and in t.[8] There are also two corner solutions: $q = 0$ and $q = 1$. The condition $\pi(t,\theta) = 0$ defines $\underline{\theta}_0(t)$ such that all farmers with θ below $\underline{\theta}_0(t)$ have $q = 0$. The condition $q(t,\theta) = 1$ defines $\overline{\theta}_1(t)$ such that all farmers with θ above $\overline{\theta}_1(t)$ have $q = 1$. Let $q^*(t,\theta)$ summarize the supply function in the farmers' problem without participation constraint. It is equal to $q(t,\theta)$ when θ is between $\underline{\theta}_0(t)$ and $\overline{\theta}_1(t)$, to zero below $\underline{\theta}_0(t)$ and to one above $\overline{\theta}_1(t)$.

Let us now come back to the farmers' problem with the participation constraint as presented in equation (1). The constraint defines two new thresholds, $\underline{\theta}^*(t,\bar{q})$ and $\overline{\theta}^*(t,\bar{q})$ such that farmers that have $\theta \leq \underline{\theta}^*(t,\bar{q})$ will choose to supply $q^*(0,\theta)$ units of grassland, farmers with θ between $\underline{\theta}^*(t,\bar{q})$ and $\overline{\theta}^*(t)$ will choose to supply exactly $\bar{q}$ units of grassland and farmers with θ above $\overline{\theta}^*(t,\bar{q})$ will chose to supply $q^*(t,\theta)$ units of grassland. The reason why this is so is as follows. Because $q(t,\theta)$ is increasing in θ, the condition $q(t,\theta) = \bar{q}$ defines a threshold $\overline{\theta}^*(t,\bar{q})$ such that all farmers with $\theta \geq \overline{\theta}^*(t,\bar{q})$ choose to participate in the program, since they comply with the participation constraint even when it is not required. This is because π is increasing in t and thus farmers always prefer to benefit from the subsidy if it is not constraining for them. Farmers just below $\overline{\theta}^*(t,\bar{q})$ face two possibilities. They can increase their supply of grassland in order to reach $\bar{q}$ and be eligible for the payment. Their profit would then be $\pi_c(\bar{q},t,\theta) = R(\bar{q},\theta) + t\bar{q}$. Or they can choose to not benefit from the subsidy and supply $q(0,\theta)$ units of grassland, for a profit of $\pi(0,\theta)$. For a farmer such that $q(0,\theta) + dq = \bar{q}$, the loss incurred by bunching at $\bar{q}$ is equal to $(R_q(q,\theta) + t)dq$ and the gain is equal to the whole difference from to $\pi(0,\theta)$ to $\pi_c(\bar{q},t,\theta)$. The first term is much smaller than the second, so that a farmer very close to $\overline{\theta}^*(t,\bar{q})$ chooses to bunch at $\bar{q}$. But as θ decreases, the cost of providing unprofitable amounts of grassland increases while the benefit from doing so decreases. At $\underline{\theta}^*(t,\bar{q})$, farmers are indifferent between participating and not participating. As a consequence, all farmer with θ below $\underline{\theta}^*(t,\bar{q})$ do not participate in the program.

Figure 3 summarizes the results of the theoretical model. The right-most curve is the supply curve when farmers face a subsidy $t = 0$. The second and third curves are defined for prices of grassland of $t = t_0$ and $t = t_1 > t_0$ respectively. These curves represent $q^*(t,\theta)$, that is the level of supply in the absence of the participation constraint. When the subsidy increases, farmers supply more grassland at each level of θ. Let us now examine what happens when the participation constraint is active. Let us focus on the case

[8] Since $R_{qq} < 0$, the sign of the derivatives of q with respect to its arguments are those of the first order condition with respect to each argument. The result follows since $\frac{\partial R_q(q,\theta)+t}{\partial t} = 1$ and $\frac{\partial R_q(q,\theta)+t}{\partial \theta} = R_{q,\theta}$.

where $t = t_0$, that is on the two rightmost curves. In the presence of the participation constraint, farmers below $\underline{\theta}^*(t_0, \bar{q})$ have no incentive to participate in the program, since the benefits of reaching the participation constraint are smaller than the costs of complying with the constraint. As a consequence, these farmers do not participate in the program and thus supply $q^*(0, \theta)$. This is materialized by the fact that the curve with $t = 0$ is drawn in a continuous line for these farmers. Farmers between $\underline{\theta}^*(t_0, \bar{q})$ and $\overline{\theta}^*(t_0, \bar{q})$ prefer to participate in the program, but choose to bunch at $\bar{q}$, because their optimal supply with a subsidy of t_0 would be lower than $\bar{q}$. This is manifested by the fact that the second curve is below $\bar{q}$ for these farmers and is drawn in a interrupted line, to show that their supply absent the participation constraint is unobserved (as is their supply absent the subsidy). Finally, farmers above $\overline{\theta}^*(t_0, \bar{q})$ participate in the program and supply the same amount of grassland they would have supplied absent the participation constraint ($q^*(t_0, \theta)$). This is shown on the plot by the fact that the curve $q^*(t_0, \theta)$ is drawn in a continuous line above $\overline{\theta}^*(t_0, \bar{q})$. Among those farmers, those that are below $\overline{\theta}_1(t_0)$ supply the quantity $q(t_0, \theta)$ predicted by the solution to the first order condition to the unconstrained problem. The farmers that are above $\overline{\theta}_1(t_0)$ bunch at $q = 1$ and affect al of their area to grassland.

3.2 The 2000 reform and sources of identification

The 2000 reform of the Grassland Conservation Program can be modeled as taking off the $\mathbb{1}[q \geq \bar{q}]$ constraint from equation (1) and increasing the subsidy from t_0 to t_1. The resulting supply curve is the leftmost curve on Figure 3. Now, almost everyone participates in the program, apart from the farmers whose grassland supply is zero (the ones with θ below $\underline{\theta}_0(t_1)$). No farmers bunch at $\bar{q}$ anymore since the participation constraint has been lifted. Finally, all farmers have increased their supply of grassland compared with the pre-reform state.[9]

Farmers can be separated in several groups on the basis of how they react to the 2000 reform. These groups are the basis of our identification strategy. We use the random variable T (for *type*) to denote the different groups formally. Farmers with $\theta \leq \underline{\theta}_0(t_1)$ supply zero proportion of grassand at all prices ($t = 0$, $t = t_0$ and $t = t_1$). We denote them with $T = b_{000}$. Farmers with $\underline{\theta}_0(t_1) < \theta \leq \underline{\theta}_0(t_0)$ supply zero proportion of grassand at prices $t = 0$ and $t = t_0$. We denote them with $T = b_{00}$. Farmers with $\underline{\theta}_0(t_0) < \theta \leq \underline{\theta}_0(0)$ supply zero proportion of grassand only when $t = 0$. We denote them with $T = b_0$. Farmers

[9]Note that this is not a general result, since bunching farmers might supply supply less than when forced to bunch at $\bar{q}$. The actual price increase from t_0 to t_1 was in practice probably large enough to avoid this type of countervailing effects.

with $\underline{\theta}_0(0) < \theta \leq \underline{\theta}^*(t_0, \bar{q})$ do not bunch neither at zero nor at $\bar{q}$. They move from not receiving the program in 2000 to receiving the program in 2005. We call them *compliers* and denote them with $T = c$. Farmers with $\underline{\theta}^*(t_0, \bar{q}) < \theta \leq \overline{\theta}^*(t_0, \bar{q})$ bunch at $\bar{q}$ when $t = t_0$. We call them *bunchers* and denote them with $T = b$. Farmers with $\overline{\theta}^*(t_0, \bar{q}) < \theta \leq \overline{\theta}_1(t_1)$ do not bunch neither at $\bar{q}$ nor at one. We call them *always takers* and denote them with $T = at$. Farmers with $\overline{\theta}_1(t_1) < \theta \leq \overline{\theta}_1(t_0)$ supply a proportion of grassland of one when $t = t_1$. We denote them with $T = b_1$. Farmers with $\overline{\theta}_1(t_0) < \theta \leq \overline{\theta}_1(0)$ supply a proportion of grassland of one when $t = t_1$ and $t = t_0$. We denote them with $T = b_{11}$. Farmers with $\theta > \overline{\theta}_1(0)$ supply a proportion of grassland of one at all prices. We denote them with $T = b_{111}$. We also add a last category of farmers: the ones who supply a positive porportion of grassland at all prices and do not participate in the program. We call them *never takers* and denote them with $T = nt$. The existence of never takers is not compatible with our model but is a feature of the dataset. It is easy to rationalize their existence, either by adding a heterogeneous fixed cost of participating in the program (measuring the hassle it takes to apply for the new contracts under the CTE/CAD program) or by introducing a second eligibility requirement, such as a sufficently small loading ratio for example.

In order to understand the idea behind our identification strategy, we are going to focus on first two groups: the *compliers* and the *always takers*. The first group of farmers moves from $t = t_0$ to $t = t_1$ between 2000 and 2005 and is our control group, while the second group moves from $t = 0$ to $t = t_1$ and is our treated group. They both are characterized by an absence of bunching, which simplifies identification. Our identification strategy consists in comparing what happens to the *compliers* who enter the program after the reform to what happens to the *always takers* who stay with the program all along. In order to state our identification strategy rigorously, we need some additional notation. First, let $q_{2000}(t, \theta)$ and $q_{2005}(t, \theta)$ denote the supply of grassland in 2000 and 2005 respectively, for farmers with a grassland productivity level of θ and facing the level of subsidy t. These two supply functions differ from $q^*(t, \theta)$ by the fact that they contain the effect of exogenous shocks to grassland supply. These shocks are of two types: annual shocks common to all farmers, such as the ones affecting the price of crops, meat, milk, farm inputs, etc; and farmer-specific idiosyncratic shocks that we assume are i.i.d. across farmers and across time and independent from θ.

Our identification strategy is based on a Difference-In-Difference estimator comparing the grassland supply of the *compliers* to the grassland supply of the *always takers*:

$$DID_q^{at} = \mathbb{E}[q_{2005}(t_1, \theta) - q_{2000}(0, \theta) | T = c] - \mathbb{E}[q_{2005}(t_1, \theta) - q_{2000}(t_0, \theta) | T = at]. \quad (2)$$

Identification of the causal effect of the grassland subsidy follows from the following assumption:

Assumption 1 (Parallel trends, always takers) *We assume that grassland supply would have followed parallel trends among compliers and always takers if they had been exposed to the same price change:*

$$\mathbb{E}[q_{2005}(t_1,\theta) - q_{2000}(t_0,\theta)|T = c] = \mathbb{E}[q_{2005}(t_1,\theta) - q_{2000}(t_0,\theta)|T = at].$$

Assumption 1 actually encompasses two separate assumptions. For one, it requires that influences other than the grassland subsidy have the same average impact among compliers and always takers between 2000 and 2005. That means that crop prices and input prices would have influenced the share of grassland in both groups in the same way. Moreover, Assumption 1 also requires that the impact of the change in the grassland subsidy from t_0 to t_1 would have been the same in the two groups. Under Assumption 1, our DID^{at} estimator identifies $LATE_{q_{2000}}$, the causal effect of moving from $t = 0$ to $t = t_0$ in 2000 for the group of compliers:

$$DID_q^{at} = \mathbb{E}[q_{2000}(t_0,\theta) - q_{2000}(0,\theta)|T = c] = LATE_{q_{2000}}. \tag{3}$$

Another route to identification would have been to use the never takers as a source of comparison for the change in grassland supply of the compliers in the absence of the reform:

$$DID_q^{nt} = \mathbb{E}[q_{2005}(t_1,\theta) - q_{2000}(0,\theta)|T = c] - \mathbb{E}[q_{2005}(0,\theta) - q_{2000}(0,\theta)|T = nt]. \tag{4}$$

Identification of the causal effect of the grassland subsidy follows from the assumption that both never takers and compliers would have had parallel trends in the absence of the reform:

Assumption 2 (Parallel trends, never takers) *We assume that grassland supply would have followed parallel trends among compliers and never takers in the absence of the reform:*

$$\mathbb{E}[q_{2005}(0,\theta) - q_{2000}(0,\theta)|T = c] = \mathbb{E}[q_{2005}(0,\theta) - q_{2000}(0,\theta)|T = nt].$$

Under Assumption 2, our DID^{nt} estimator identifies $LATE_{q_{2005}}$, the causal effect of moving from $t = 0$ to $t = t_1$ in 2005 for the group of compliers:

$$DID_q^{nt} = \mathbb{E}[q_{2005}(t_1, \theta) - q_{2005}(0, \theta) | T = c] = LATE_{q_{2005}}. \quad (5)$$

3.3 Estimating the effect of the reform at the commune level

In practice, we choose to perform our analysis not at the individual level, but at the commune level. We choose this approach in because it helps solve several issues we have encountered when trying to take our identification strategy to the data. We face two main issues when trying to operationnalize the estimators presented in equations (2) and (4). Let us examine each of them in turn and explain why using data aggregated at the commune level helps solve them.

The first issue is that we do not observe the groups of *compliers*, *always takers*, and *never takers*. Our data does not allow us to identify with enough certainty the policy recipients in the outcome data. We are actually missing a lot of beneficiaries of the grassland program in the pre-2000 data. This is because the identifiers used in the surveys where outcomes are measured differ from the identifiers used in the administrative data where beneficiaries of the Grassland Conservation Program are listed. We have tried to do our best at matching the two sources but our matching rate is far from satisfactory. The problem is that the measurement error changes over time: we fail to identify a lot of beneficiaries before 2000, but the successful matching rate increases steeply after 2000. As a consequence, at the individual level, we wrongly allocate farmers that are *always takers* into the group of *compliers*. This biases our estimator downwards perhaps severely.

The second issue is that we have made the implicit assumption that there are no leakage effects of the program. Leakage would occur if contracting farmers exchanged land with non contracting farmers because of the policy, the former renting or buying grassland from the latter, and the latter renting or buying cropland from the former. Leakage is a plausible reaction to the program, since contracting farmers receive a subsidy per hectare of grassland, they now value grassland more relative to cropland than non contracting farmers do. A comparison between contracting and non contracting farmers at the individual level would confound the leakage effects with a true additional effect of the program and would thus overestimate the total effect of the program. The overall effect of the subsidy on grassland area could very well be null but our individual level DID estimator would estimate it to be positive. Performing our treatment effect estimate at the commune level enables us to account for possible leakage effects of the policy. We posit that most leakage, if it exists, takes place at the commune level, between geographically close farmers. This is a credible assumption since land markets are mostly local. As a consequence, with our approach, any transfer of land between farmers residing in the same commune that does not alter the overall land use within the commune is not counted as additional.

We thus estimate our main regressions at the commune level. At the commune level, we have access to accurate data on the number of beneficiaries of the Grassland Conservation Program and to accurate data on the proportion of grassland in the usable agricultural area. We compute the growth rate in the total number of beneficiaries of grassland contracts per commune between 2000 and 2005. If the growth rate is positive, the commune belongs to the treated group, while if the growth rate is equal to zero, the commune is used as a control. We denote communes in the treated group with the random variable $D = 1$ and communes in the control group with the random variable $D = 0$. Our main outcome variable of interest is $Q_{c,y}$, the proportion of grassland in the usable agricultural area of commune c in year y. $Q_{c,y}$ is the average of the proportion of grassland in the usable agricultural area of all farms in commune c in year y, weighted by $w_{i,c}$ the share of each farm in the total usable agricultural area of commune c:

$$Q_{c,y} = \sum_{i=1}^{N_c} w_{i,c} q_{i,y}(t_{i,y}, \theta_i), \tag{6}$$

with N_c the number of farms in commune c, $t_{i,y}$ the value of the subsidy received by farmer i in year y and $q_{i,y}$ the functions $q_{2000}(t, \theta)$ and $q_{2005}(t, \theta)$ as defined above. Our commune-level DID estimator can then be defined as follows (omitting the c index for brevity):

$$DID_Q = \mathbb{E}[Q_{2005} - Q_{2000}|D = 1] - \mathbb{E}[Q_{2005} - Q_{2000}|D = 0]. \tag{7}$$

The main theoretical result of this section is that, under a mild set of assumptions, DID_Q is equal to a weighted average of farm-level LATEs as defined in equations (3) and (5):

Proposition 1 *Under a set of conditions made precise in Appendix A.1, there exists strictly positive scalars α and β with $\alpha + \beta = \Pr(T = c|D = 1)$ such that:*

$$DID_Q = \alpha LATE_{q_{2000}} + \beta LATE_{q_{2005}}.$$

Proof: See Appendix A.1. ■

Finally, in order to compute elasticity estimates and benefit-cost ratios, we also compute the impact of the reform on the monetary transfers received at the commune level using the same DID estimator as in equation (7):

$$DID_M = \mathbb{E}[M_{2005} - M_{2000}|D=1] - \mathbb{E}[M_{2005} - M_{2000}|D=0], \tag{8}$$

with $M_{c,y}$ the monetary transfer received by farmers in commune c in year y as part of the Grassland Conservation Program. The following proposition shows that this DID estimator identifies the weighed average of the transfers received by compliers in 2000 and in 2005 multiplied by N, the average number of farms in a commune:

Proposition 2 *Under a set of conditions made precise in Appendix A.2, there exists strictly positive scalars α and β with $\alpha + \beta = \Pr(T = c|D = 1)$ such that:*

$$DID_M = N(\alpha \mathbb{E}[t_0 q_{2000}|T=c] + \beta \mathbb{E}[t_1 q_{2005}|T=c]).$$

PROOF: See Appendix A.2. ■

Propositions 1 and 2 are the core of our empirical strategies. They show that, under plausible assumptions, our identification strategy relying on commune-level data identifies meaningful treatment effect parameters. First, these parameters are computed on the subpopulation of *compliers*, the farmers that enter the program after the 2000 reform. Second, the DID estimate of the effect of the reform on the proportion of grassland in the usable agricultural area DID_Q is equal to a weighted average of two impacts of the reform on compliers: the one moving them from a subsidy of 0 to t_0 in 2000 and the one moving them from 0 to t_1 in 2005. The dual nature of our treatment effect parameter stems from the dual nature of the comparison groups that we use to proxy the trends of compliers absent the reform: *always takers* and *never takers*. *Always takers* benefit from the program both in 2000 and in 2005. As a consequence, they proxy for the change that *compliers* would have experienced if the requirement of a specialization rate higher than 75% had been cancelled before 2000 and *compliers* had been allowed to enter the program with a subsidy rate of t_0. *Never takers* do not benefit from the program in 2000 nor in 2005. As a consequence, they proxy for the change that compliers would have experienced if they had not been allowed to enter the program after 2000. Third, under the same assumptions, the DID estimate at the commune level of the effect of the reform on the transfers received by farmers enrolled in the Grassland Conservation Program DID_M is a also a weighted average of two transfers. The first transfer is the average amount of money that would have been received by *compliers* if they would have been allowed to enter the Grassland Conservation Program before 2000. The second transfer is the average amount of money received by *compliers* once they have been allowed to enter the Grassland Conservation Program after 2000. Fourth, the weights involved in computing the treatment effect parameters identified by DID_Q and DID_M are the same: α weighs the treatment effects defined in 2000 and β the ones defined in 2005. α is equal to the difference in the proportion of *always takers* between the control and treated communes while β is equal to the difference in the proportion of *never takers* between the control and treated communes. Under our assumptions, $\alpha + \beta$ is equal to the proportion of *compliers*. DID_Q and DID_M thus identify the sum of two Intention to Treat Effects (ITE): the effect on compliers multiplied by the proportion of compliers. Fifth, when we compute the elasticity of grassland supply, we compare the change in grassland area (obtained by multiplying our proportion estimate DID_Q by the average agricultural area at the commune level and dividing it by the average 2000 level) to the change in monetary transfers estimated by DID_M (divided by the average amount of transfers at the commune level in 2000). Even though this estimate is not the average of the two separate elasticities of the 2000 and 2005 impacts taken separately, it still is a valid elasticity of the average response of the compliers to two different transfers. Sixth, all of these interpretations of DID_Q and DID_M rest on several assumptions, among which the most important is the absence of diffusion effects. Nevertheless, our approach is robust to a relaxation of this assumption. If the diffusion effects are limited to the commune level (which is highly likely since most difusion effects take place on the land market and thus are concentrated within a commune), our estimators include the response of both always takers and never takers to the reform. They thus estimate the total effect of the reform, net of any indirect impacts on *never takers* and *always takers*. Seventh and finally, another critical assumption for the valid interpretation of our estimator is that bunchers are in the same proportion in treated and control communes, so that their fate does not influence our estimator. We believe this assumption is well-justified since the proportion of compliers is small. If this assumption was to be wrong, our resulting estimates would be biased upwards. Indeed, bunchers experience a less intense response to the reform since they were already bunching too high with respect to the unconstrained incentive. As a consequence, their change in grassland area between 2000 and 2005 is less steep than the one that would have been experienced by *compliers* if they had been allowed into the program in 2000. If bunchers aere not in the same proportion in both treatment and control groups, our estimate thus provides an upper bound on the effect of the reform on compliers.

3.4 Estimation

Our data is a commune-year panel over four periods. We estimate a two-way fixed effects model, which is an extension of the simple DID to more than two periods.The baseline equation is given by:

$$Y_{ct} = \widetilde{\alpha} D_{ct} + \widetilde{\beta} X_{ct} + \widetilde{\eta_c} + \widetilde{\xi_t} + \widetilde{\epsilon_{ct}} \quad (9)$$

where Y_{ct} is the aggregated outcome variable (for example the share of permanent grassland area in commune c at time t), D_{ct} is a dummy taking a value of one starting in 2003 for communes where the number of beneficiaries increased after the reform, X_{ct} is the vector of aggregated control variables (for example the number of small farms in commune c at time t), $\widetilde{\eta_c}$ and $\widetilde{\xi_t}$ represent the commune and year fixed effects. The fixed effects control for time-invariant unobserved commune characteristics (e.g. altitude, slope) and for effects that are common to all communes at one point in time (e.g. changes in CAP policies that affect every farmer in the same way). ϵ_{ct} is the error term and includes unobserved variables such as managerial ability, environmental preferences and prices. We also include department-specific yearly effects in our main specification. The estimated standard errors are robust to heteroskedasticity and are clustered at the commune level to account for serial correlation in the outcome variables (Bertrand et al., 2003).

The parameter of interest, $\widetilde{\alpha}$, captures the average causal effect of the program expansion that followed the change in eligibility criteria. This estimate captures the full impact of the reform, on both beneficiaries and non-beneficiaries located in the same commune. For this parameter to be a consistent estimate of the impact of the reform, the parallel trends assumption must hold, meaning that there should be no systematic differences in outcome trends between treated and control communes before the reform. We test this assumption by comparing trends in outcomes between treated and control communes before the reform.

To check the robustness of the DID specification we re-estimate the intention-to-treat effect using the changes-in-changes (CIC) model proposed by Athey and Imbens (2006). The CIC model is a nonlinear generalization of the DID model to the entire distribution of potential outcomes. The estimated treatment effect is given by the difference between the actual and the counterfacual distribution of the outcome variable in the treated communes. In turn, this difference is given by the difference between the outcome variable of the control communes with the same rank (i.e. in the same quantile) before and after the reform.[10] The key identifying assumption of the CIC method is the time invariance within groups assumption. It is the counterpart of the parallel trends assumption in the DID case and it requires that the population of agents within groups does not change over time.

[10]Specifically, a treated group with a level Y of the outcome variable in the pre-treatment period is matched with a control commune with the same level of the outcome in the same period. Then, this control commune is matched to a control commune with the same rank in the post-treatment period.

However, it has been rarely used in practice so far as the existing statistical tools used for its implementation are quite limited.[11]

4 Data

We construct our database at commune level using two types of data. First, we use administrative data from France's Service and Payment Agency (ASP) provided to us by the Sustainable Development Observatory (ODR). This data contains information on all beneficiaries of grassland programs from 1999 to 2006.[12] To build our treated and control groups we count the number of beneficiaries in each commune and we compute the growth rate in the number of beneficiaries from before to after the reform.

Second, in order to estimate the outcome and control variables, we resort to farm level data provided by the Ministry of Agriculture. More specifically, we use the 2000 agricultural census and the farm structure surveys from 1993 to 2007. These surveys are conducted every two years between censuses on 10% of the population of farmers. To construct our variables of interest, we first weight the farm level data using the sampling weights provided in the survey and then sum the weighted data at commune level.

Our main outcomes are the share of permanent grassland, crops and fodder in the total utilised agricultural area, the specialization rate (% of permanent and temporary grassland in the total utilised agricultural area) and the loading ratio (the ratio of livestock units to the forage area). To obtain a better understanding of the potential land use changes triggered by the grassland program, we also look at variables such as the share of total usable agricultural area, the share of forest area and the share of nonproductive land in the total farm area within a commune. Except for the loading ratio, which is transformed applying the inverse hyperbolic sine,[13] we express all our outcome variables as shares in order to account for size differences between communes. Our control variables include the number of farms for each type of crop orientation and for each economic size and the total number of farms in each commune. A detailed definition of all these variables is given in Appendix B.

[11]In R, we use the single available command, "CiC" from the "qte" package, which only allows for one pre-treatment period and one post-treatment period and does not allow for the inclusion of covariates.

[12]That dataset contains information such as the commune of residence, the years in which the farmers were enrolled in a grassland program, the number of hectares enrolled and the payment they received every year.

[13]We apply the inverse hyperbolic sine (IHS) transformation to the loading ratio to correct for its highly skewed distribution with a mass point at zero and to ensure equivalence in the unit of measure and interpretation of results with the other outcome variables. IHS is defined as $log(Y_i + (Y_i^2 + 1)^{\frac{1}{2}})$. It is defined at zero and can be interpreted similarly to a log-linear specification.

Our final dataset includes only farmers having at least one hectare of utilised agricultural area and only those communes where at least one farmer has received a subsidy for grassland conservation over the period 1999 to 2006. The sample constraint on communes enables us to build treatment groups with more similar characteristics than if we would have included also communes with no beneficiary of teh Grassland Conservation Program over the analysed period. We work with two balanced panels: one from 1993 to 1997 and one from 2000 to 2007. The reason why we decided to split the data into two periods is that survey identifiers are erased after each census. In our case this happens in 2000, so having a coherent balanced panel over the whole period is impossible. We thus use a balanced panel of 9,998 communes from 1993 to 1997 to perform the placebo test and a balanced panel of 10,468 communes from 2000 to 2007 to recover the treatment effect. Among these, 7,808 communes are common between the two periods.[14] We choose the time window 1993-2007 to avoid possible complications due to the fact that there was no Grassland Conservation Program before 1993 and that the new scheme starting in 2007 had many changes compared to the previous one.

Table 2 reports the mean and standard deviation of our outcome variables, by treatment group and sample. Recall that our control communes are those in which farmers are benefiting from the grassland subsidy for the whole 1993-2007 period. Thus, as a consequence of the program requirements, they have a higher share of permanent grassland and specialization rate and a lower loading ratio than the treated communes, where farmers became beneficiaries only after the 2000-2003 reform. The control communes have also a higher share of forest and nonproductive land and a bigger part of the agricultural area that is owned. Conversely, the farms located in treated communes have a higher share of crops, fodder and utilised agricultural area and have more rented land than farmers in control communes. This selection in levels does not create any problems for our identification strategy since the DID methodology removes permanent differences between the treated and control groups.

5 Results

In this section we start by presenting the magnitude of the effect of the 2000 reform on the number of contracting farmers and the amount of transfers received as part of the

[14] We also build a balanced panel of the 7,808 communes over the whole period, but we observe a huge drop in all our outcome variables between 1997 and 2000 that we cannot explain otherwise than by a change in the weighting system starting with the 2000 census. We thus choose to split the sample into two periods in order to avoid capturing this decrease in the treatment effect estimation.

Grassland Conservation Program in the communes affected by the program expansion. We then show the results of the main regressions estimating the impact of the reform on outcomes based on our baseline equation 9. Finally we present some robustness checks of the main results.

5.1 The Size of the Program Expansion in Treated Communes

Figure 4 shows the total number of beneficiaries of grassland conservation contracts over time, as a function of the treatment status of the commune. As expected and by construction, the treated communes see a sharp increase in the number of participants starting after 2000 and especially marked from 2002 to 2003. The number of beneficiaries in treated communes jumps from slightly above 20,000 in 2000 to slightly above 35,000 in 2003, or an increase of about 75%. In the control communes, the number of beneficiaries is almost constant over time. Figure 6 shows that the proportion of farmers benefitting from the Grassland Conservation Program also rises sharply after 2000 in treated communes, while it remains stable in control communes. Formally, we estimate the impact of the reform on the share of beneficiaries in treated communes to be 10.7 ± 0.35 p.p. (Table 3), which represents a near doubling of the proportion of contracting farmers in treated communes. The map of France in Figure 5 shows that both treated and control communes are quite heterogeneously dispersed throughout the country, which is good for our identification strategy since it suggests that they are rather similar at least in their location and thus for the opportunity cost of grassland. The only two areas not covered are the Paris basin where there is no grassland and Corsica that we exclude from the analysis.

The key insight behind the change in the proportion of participants on which our identification strategy rests is that this increase in the number of beneficiaries stems from the entry of the *compliers* in the program. The *compliers* are farmers that were ineligible to the program before 2000 because their specialization rate was too low, but that are free to enter the program after 2000 once the requirement on the specialization rate is relaxed. In order to test this part of our model, we define *potential compliers* as farmers who have a specialization rate strictly lower than 75% in 2000 and we regress this indicator on the treatment dummy (which is defined at the commune level). Our assumption is that we will see more *potential compliers* in 2000 in treated communes (where a lot of new entrants will appear after the 2000 reform). Hopefully, the proportion of *potential compliers* in 2000 will be higher in treated communes by the same amount as the proportion of compliers that we have estimated in Table 3 (roughly 10%). The results from this regression are presented in Table 4. We find that the proportion of *potential compliers* is higher in treated communes than in control communes by 7.5 to 10.3 p.p., which is very close to our estimate of the proportion of *compliers*. As a consequence, our theory that the increase in the proportion of participants in treated communes comes mainly from farmers ineligible to the program before the 2000 reform is vindicated.

The amount of monetary transfers as part of the French Grassland Conservation Program increased markedly in treated communes, as shown in Figure 7. We estimate that the program expansion increased the total amount of grassland subsidies in treatment communes by 5,000±513 euro (Table 3), or a 42% increase. Figure 7 shows that the amount of subsidies increased in control communes as well, because of the increase in the per hectare payment that accompanied the introduction of the new programs, but this increase is of smaller magnitude. Note finally that the average increase of transfers in treated communes is very close to the increase received by the average *complier*. Indeed, the average monetary transfer to *compliers* is equal to the average transfer at the commune level divided by the proportion of compliers (roughly 0.10) and by the average number of farmers per commune (roughly 10). These two operations approximately cancel out, which implies that the average monetary impact of the reform at the commune level is roughly equal to the average monetary impact at the complier level.

5.2 The Impact of the Program Expansion on Outcomes

We present both graphical evidence and regression results of the effect of the 2000 reform of the Grassland Conservation Program on our outcomes of interest. As a general description of the graphical evidence, the first column of plots in each figure, denoted by (a), represents the placebo test on the 1993-1997 sample of communes. The second one, denoted by (b), shows the treatment effect of the program on the sample of communes from 2000 to 2007. The first line of plots presents the trends in average outcome variables by treatment status, while the second line shows the yearly coefficients on the difference between treated and controls. These coefficients can be interpreted as an estimate of the impact of being treated on the outcome variable in a given year relative to the reference year. The effect is statistically significant if zero is not included in the 95% confidence interval, represented by dashed lines. We present regression results for different specifications with and without additional control variables and with and without department-year fixed effects. The results are consistent across specifications even though the point estimates slightly change with the introduction of controls or additional fixed effects. Our preferred specification is the one that accounts for both commune characteristics and yearly, department specific shocks.

Figure 8 shows that, graphically, there is no difference in the share of permanent grassland between treated and control communes from 1993 to 1997, as the coefficients of the interaction term fluctuate around zero before 2000. Between 2000 and 2007 the wedge opens up, suggesting a small positive impact of the Grassland Conservation Program on the share of permanent grassland area. Figure 9 shows that there is a small increase in crop area in treated communes compared to control communes from 1995 to 1997, while after 2000 the difference becomes negative. The share of fodder area does not appear to be affected by the change in eligibility requirements, as the yearly coefficients swing around zero both before and after 2000 (Figure 10). In Figure 11 we can observe that the specialization rate is stable before 2000 and increases afterwards, indicating a positive effect of the grassland program on this outcome. Finally, in Figure 12 it seems that there is a slight decrease in the loading ratio between 1993 and 1997 in the treated communes compared to control communes, while after 2000 there is no difference in the loading ratio of the two groups. All in all, the visual evidence suggests that the grassland program leads to a small increase in the share of permanent grassland area and the specialization rate, a decrease in the share of crops and no change in the share of fodder area and the loading ratio.

Table 1 presents the results of the fixed effects regressions. The estimated coefficients confirm the conclusions of the graphical evidence, but are in general not statistically different from zero. Nevertheless, we find that the share of permanent grassland area increases after the reform by 0.28±0.55 p.p. in treated communes compared to control communes. Likewise, the specialization rate increases by 0.45±0.49 p.p. At the same time, the share of crop area decreases by a similar amount, -0.40±0.39 p.p., while there is no difference in the share of fodder area and loading ratio between the two groups of communes. An interesting pattern that arises from these results is a potential switch from crops to grassland in the treated communes from the pre- to the post-treatment period.

Apart from croplands, the additional grassland area that we find after 2003 might also come from forest or nonproductive land. Figure 13 shows that the share of utilised agricultural area in total farm area slightly decreases in treated communes with respect to control communes after 2000, while before there was no difference between the two groups. Contrariwise, as shown in Figure 14, the share of forest area increases in the post-treatment period. Figure 15 indicates that the difference in the share of nonproductive land between the comparison groups was slightly positive in the pre-treatment period and it became almost null afterwards. The regression results from Table 5 suggest that the share of utilised agricultural area in total farm area remains rather stable over the whole period between the treated and control communes. Moreover, the share of forest area increases over time, from -0.25±0.43 p.p. to 0.10±0.35 p.p., while the share of nonproductive land decreases by almost the same amount, from 0.23±0.33 p.p. to 0.00±0.29 p.p. Thus, since the share of utilised agricultural area does not change over time and the decrease in nonproductive land is compensated by the increase in forest area, we argue that the increase in the share of grassland comes mainly from the decrease in the share of crops.

Putting everything together, our interpretation of the results is that the policy reform induced some farmers living in the treated communes to keep more grassland on their farms mainly at the expense of croplands.

5.3 Robustness Checks

Changes-in-changes. Our identification strategy relies on the parallel trends assumption. However, for some of our outcome variables we acknowledge the existence of pre-treatment trends that, even though not statistically significant, might invalidate our methodology. For this reason we perform a robustness check using the non-parametric equivalent of the DID method, the CIC strategy. Due to difficulty in practical implementation, the CIC regressions do not include fixed effects or additional controls. Table 6 shows that this method yields very similar results to our preferred specification including both control variables and commune, year and department-year fixed effects.

Different samples. Our sample is composed of two balanced panels, one from 1993-1997 and one from 2000-2007. To test the sensitivity of our results to this choice, we re-estimate the model using two unbalanced panels from 1993-1997 and 2000-2007 and a balanced panel restricted to the same communes for the whole 1993-2007 period. The results are summarized in Table 7 and Table 8. Even though the precision and magnitude of the estimated coefficients vary slightly with the sample size (i.e. the bigger the sample size, the more precise the estimate), in all cases the qualitative findings remain similar to the ones estimated on the balanced sample of different communes between the two periods.

6 Elasticity Estimates and Cost-Benefit Analysis

In this section we start by computing the elasticity of the additional permanent grassland supply with respect to the amount of subsidies. Next, we build a cost-benefit analysis by comparing the additional costs of the program due to the eligibility criteria change with its additional benefits, quantified using values taken from the literature. Throughout this section we present mean estimates along with their 95% confidence intervals that we build using transformed standard errors through the Delta Method.[15]

6.1 Elasticity Estimate

The impact we measure of the French Grassland Conservation Program's reform on commune level outcomes is not statistically different from zero. However, what matters for policymakers is the relative size of the impact compared with the amount of money spent. We find evidence that the policy reform was accompanied by a substantial inflow of money in treated communes compared to control communes, of around 5,000±513 euro per hectare over the 5 years of grassland contracts, corresponding to an increase of 42.46±6.21%.[16] This amount of additional subsidies corresponds to a comparatively small increase in grassland area of 3.73±7.31[17] hectares per treated commune, or an increase of 0.76±1.49%[18] in grassland area. Therefore, we estimate a low elasticity of the supply of grassland with respect to the amount of the subsidy of 0.02±0.04.[19] These elasticity estimates are summarized in Table 9.

Our results imply that the cost per hectare of additional permanent grassland over the 5 years of contracts is 1,340±2,628 euro,[20] which is almost three times bigger than the actual subsidy per hectare over the same period of time, of 450 euro.[21] Dividing the additional spending due to the reform by the actual subsidy per hectare of grassland gives an estimate of the increase in the subsidized area at the commune level. We find that the reform has increased the amount of subsidized area by 11 hectares per treated commune. Given that the corresponding increase in grassland area is 3.73 hectares per commune, we estimate a low additionality ratio of 34%.[22]

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[15]See Appendix A.4 for a description of the Delta Method.

[16]The percentage change is computed as the ratio between the estimate of the additional amount of subsidies and the counterfactual mean of the amount of subsidies in treated communes after the reform (i.e. (5,000 euro /11,775 euro) × 100).

[17]The additional hectares of grassland are computed by multiplying the estimate of the share of permanent grassland area with the sample mean of the total utilised agricultural area in treated communes after the reform (i.e. 0.28p.p./100 × 1,333 ha).

[18]The percentage change is computed as the ratio between the estimate of the share of permanent grassland area and the counterfactual mean of the share of permanent grassland area in treated communes after the reform (i.e. (0.28p.p./37.02%) × 100).

[19]The elasticity of the supply of grassland is computed as the ratio between the percentage change in grassland area and the percentage change is the amount of subsidies (i.e. 0.76/42.46%).

[20]The cost per additional hectare of grassland is obtained by dividing the estimated additional cost to the additional hectares of grassland (i.e. 5,000 euro/3,73 ha).

[21]The subsidy per hectare of grassland for PHAE and CTE/CAD together was about 90 euro.

[22]The additionality ratio is as the ratio between the additional subsidized hectares and the additional hectares of grassland (i.e. (3.73 ha/11 ha) x 100)

6.2 Cost-Benefit Analysis

In this section, we perform a cost-benefit analysis of the reform. To estimate the benefits of the reform, we model the emissions per hectare in the presence of the reform and in its absence. We choose to model the dynamics of carbon stored in the soil after a change in soil usage using the saturated exponential function that Arrouay et al. (2002) propose for France:

$$F_{s,u}(t) = \Delta_{s,u}(1 - e^{-k_{s,u}t}), \tag{10}$$

where $F_{s,u}(t)$ is the cumulated flow of carbon into the soil t years after converting the soil from use s to use u in tons of carbon per hectare (tC/ha), $\Delta_{s,u}$ is the long run difference in carbon storage between soil use u and soil use s and $k_{s,u}$ is the speed at which carbon flows after conversion. Figure 16 shows the flows of carbon after the conversion from grassland to cropland and from cropland to grassland using the parameterizations proposed by Arrouay et al. (2002). In the long run, grassland stores 25tC/ha more than cropland on average in France. The conversions between grassland and cropland are not symetric: while carbon is depleted very fast when grassland is converted to cropland ($k_{g,c} = 0.07\text{year}^{-1}$, implying that 7.4tC are lost in the first 5 years after conversion of grassland (g) to cropland (c)), it takes a lot of time to rebuild the carbon content in the soil after conversion of grassland ($k_{c,g} = 0.025\text{year}^{-1}$, implying that 2.9tC are stored in the first five years after cropland is converted to grassland).

To estimate the benefits from the program, we estimate the value of an hectare of grassland saved by the program. In the absence of the program, grassland is converted into cropland at $t = 0$ and start emitting immediately. Emissions per unit of time (here per year) in the absence of the program, $E^0(t)$, can be computed as the negative of the first derivative of the cumulated carbon flow into the soil after conversion of grassland to cropland:

$$\begin{aligned} E^0(t) &= -3.66F'_{g,c}(t) \\ &= -3.66\Delta_{g,c}k_{g,c}e^{-k_{g,c}t} \end{aligned} \tag{11}$$

where 3.66 is the constant of conversion from tons of carbon into the soil to tons of CO_2 equivalent, so that emissions are expressed in $tCO_2eq/ha/year$. In the presence of the program, depending on how fast the effect of the program stops, emissions start at $t = x$. In our main specification, we assume that $x = 5$, meaning that the program has no permanence: the area in grassland saved by the program is converted to cropland as soon as the payments stop. As a consequence, we have:

$$E^1(t,x) = \begin{cases} 0 & \text{if } t \leq x \\ -3.66\Delta_{g,c} k_{g,c} e^{-k_{g,c}(t-x)} & \text{if } t > x. \end{cases} \tag{12}$$

In order to compute the value of the program, we first compute the value of one hectare of grassland saved by the program. We assume that, absent the program, this hectare would have been converted into cropland at year $t = 0$ and would have emitted $E^0(t)$ tons of CO_2 equivalent each year. We also assume that, under the program, this hectare would have been conserved as grassland until year $t = x$ and would have emitted $E^1(t)$ tons of CO_2 equivalent each year. The climate benefits of one hectare of grassland saved by the program until year x is thus:

$$B_c(x) = -\int_0^\infty \left(E^1(t) - E^0(t)\right) SCC_t e^{-rt} dt, \tag{13}$$

with SCC_t the social cost of carbon at time t and r the discount rate. Assuming a constant social cost of carbon, we show in Appendix A.3 that the climate benefits from preventing the conversion of one hectare of grassland until date x is:

$$B_c(x) = \frac{-3.66\Delta_{g,c} SCC}{1 + \frac{r}{k_{g,c}}} \left(1 - e^{-xr}\right). \tag{14}$$

The intuition for the formula for $B_c(x)$ is as follows. The ratio in the first part of the formula measures the discounted benefit of keeping one hectare of grassland from converting to cropland forever. The numerator measures the social value of all the carbon stored in the ground under one hectare of grassland instead of one hectare of cropland. This is the social value of 25 tons of carbon, or 91.5 tCO_2eq. Using a Social Cost of Carbon of 24 Euros as proposed by the U.S. Environmental Protection Agency (EPA),[23]the social value of the carbon stored in the ground under one hectare of grassland versus one hectare of cropland is 2196 Euros. The denominator serves to discount the stock of carbon by the time it takes for it to be released after conversion. The carbon is indeed not released all at once after conversion to cropland. What drives the amount of discounting is the ratio $\frac{r}{k_{g,c}}$. When $k_{g,c}$, the speed of extraction of carbon from the ground, is low relative to r,

[23]The EPA middle estimate (i.e. using a discount rate of 3%) for the SCC in 2010 is $31 (in 2007 USD) per ton of averted CO_2. Using the USD-EUR exchange rate of 2007 (i.e. 1 USD = 0.77 EUR), the SCC equals approximately 24 euro.

a lot of emissions occur far in the future and the discounting is important. When $k_{g,c}$ is large, a lot of emissions happen very soon after conversion and the discounting is small. With $k_{g,c} = 0.07$ and $r = 0.02$, the value of the total stock of carbon into the ground under grassland is discounted by 77%. The last part of the formula accounts for the fact that the program only displaces emissions over time. As expected, when $x \to \infty$, this term tends to one and there is no discounting. When $x = 5$ years, the discounting is equal to 9.5%, meaning that the program only saves the equivalent of 9.5% of the total value of carbon stored in the soil. With the parameter values selected up to now, the climate value of preventing one hectare of grassland from converting to cropland for 5 years is equal to 162.54 Euros.

Grassland also brings benefits beyond reducing carbon emissions (cleaner water, pollination services, hunting and landscape). We assume that the value of these services is B_a Euros/ha/year and that they disappear instantaneously when grassland is converted into cropland. Adding these services to the climate benefits brings the following formula for computing the total climate benefits from grassland:

$$B(x) = \left(\frac{-3.66\Delta_{g,c} SCC}{1 + \frac{r}{k_{g,c}}} + \frac{B_a}{r} \right) \left(1 - e^{-xr}\right). \tag{15}$$

The proof of this result is in Appendix A.3. Puydarrieux and Devaux (2013) estimate the values of the services brought by grassland as 44 Euros/ha/year for water quality, 60 Euros/ha/year for pollination, 4 Euros/ha/year for hunting,[24] and 60 Euros/ha/year for landscape amenities. In total, these additional benefits bring 168 Euros/ha/year. The discounted value of these benefits over 5 years is equal to 799.36 Euros/ha. Thus, the total benefit of preventing the conversion of 1 ha of grassland to cropland for five years is equal to 961.9 Euros.

Let us now compute the total benefit from the program and its benefit-cost ratio using our estimates of the impact of the reform on additionality and on transfers. We estimate that the program reform has increased grassland area at the commune level by 3.73±7.31 ha for a cost of 5000±513 Euros. Assuming that these benefits last for five years only, and that grassland is converted to cropland as soon as the payments stop, the total value generated by the program is equal to 3.73*961.9=3587.88 Euros, which implies a benefit-cost ratio of 0.72±1.41. The climate benefits of the program are equal to 3.73*162.54=606.27 Euros, which implies a climate benefit-cost ratio of 0.12±0.24. Assuming instead that the benefits

[24]Here we consider the hunting as a supply activity and not as a leisure activity. Thus we value it at the market price of the prey.

of the program last forever, even if the payments stop after 5 years (a very optimistic assumption which yields to an upper bound on the benefit estimates), we find that the total value generated by the program would be equal to 10108*3.73=37,702.84 Euros, and thus that the program would have a benefit-cost ratio of 7.54±14.8. Under the assumption of full permanence of the program impacts after 5 years, the climate benefits of the program would be equal to 3.73*1708=6370.84, and its benefit-cost ratio to 1.27±2.53. Our estimates enable us to compute two additional critical values: the degree of permamence of the program effects that would enable the program to break even and the social cost of carbon that would make the program break even. Considering only climate benefits, the effects of the program have to persist for 72 years after payments stop for the program to break even. When taking into account both climate benefits and the other benefits from grassland, the effects of the program have to persist for 2 years and 2 months for the program to break even. In the absence of any effect of the program beyond five years, the social cost of carbon that would make the program break even on climate benefits alone is equal to 198±392 Euros/tCO_2eq. Under the same assumption, but including all the other benefits that grassland provides, the program would break even for a carbon price of 80±389 Euros/tCO_2eq. The summary of the cost-benefit analysis in presented in Table 10.

To improve the precision and validity of our benefit-cost analysis, we combine our own estimates of the additionality of the program with similar estimates obtained in the literature. Two other works have estimated the additionality of the French Grassland Conservation Program. Chabé-Ferret and Subervie (2009) use DID-matching to estimate the additionality of the Grassland Conservation Program in 2005 and find that it has increased the specialization rate of treated farms by 2±4 p.p., or 1.4±2.7 ha, for an additional cost of 3,500 Euros. Gallic and Marcus (2019) use a change in the eligibility rules of the French Grassland Conservation Program in 2015 in order to estimate its additionality. They use two changes as natural experiments: the end of grassland subsidies for farmers located outside of Less Favoured Areas and the opening of grassland subsidies to some farmers inside Less Favoured Areas that were not eligible before. Since Gallic and Marcus have access to data on all French farmers, their estimates are much more precise than ours.[25] There are several points worthy of notice in Gallic and Marcus (2019). First, they estimate that the program has no permanence: farmers leaving the program immediately decrease their proportion of grassland by 2.47±0.39 p.p., and do not move further in the subsequent years. Second, farmers entering the program experience a similar increase in their proportion of

[25] We have tried to access the same data as Gallic and Marcus (2019) but their access is reserved to members of the statistical services of the French Ministry of Agriculture.

grassland area: 2.48±0.43 p.p.[26] Both of these estimates yield an impact of the Grassland Conservation Program of 1.2±0.35 additional hectares of grassland for each treated farm, for a cost of 2,622 Euros per farm.[27] The benefit-cost ratios obtained using Chabé-Ferret and Subervie (2009) estimates is equal to 1.4*961.9/3500=0.38±0.74 for the total benefits and to 1.4*162.54/3500=0.07±0.13 for the climate benefits alone. The benefit-cost ratios obtained using Gallic and Marcus (2019) estimates is equal to 1.2*961.9/2622=0.44±0.16 for the total benefits and to 1.2*162.54/2622=0.07±0.03 for the climate benefits alone. Combining these three estimates of the benefit-cost ratio of the French Grassland Conservation Program into one using a meta-regression, we find a climate benefit-cost ratio of 0.07±0.03 and a total benefit-cost ratio of 0.44±0.15 (Figure 17). We also estimate that the program would break even for a carbon price of 194±122 Euros/tCO_2eq.

7 Conclusion

Payments for Ecosystem Services are being increasingly used in the context of development and environmental policies around the world. Yet, the empirical analysis of their effectiveness remains somewhat sparse. In this paper we provide an evaluation of a major nationwide Payments for Ecosystem Services program, the French Grassland Conservation Program, the largest of such programs in the world. Grassland Conservation Programs, that pay farmers for maintaining grassland cover, might be an effective way to combat climate change, if they succeed in triggering an increase in grassland cover at the expense of cropland for a reasonable amount of money. Unlike most of the previous literature evaluating the effect of Payments for Ecosystem Services, our approach does not rely on matching beneficiaries with similar non-beneficiaries. Instead, we use an exogenous change in the eligibility criteria for participating in a grassland program as a natural experiment. We perform our analysis at the aggregated, commune level in order to account for potential leakage effects within communes and we exploit the natural experiment in a difference-in-differences design: we compare changes in outcomes both over time and between areas where the number of grassland beneficiaries increased after the policy change and areas where the number of beneficiaries remained the same. We show in a theoretical model that our estimator recovers a policy-relevant treatment effect under plausible assumptions.

Our results suggest that the reform of the French Grassland Conservation Program

[26]This is the average of the additionality impacts estimated by Gallic and Marcus on cattle growers and on crop growers weighted by their respective proportion in the treated population.

[27]Amounts computed using Figure 8 in Gallic and Marcus (2019) in a DID design and weighting the results bythe proportion of cattle growers and crop growers among the treated.

did increase the amount of transfers in the communes most affected by the reform (by 5000±513 Euros, or 52.46±6.21%). The reform also managed to induce beneficiaries located in treated communes to increase the grassland area on their farm mainly at the expense of croplands. As such, the reform has generated positive environmental benefits. However, we find that the additionality of the program is low as the subsidized area increased by 11 hectares per commune, while the permanent grassland area only increased by 3.73 hectares (or 0.76±1.49%). As a consequence, we estimate that the elasticity of the supply of grassland is low (0.02±0.04). To estimate the benefit-cost ratio of the reform, we combine our additionality estimate with a model of the dynamics of carbon storage in grassland and estimates of the value of the various ecosystem services provided by grassland. We find that the reform of the Grassland Conservation program has provided climate benefits equal to 12±24% of its costs, and total environmental benefits equal to 72±141% of its costs. In order to improve the precision of our estimates, we combine them with other estimates of the additionality of the French Grassland Conservation Program using a meta-regression. These estimates are similar in size, even if somewhat smaller than ours, and, together with ours, imply that the climate benefits of the French Grassland Conservation Program are equal to 7±3% of its costs and its total benefits to 44±15% of its costs. We estimate that the carbon price that would make the benefits of the program equal to its cost is 194±122 Euros/tCO_2eq.

Our study contributes to the current increase in policymakers' demand for evidence based analysis of public policies. Several issues deserve attention in future research. First, the cost-effectiveness of the program might be increased if we use an estimate of the true cost for a farmer to participate in a Payment for Ecosystem Service program instead of the government transfers to the farmers. Because participation in Payments for Ecosystem Services is voluntary, farmers' costs of adopting the greener practices are lower than the transfer they receive. Estimating these true costs is still an area for further research. Second, explicitly estimating the heterogeneity across space in both costs and treatment effects would potentially demonstrate the advantage of spatially targeting grassland subsidies.

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A Proofs

A.1 Proof of Proposition 1

In what follows, in order to save on notation and to simplify the derivations, we assume that all farms are of the same size and all communes are of the same size (in practice, we weigh each farm by its usable agricultural area in our commune-level regressions). As a consequence, we assume that each commune has the same number of farms. We also assume an absence of diffusion effects, so that the Stable Unit Treatment Value Assumption is valid. That means that the the treatment status of farm i only affects the outcome of farm i and no other. This is not a mild assumption and the main text discusses what happens to our estimator when it is relaxed. Under these simplifying assumptions, the area of grassland among treated and control communes can be written as the sum of the area of grassland in each of the type of farm weighted by their respective proportions in each type of commune:

$$\mathbb{E}[Q_y|D=d] = \sum_{\tau\in\Omega} \mathbb{E}[q_{i,y}(t_{i,y},\theta_i)|D=d, T_i=\tau]\Pr(T_i=\tau|D=d), \tag{16}$$

for $d \in \{0,1\}$ and $\Omega = \{b_{000}, b_{00}, b_0, c, b, at, b_1, b_{11}, b_{111}, nt\}$.

We can now write the commune-level DID_Q estimator as a function of the changes in types:

$$\begin{aligned} DID_Q = \sum_{\tau\in\Omega} & \left(\mathbb{E}[q_{i,2005}(t_{i,2005},\theta_i) - q_{i,2000}(t_{i,2000},\theta_i)|D=1, T_i=\tau]\Pr(T_i=\tau|D=1)\right. \\ & \left. -\mathbb{E}[q_{i,2005}(t_{i,2005},\theta_i) - q_{i,2000}(t_{i,2000},\theta_i)|D=0, T_i=\tau]\Pr(T_i=\tau|D=0)\right). \end{aligned} \tag{17}$$

We now assume that the average changes of grassland area over time are the same for each type of farms in both treated and control communes:

Assumption 3 (Same trends by type) *We assume that,* $\forall\tau\in\Omega$*:*

$$\begin{aligned} & \mathbb{E}[q_{i,2005}(t_{i,2005},\theta_i) - q_{i,2000}(t_{i,2000},\theta_i)|D=1, T_i=\tau] \\ & = \mathbb{E}[q_{i,2005}(t_{i,2005},\theta_i) - q_{i,2000}(t_{i,2000},\theta_i)|D=0, T_i=\tau] = \delta^{\tau}. \end{aligned}$$

Assumption 3 is mild in that it is highly plausible that farms of the same type react in the same way to the same price changes. Under Assumption 3, we have:

$$DID_Q = \sum_{\tau \in \Omega} \delta^\tau \left(\Pr(T_i = \tau | D = 1) - \Pr(T_i = \tau | D = 0) \right). \tag{18}$$

Finally, let us assume the following on the proportion of each types:

Assumption 4 (Proportion of types) *We assume that:*

1. $\forall \tau \in \{b_{000}, b_{00}, b_0, b, b_1, b_{11}, b_{111}\}$, $\Pr(T_i = \tau | D = 1) = \Pr(T_i = \tau | D = 0)$,
2. $\Pr(T_i = c | D = 0) = 0$.

Item 1 in Assumption 4 implies that the proportion of *bunchers* in treated and control communes is the same. This is a strong assumption. In general, it mostly means that we disregard the behavior of bunchers in our estimator. This is warranted since they represent a tiny fraction of the farmers. Item 2 in Assumption 4 implies that the proportion of *compliers* in control communes is zero. It means that the reason why these communes see a stability in the number of participants over time is because there are no new entrants in the Grassland Conservation Program.

A consequence of Assumption 4 is that the proportion of *compliers* in the treated group is equal to a fraction of the proportion of *always takers* and of *never takers* from the control group. In order to see this, note that the sum of the proportions of all of the types conditional on the treatment indicator is equal to one (T_i is a partition): $\forall d \in \{0,1\}$, $\sum_{\tau \in \Omega} \Pr(T_i = \tau | D = d) = 1$. Since the proportion of *bunchers* is the same in both treated and control groups (item 1 in Assumption 4), we have that $\Pr(T_i = c | D = 1) + \Pr(T_i = at | D = 1) + \Pr(T_i = nt | D = 1) = \Pr(T_i = at | D = 0) + \Pr(T_i = nt | D = 0)$. As a consequence, we have: $\Pr(T_i = c | D = 1) = \Pr(T_i = at | D = 0) - \Pr(T_i = at | D = 1) + \Pr(T_i = nt | D = 0) - \Pr(T_i = nt | D = 1) = \alpha + \beta$.

Under Assumption 4, equation (18) becomes:

$$\begin{aligned} DID_Q &= \sum_{\tau \in \{at, nt, c\}} \delta^\tau \left(\Pr(T_i = \tau | D = 1) - \Pr(T_i = \tau | D = 0) \right) && (19) \\ &= -\alpha \delta^{at} - \beta \delta^{nt} + (\alpha + \beta) \delta^c && (20) \\ &= \alpha(\delta^c - \delta^{at}) + \beta(\delta^c - \delta^{nt}) && (21) \\ &= \alpha LATE_{q_{2000}} + \beta LATE_{q_{2005}}, && (22) \end{aligned}$$

where the first equality uses item 1 in Assumption 4, the second and third equalities use the implication of Assumption 4 and the last equality uses Assumptions 1 and 2.

A.2 Proof of Proposition 2

We use the same set of simplifications used in Section A.2. All farms are of the same size and all communes are of the same size. As a consequence, each commune has the same number of farms. We also assume an absence of diffusion effects, so that the Stable Unit Treatment Value Assumption is valid. Under these simplifying assumptions, the transfers received by treatment and control communes are the sum of the transfers received by each type of farm weighted by their respective proportions in each type of commune multiplied by N, the number of farms in each commune:

$$\mathbb{E}[M_y|D=d] = N \sum_{\tau\in\Omega} \mathbb{E}[t_{i,y}q_{i,y}(t_{i,y},\theta_i)|D=d, T_i=\tau] \Pr(T_i=\tau|D=d), \tag{23}$$

for $d \in \{0,1\}$ and $\Omega = \{b_{000}, b_{00}, b_0, c, b, at, b_1, b_{11}, b_{111}, nt\}$.

We can now write the commune-level DID_Q estimator as a function of the changes in types:

$$\begin{aligned} DID_M = N \sum_{\tau\in\Omega} (&\mathbb{E}[t_{i,2005}q_{i,2005}(t_{i,2005},\theta_i) - t_{i,2000}q_{i,2000}(t_{i,2000},\theta_i)|D=1, T_i=\tau] \Pr(T_i=\tau|D=1) \\ &-\mathbb{E}[t_{i,2005}q_{i,2005}(t_{i,2005},\theta_i) - t_{i,2000}q_{i,2000}(t_{i,2000},\theta_i)|D=0, T_i=\tau] \Pr(T_i=\tau|D=0)) . \end{aligned} \tag{24}$$

Under Assumption 3, the change in transfers received by the *always takers* and the various types of *bunchers* is the same in treated and control communes. Under Assumption 4, the contribution of the *bunchers* to DID_M becomes zero. The copntributions of *never takers* to DID_M is also zero by construction (they receive no transfers). We thus have:

$$\begin{aligned} DID_M = N (&\mathbb{E}[t_1 q_{i,2005}(t_1,\theta_i) - t_0 q_{i,2000}(t_0,\theta_i)|T_i=at](\Pr(T_i=at|D=1) - \Pr(T_i=at|D=0)) \\ &+\mathbb{E}[t_1 q_{i,2005}(t_1,\theta_i)|D=1, T_i=c] \Pr(T_i=c|D=1)) . \end{aligned} \tag{25}$$

Under Assumption 1, we also have:

$$\mathbb{E}[t_1 q_{2005}(t_1,\theta) - t_0 q_{2000}(t_0,\theta)|T=c] = \mathbb{E}[t_1 q_{2005}(t_1,\theta) - t_0 q_{2000}(t_0,\theta)|T=at].$$

Using the fact that $\Pr(T_i=c|D=1) = \alpha+\beta$ and $\Pr(T_i=at|D=1) - \Pr(T_i=at|D=0) = -\alpha$, we have:

$$DID_M = N (\alpha\mathbb{E}[t_0 q_{i,2000}(t_0,\theta_i)|T_i=at] + \beta\mathbb{E}[t_1 q_{i,2005}(t_1,\theta_i)|T_i=c]) . \tag{26}$$

A.3 Closed form solutions for the discounted benefits of grassland

Let us start with the formula for climate benefits:

$$B_c(x) = -\int_0^\infty \left(E^1(t) - E^0(t)\right) SCC_t e^{-rt} dt,$$

The second part of the expression is the simplest to start with:

$$\begin{aligned}
B_c^0(x) &= \int_0^\infty E^0(t) SCC_t e^{-rt} dt \\
&= -3.66\Delta_{g,c} k_{g,c} SCC \int_0^\infty e^{-(k_{g,c}+r)t} dt \\
&= -3.66\Delta_{g,c} k_{g,c} SCC \left[-\frac{1}{k_{g,c}+r} e^{-(k_{g,c}+r)t}\right]_0^\infty \\
&= -3.66\Delta_{g,c} k_{g,c} SCC \left[\frac{1}{k_{g,c}+r}\right] \\
&= -\frac{3.66\Delta_{g,c} SCC}{1+\frac{r}{k_{g,c}}},
\end{aligned}$$

where the second equality stems from assuming that SCC_t is constant over time and uses the formula for E_t^0, the third equality uses the formula for the integral of an exponential, the fourth equality the fact that $\lim_{t\to\infty} e^{-(k_{g,c}+r)t} = 0$ and $e^0 = 1$.

The second part of the expression requires a change of variable $y = t - x$:

$$\begin{aligned}
B_c^1(x) &= \int_0^\infty E^1(t) SCC_t e^{-rt} dt \\
&= -3.66\Delta_{g,c} k_{g,c} SCC \int_x^\infty e^{-k_{g,c}(t-x)} e^{-rt} dt \\
&= -3.66\Delta_{g,c} k_{g,c} SCC \int_0^\infty e^{-k_{g,c}y} e^{-r(y+x)} dy \\
&= -3.66\Delta_{g,c} k_{g,c} SCC e^{-rx} \int_0^\infty e^{-(k_{g,c}+r)y} dy \\
&= -\frac{3.66\Delta_{g,c} SCC e^{-rx}}{1+\frac{r}{k_{g,c}}},
\end{aligned}$$

where the second equality stems from assuming that SCC_t is constant over time and using the formula for E_t^1, the second equality uses the change of variable $y = t - x$ and the last equality uses the formula for the integral of an exponential.

Let us now examine the closed form formula for the discounted benefits from a stream of yearly services B_a lasting x years:

$$\begin{aligned} B_a(x) &= \int_0^x B_a e^{-rt} dt \\ &= B_a \int_0^x e^{-rt} dt \\ &= \frac{B_a}{r}(1 - e^{-rx}), \end{aligned}$$

where the last equality stems from the formiula for the integral of an exponential function.

A.4 The Delta Method

Transformation of one variable. We denote by ω^2 the asymptotic variance of the estimated coefficient $\widetilde{\alpha}$. Then, for the regression coefficient holds $\sqrt{n}(\widetilde{\alpha}\text{-}\alpha) \xrightarrow{d} N(0, \omega^2)$. The statement of the Delta Method says that if we transform an estimator by a function g, the following property holds:

$\sqrt{n}(g(\widetilde{\alpha})\text{-}g(\alpha)) \xrightarrow{d} N(0, \omega^2 g'(\alpha)^2)$, where g' denotes the first derivative of g.

This implies that the variance of the transformed estimator is given by:

$V[g(\widetilde{\alpha})] = V[\widetilde{\alpha}] \times g'(\widetilde{\alpha})^2$.

Transformation of two variables. To approximate the variance of some multi-variable function $G = G(\widetilde{\alpha}_x, \widetilde{\alpha}_y)$, we:

- take the vector of partial derivatives of the function G with respect to each parameter in turn : $\frac{\partial G}{\partial \widetilde{\alpha}_x}$ and $\frac{\partial G}{\partial \widetilde{\alpha}_y}$;
- right-multiply this vector by the variance-covariance matrix, $\Sigma = \begin{bmatrix} Var(\widetilde{\alpha}_x) & Cov(\widetilde{\alpha}_x, \widetilde{\alpha}_y) \\ Cov(\widetilde{\alpha}_x, \widetilde{\alpha}_y) & Var(\widetilde{\alpha}_y) \end{bmatrix}$
- right-multiply the resulting product by the transpose of the original vector of partial derivatives, G^T.

What we are interested in here is the standard error of the transformed variables, which equals the square root of the estimated variance. We apply the Delta Method transformation of one variable to obtain the standard error of the additional hectares of permanent grassland area and of the total benefits in euro and the standard error of the percentage changes in grassland and money. We also use the Delta Method transformation of two variables to compute the standard errors of the elasticity estimates and the benefit-cost ratios, the standard error of the cost per additional hectare of grassland ratio and the cost per unit of averted CO_2 emission. We performed the computations in R using the ”deltamethod” command from the ”msm” package.

B Data

Outcome variables:

- share of permanent grassland area (% of total utilised agricultural area) = share of natural grassland or pastures having more than 6 years on the same plot and low productivity grassland area;
- share of crop area (% of total utilised agricultural area) = share of cereals, industrial crops, pulses and protein crops;
- share of fodder area (% of total utilised agricultural area) = share of corn forage and silage, forage root crops and other annual forages;
- specialization rate (%) = the share of temporary and permanent grassland in the total utilised agricultural area;
- loading ratio = density of livestock units (cattle, equines, goats and sheep expressed in cattle units) in the forage area (permanent grassland and fodder area without corn forage);
- share of utilised agricultural area (% of total farm area) = share of annual crops, permanent crops and temporary and permanent grassland;
- share of forest area (% of total farm area) = share of timber and logging forests;
- share of nonproductive land (% of total farm area) = share of nonproductive heath, wasteland and non-agricultural area;
- share of owned land (% of total utilised agricultural area);
- share of permanently rented land (% of total utilised agricultural area);
- share of temporary rented land (% of total utilised agricultural area) = share of temporary rented land and land in sharecropping.

Control variables:

- type of crop orientation = cereals and protein crops, general crops, vegetable crops, flowers and horticulture, designated viticulture, other type of viticulture, fruits and other permanent crops, milk cattle, beef cattle, milk-beef cattle, other herbivorous, granivorous, mixed crops, poly-elevation herbivorous orientation, poly-elevation granivorous orientation, field crops and herbivorous;
- economic size = less than 4 ESU[28], between 4 and 8 ESU, between 8 and 16 ESU, between 16 and 40 ESU, between 40 and 100 ESU and more than 100 ESU ;
- number of farms = weighted number of farms.

[28]European Size Unit is a standard gross margin of 1200 Euro that is used to express the economic size of a farm (Eurostat:Statistics Explained).

C Figures

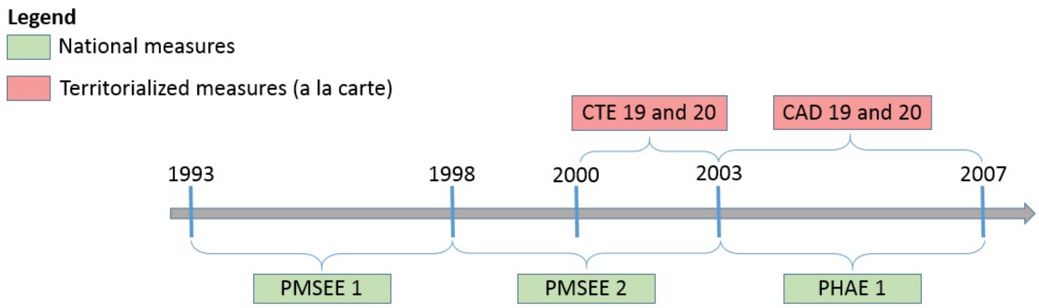
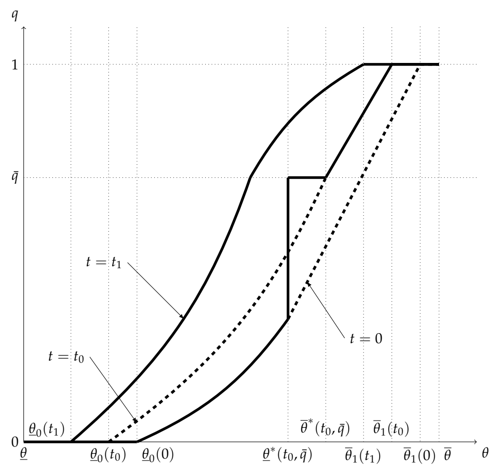


Figure 1: Timeline of the reforms of the French Grassland Conservation Program.

Eligibility Criteria \ Measure	PMSEE 2	PHAE 1	CTE/CAD 19 AND 20
Farmer's age	≤ 60 years	≤ 60 years	—
Farm size	≥ 3 ha UAA and ≥ 3 LU	—	—
Specialization Rate (Grassland/Utilised Agricultural Area)	≥ 75%	≥ 50% - ≥ 75% department dependent	—
Loading Ratio (Livestock Units/Fodder Area)	≤ 1.4	≤ 1.4 - ≤ 1.8 department dependent	≤ 1.4 - ≤ 1.8 department dependent
Fertiliser use (Units of Azote/ha of Grassland)	≤ 70	≤ 60	≤ 60
Max amount of subsidy / ha of grassland	**46€**	**76€**	**91€**

Figure 2: Eligibility rules of the French Grassland Conservation Program.

Figure 3: Theoretical model of grassland supply



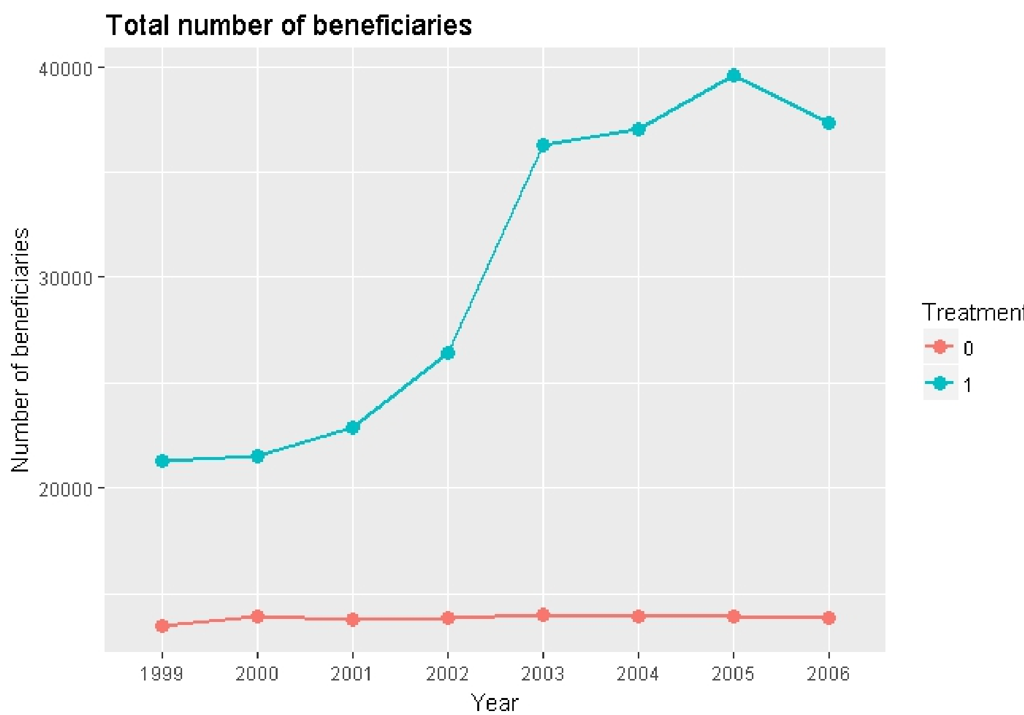


Figure 4: Total number of beneficiaries of grassland conservation schemes from 1999 to 2006, by treatment status.

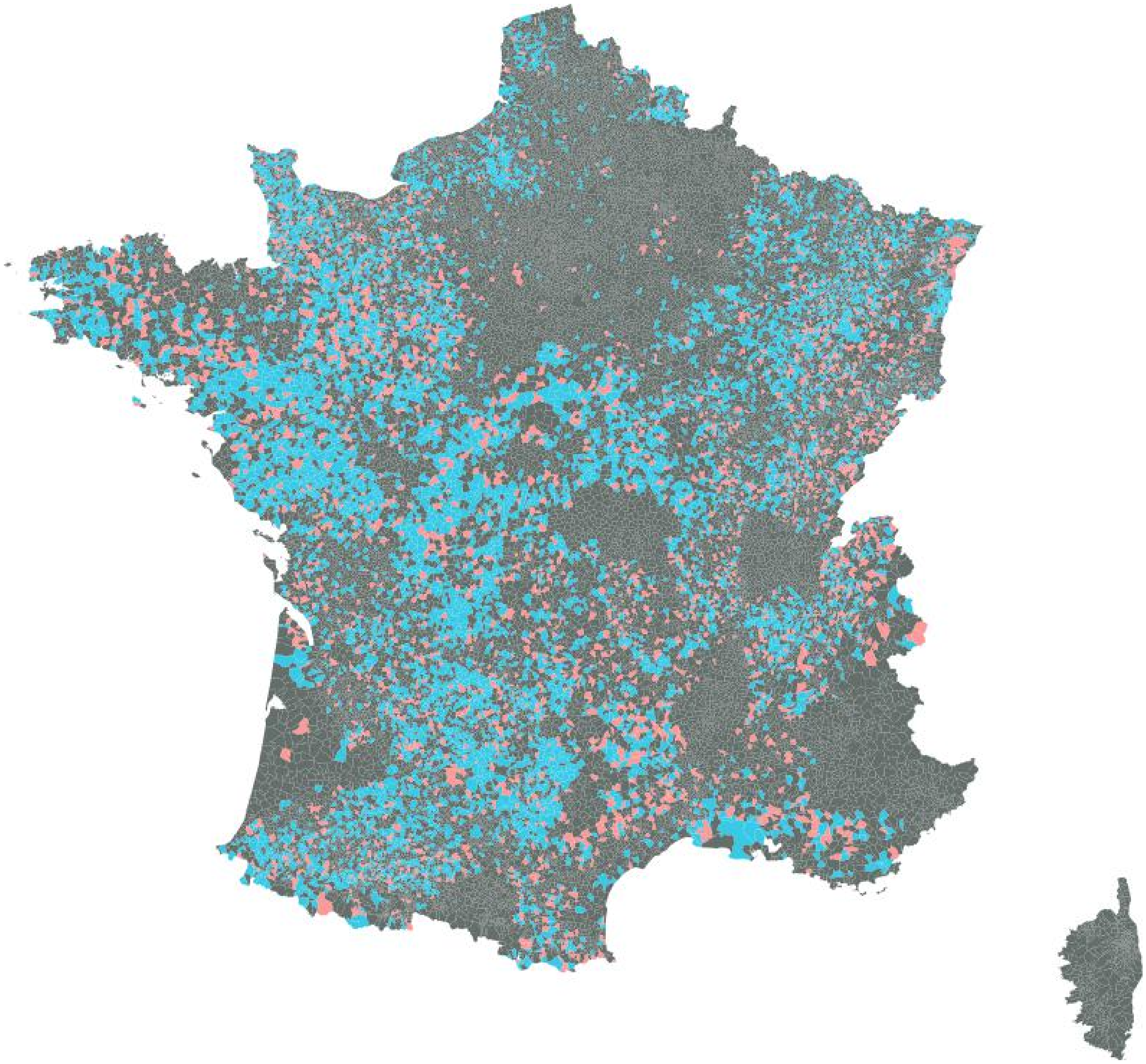


Figure 5: Map of France showing the treated communes (in blue) and the control communes (in pink).

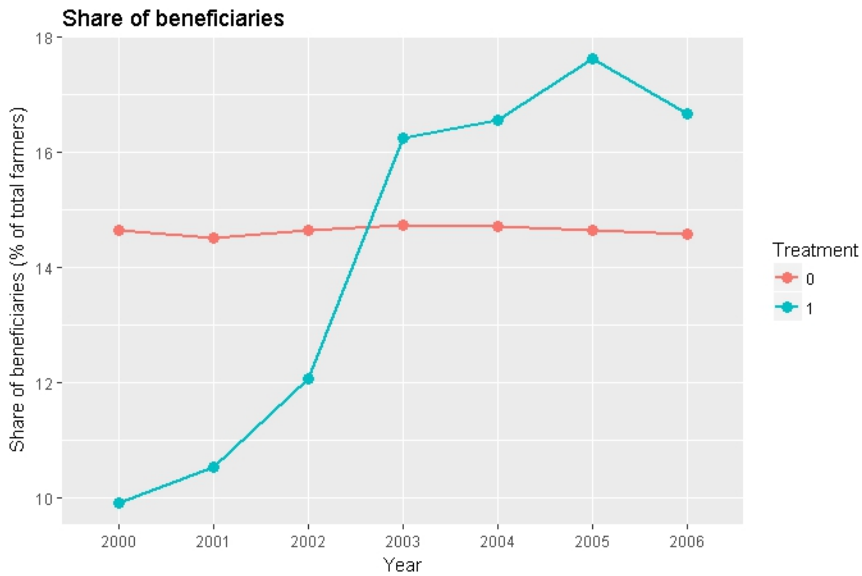


Figure 6: Share of beneficiaries of grassland conservation schemes in total farmers from 2000 to 2006, by treatment status.

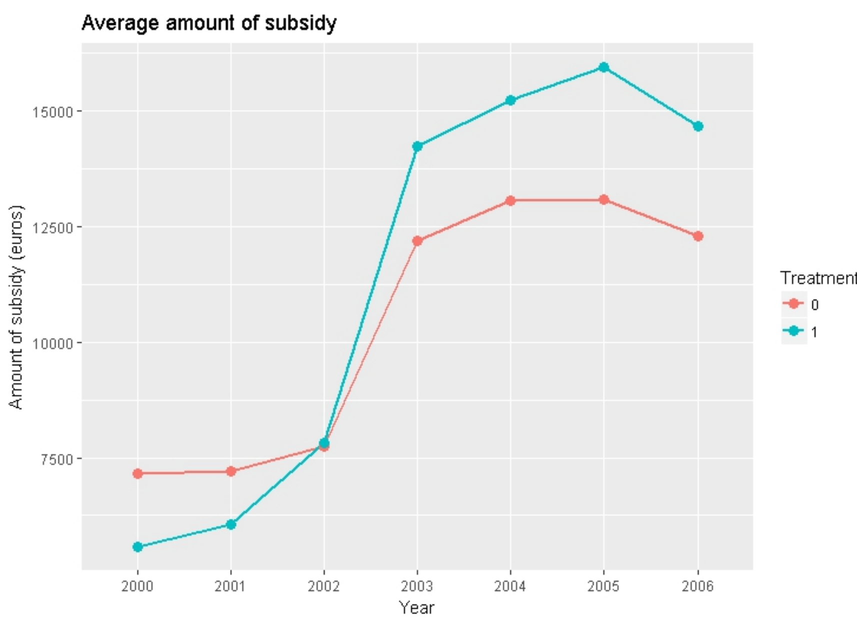
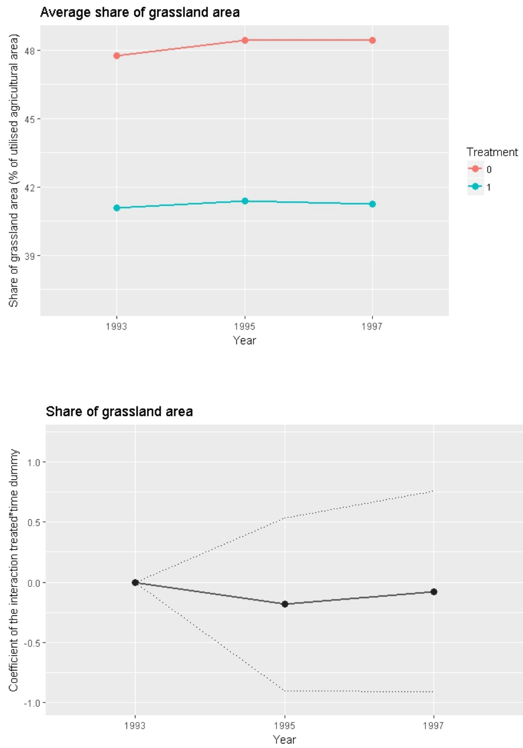
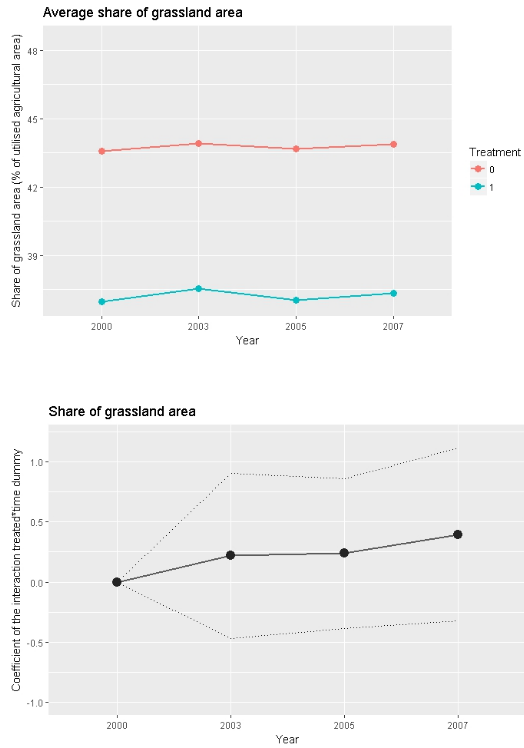


Figure 7: Average amount of subsidies (in euro) paid to beneficiaries between 2000 and 2006, by treatment status.

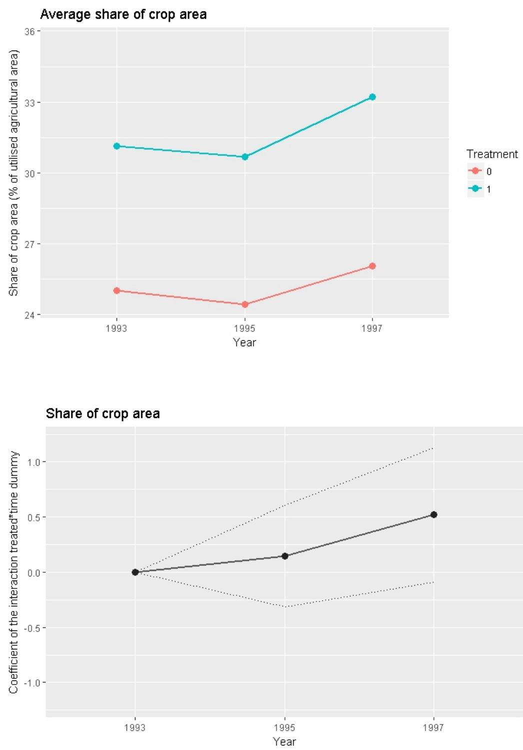


(a) Placebo Test (1993-1997)

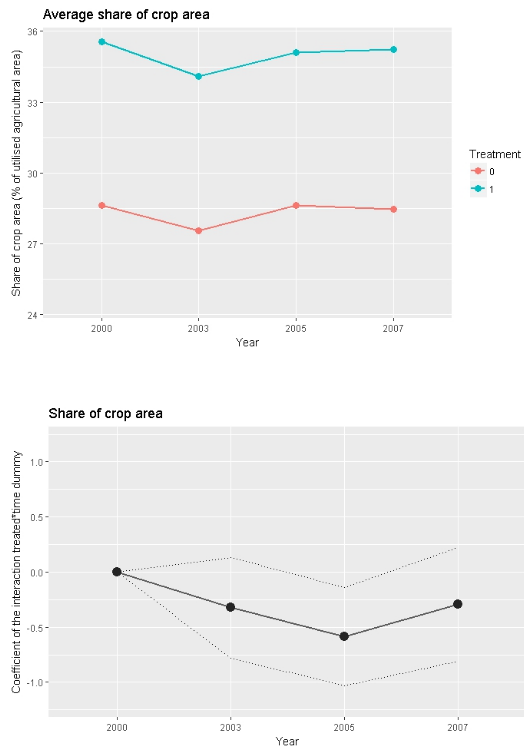


(b) Treatment Effect (2000-2007)

Figure 8: (i) Trends in the average share of permanent grassland area in total utilised agricultural area by treatment status and (ii) Estimated coefficients of the interaction treated*time dummy on the share of permanent grassland area and their 95% confidence interval (represented by dashed lines).

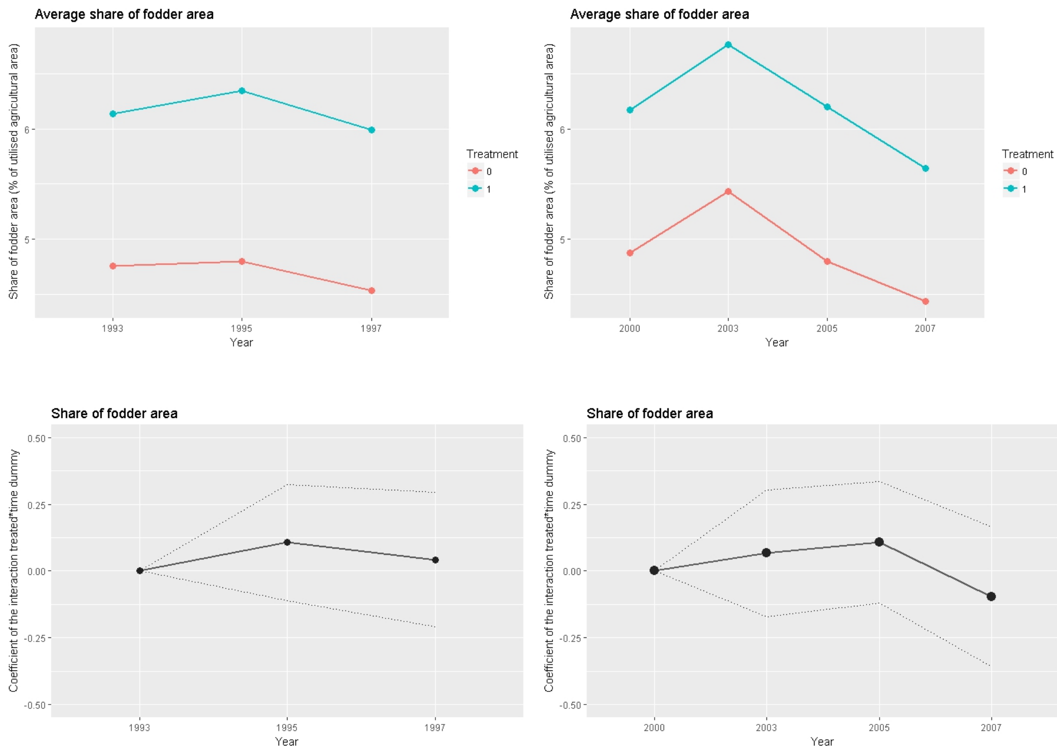


(a) Placebo Test (1993-1997)



(b) Treatment Effect (2000-2007)

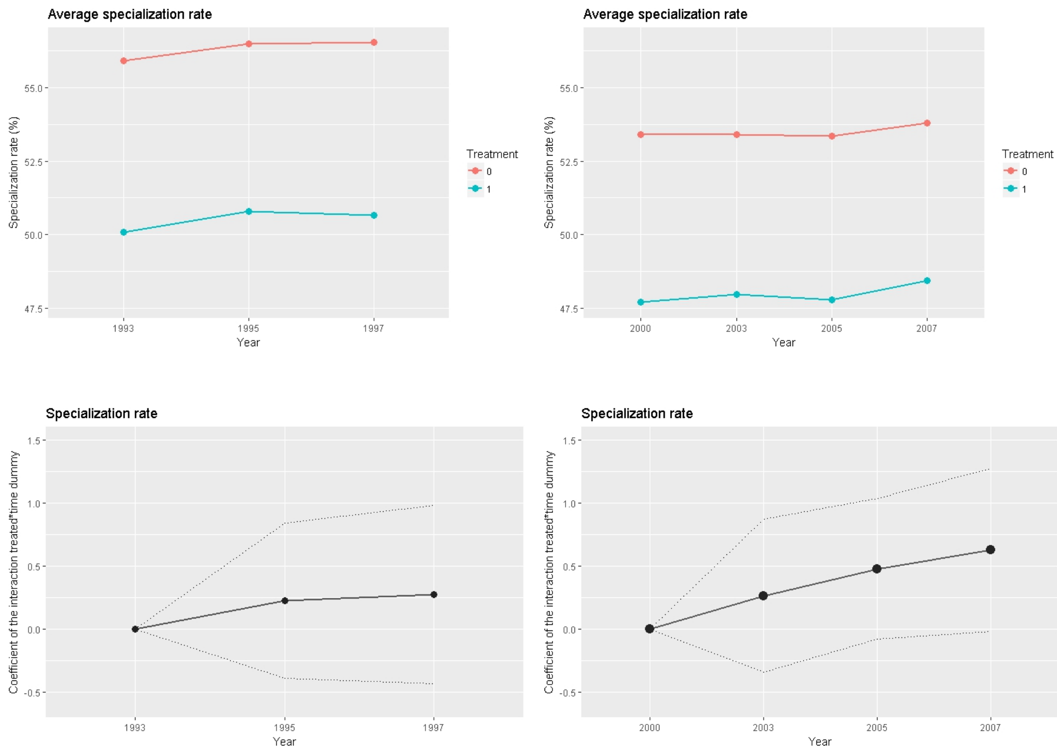
Figure 9: (i) Trends in the average share of crop area in total utilised agricultural area by treatment status and (ii) Estimated coefficients of the interaction treated*time dummy on the share of crop area and their 95% confidence interval (represented by dashed lines).



(a) Placebo Test (1993-1997)

(b) Treatment Effect (2000-2007)

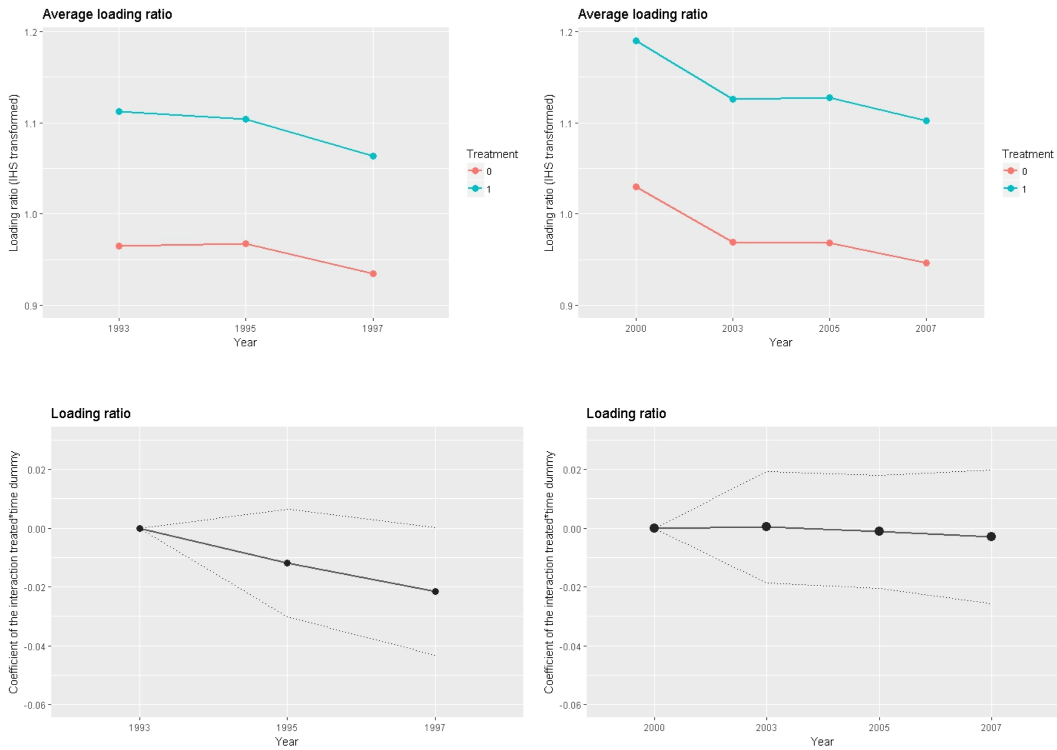
Figure 10: (i) Trends in the average share of fodder area in total utilised agricultural area by treatment status and (ii) Estimated coefficients of the interaction treated*time dummy on the share of fodder area and their 95% confidence interval (represented by dashed lines).



(a) Placebo Test (1993-1997)

(b) Treatment Effect (2000-2007)

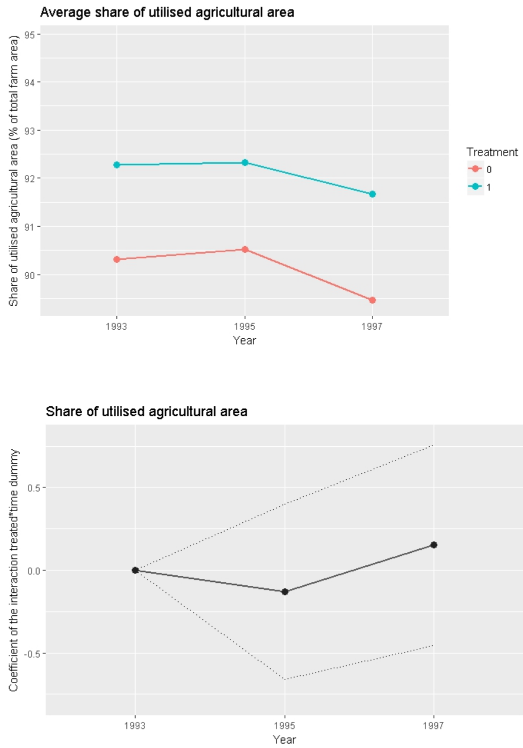
Figure 11: (i) Trends in the average specialization rate by treatment status and (ii) Estimated coefficients of the interaction treated*time dummy on the specialization rate and their 95% confidence interval (represented by dashed lines).



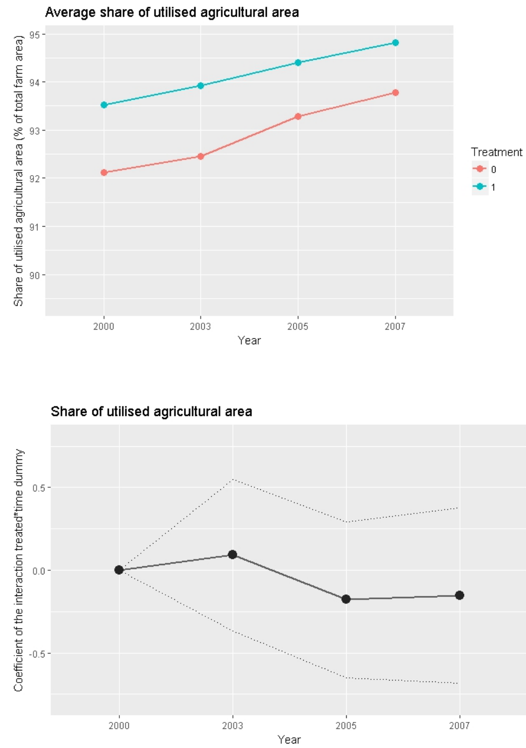
(a) Placebo Test (1993-1997)

(b) Treatment Effect (2000-2007)

Figure 12: (i) Trends in the average loading ratio by treatment status and (ii) Estimated coefficients of the interaction treated*time dummy on the loading ratio and their 95% confidence interval (represented by dashed lines).

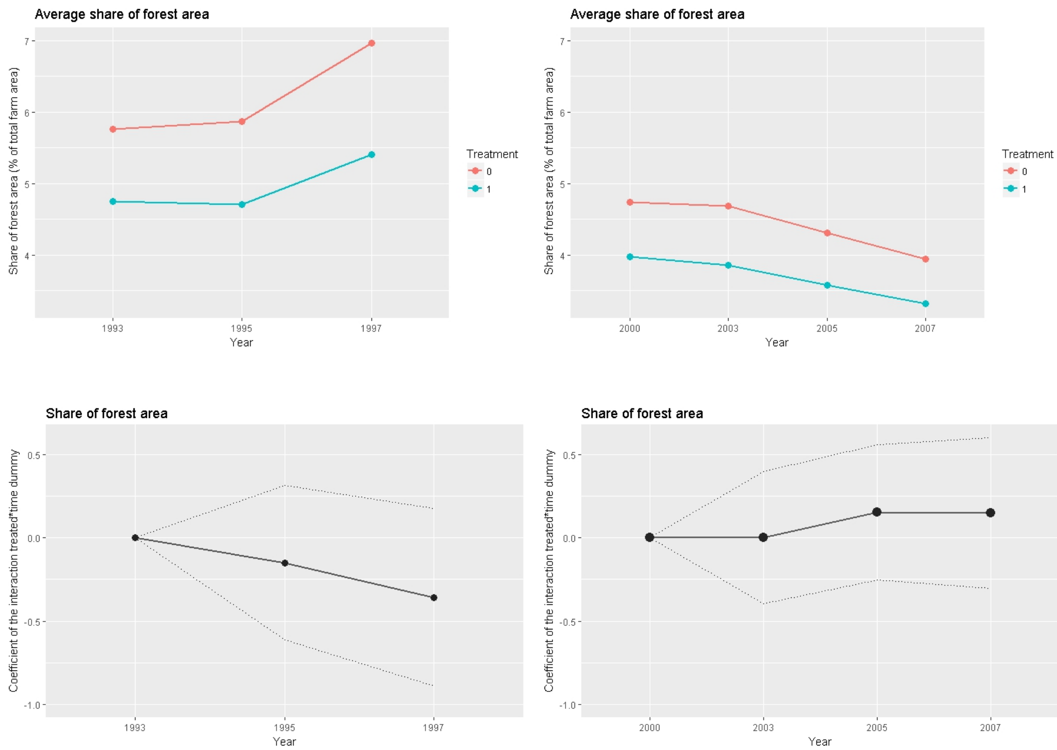


(a) Placebo Test (1993-1997)



(b) Treatment Effect (2000-2007)

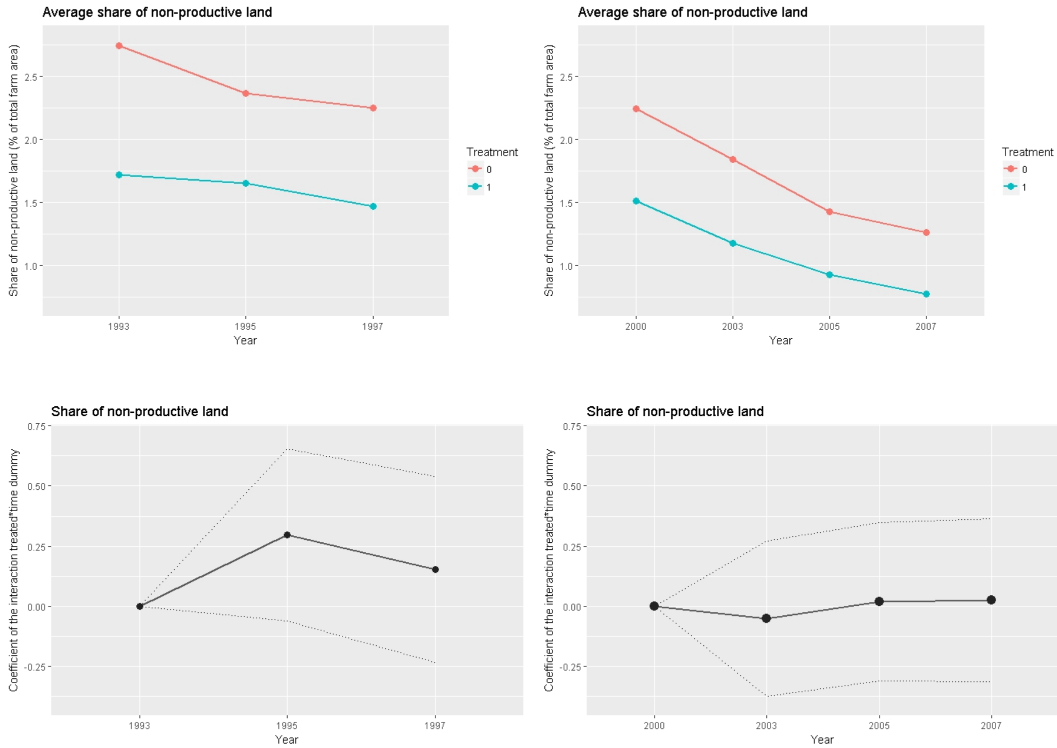
Figure 13: (i) Trends in the average share of utilised agricultural area in total farm area by treatment status and (ii) Estimated coefficients of the interaction treated*time dummy on the share of utilised agricultural area and their 95% confidence interval (represented by dashed lines).



(a) Placebo Test (1993-1997)

(b) Treatment Effect (2000-2007)

Figure 14: (i) Trends in the average share of forest area in total farm area by treatment status and (ii) Estimated coefficients of the interaction treated*time dummy on the share of forest area and their 95% confidence interval (represented by dashed lines).



(a) Placebo Test (1993-1997) (b) Treatment Effect (2000-2007)

Figure 15: (i) Trends in the average share of nonproductive land in total farm area by treatment status and (ii) Estimated coefficients of the interaction treated*time dummy on the share of nonproductive land and their 95% confidence interval (represented by dashed lines).

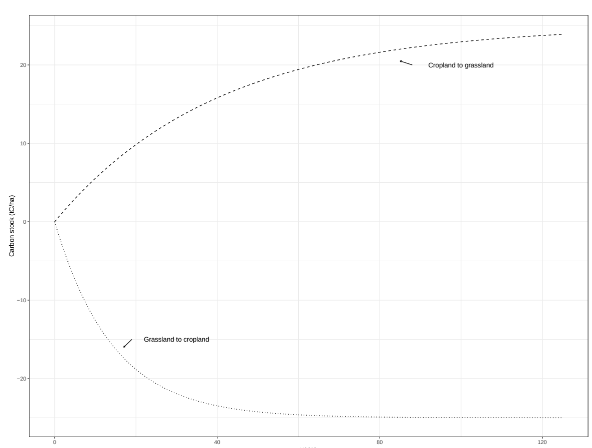
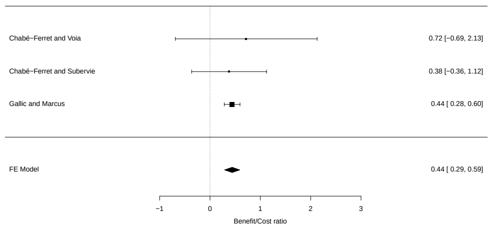
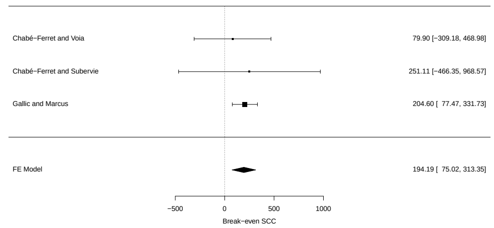


Figure 16: Evolution of the stock of Carbon in the soil when land use changes



(a) benefit-cost ratio



(b) Break-even SCC

Figure 17: Meta-analysis of the benefit-cost ratio and break-even SCC of the French Grassland Conservation Program

D Tables

Table 1: DID-FE Results: Panel A

	Placebo Test (1993-1997)				**Treatment Effect (2000-2007)**			
	No DEPxTIME FE		With DEPxTIME FE		No DEPxTIME FE		With DEPxTIME FE	
	No controls	With controls	No controls	With controls	No controls	With controls	No controls	With controls
Outcome Variables								
Share of permanent grassland area	−0.44	−0.38	−0.17	−0.13	0.09	0.24	0.16	0.28
	(0.34)	(0.34)	(0.36)	(0.35)	(0.27)	(0.27)	(0.28)	(0.28)
Share of crop area	0.58	0.59	0.35	0.33	−0.33	−0.33	−0.38	−0.40
	(0.24)	(0.23)	(0.25)	(0.24)	(0.19)	(0.19)	(0.20)	(0.20)
Share of fodder area	0.12	0.11	0.08	0.07	0.01	−0.01	0.04	0.03
	(0.10)	(0.10)	(0.11)	(0.11)	(0.10)	(0.10)	(0.10)	(0.10)
Specialization rate	0.06	0.12	0.21	0.25	0.26	0.40	0.35	0.45
	(0.29)	(0.29)	(0.31)	(0.30)	(0.25)	(0.25)	(0.26)	(0.25)
Loading ratio	−0.02	−0.02	−0.02	−0.02	−0.00	−0.01	0.00	−0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Observations	**9,998**	**9,998**	**9,998**	**9,998**	**10,468**	**10,468**	**10,468**	**10,468**

Note: Year and commune fixed effects estimation. Robust standard errors clustered at commune level in parenthesis. *p $<$ 0.1; **p $<$0.05; ***p $<$ 0.01.

Table 2: Mean and standard deviation of outcome variables, by treatment group and by sample

	1993-1997		2000-2007	
	Treated group	**Control group**	**Treated group**	**Control group**
Panel A				
Share of permanent grassland area	41.24	48.20	37.22	43.76
	(31.87)	(34.66)	(30.41)	(34.41)
Share of crop area	31.67	25.18	35.00	28.33
	(26.97)	(26.49)	(27.62)	(27.94)
Share of fodder area	6.15	4.69	6.19	4.89
	(8.63)	(8.01)	(7.96)	(7.81)
Specialization rate	50.52	56.32	47.97	53.49
	(31.97)	(34.32)	(31.35)	(34.60)
Loading ratio	1.68	1.42	1.73	1.47
	(3.07)	(2.76)	(4.41)	(2.96)
Panel B				
Share of utilised agricultural area	92.09	90.13	94.17	92.91
	(13.36)	(16.09)	(10.75)	(13.42)
Share of forest area	4.96	6.20	3.69	4.42
	(10.77)	(12.57)	(9.06)	(10.66)
Share of nonproductive land	1.61	2.45	1.10	1.69
	(6.22)	(8.42)	(4.32)	(6.85)
Observations	**6,827**	**3,171**	**7,243**	**3,225**

Table 3: First Stage Results

	Treatment Effect (2000-2007)
Outcome Variables	
Share of beneficiaries (%)	10.71
	(0.18)
Total subsidies (euro)	4,994.86
	(261.93)
Observations	**10,468**

Note: Year, commune and department-year fixed effects estimation. All regressions include the full set of control variables. Robust standard errors clustered at commune level in parenthesis.

Table 4: Testing the identification strategy

	(1)	(2)	(3)
Treated commune	0.075	0.103	0.078
	(0.007)	(0.007)	(0.007)
Constant	0.538	0.461	0.369
	(0.006)	(0.006)	(0.006)
Observations	10,468	10,435	10,075

Note: Estimates of the impact of the treatment at the commune level on the proportion of farmers ineligible to the program in 2000. Column (1) considers all farmers with a specialization rate below 75% in 2000 to be ineligible. Column (2) considers all farmers with a specialization rate below 75% and strictly positive in 2000 to be ineligible. Column (2) considers all farmers with a specialization rate below 75% and strictly positive in 2000 and with a loading ratio between 0.3 and 1.8 to be ineligible. Standard errors are in parenthesis.

Table 5: DID-FE Results: Panel B

	Placebo Test (1993-1997)				**Treatment Effect (2000-2007)**			
	No DEPxTIME FE		With DEPxTIME FE		No DEPxTIME FE		With DEPxTIME FE	
	No controls	With controls	No controls	With controls	No controls	With controls	No controls	With controls
Outcome Variables								
Share of utilised agricultural area	0.04	0.04	0.02	0.01	−0.19	−0.17	−0.06	−0.08
	(0.25)	(0.25)	(0.25)	(0.25)	(0.21)	(0.21)	(0.21)	(0.21)
Share of forest area	−0.34	−0.34	−0.25	−0.25	0.03	0.03	0.09	0.10
	(0.22)	(0.22)	(0.22)	(0.22)	(0.17)	(0.17)	(0.18)	(0.18)
Share of nonproductive land	0.28	0.27	0.22	0.23	0.18	0.16	−0.01	0.00
	(0.17)	(0.17)	(0.17)	(0.17)	(0.15)	(0.15)	(0.15)	(0.15)
Observations	**9,998**	**9,998**	**9,998**	**9,998**	**10,468**	**10,468**	**10,468**	**10,468**

Note: Year and commune fixed effects estimation. Robust standard errors clustered at commune level in parenthesis. *p < 0.1; **p <0.05; ***p < 0.01.

Table 6: CIC Results

	Placebo Test (1993-1997)	**Treatment Effect (2000-2007)**
Outcome Variables: Panel A		
Share of permanent grassland area	−0.12	0.28
	(0.34)	(0.32)
Share of crop area	0.29	−0.43
	(0.26)	(0.25)
Share of fodder area	0.15	0.00
	(0.12)	(0.13)
Specialization rate	0.23	0.46
	(0.28)	(0.30)
Loading ratio	−0.02	−0.01
	(0.01)	(0.01)
Outcome Variables: Panel B		
Share of utilised agricultural area	−0.09	−0.13
	(0.20)	(0.19)
Share of forest area	−0.32	0.04
	(0.18)	(0.16)
Share of nonproductive land	0.20	0.04
	(0.11)	(0.09)
Observations	**9,998**	**10,468**

Note: Changes-in-changes estimation. Regressions do not include fixed effects and control variables. Bootstrapped standard errors in parenthesis. *p $<$ 0.1; **p $<$0.05; ***p $<$ 0.01.

Table 7: DID-FE Results: Unbalanced Panel

	Placebo Test (1993-1997)				**Treatment Effect (2000-2007)**			
	No DEPxTIME FE		With DEPxTIME FE		No DEPxTIME FE		With DEPxTIME FE	
	No controls	With controls	No controls	With controls	No controls	With controls	No controls	With controls
Outcome Variables: Panel A								
Share of permanent grassland area	−0.35	−0.29	−0.08	−0.04	−0.02	0.14	0.08	0.21
	(0.35)	(0.34)	(0.36)	(0.35)	(0.27)	(0.27)	(0.28)	(0.28)
Share of crop area	0.56	0.57	0.33	0.31	−0.22	−0.23	−0.27	−0.30
	(0.24)	(0.23)	(0.25)	(0.24)	(0.20)	(0.19)	(0.21)	(0.20)
Share of fodder area	0.12	0.11	0.08	0.07	−0.01	−0.03	0.03	0.01
	(0.10)	(0.10)	(0.11)	(0.11)	(0.10)	(0.10)	(0.10)	(0.10)
Specialization rate	0.14	0.19	0.28	0.32	0.19	0.33	0.29	0.41
	(0.30)	(0.30)	(0.31)	(0.31)	(0.25)	(0.25)	(0.26)	(0.25)
Loading ratio	−0.02	−0.02	−0.02	−0.02	−0.01	−0.01	−0.00	−0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Outcome Variables: Panel B								
Share of utilised agricultural area	−0.10	−0.10	−0.13	−0.13	−0.23	−0.22	−0.06	−0.09
	(0.25)	(0.25)	(0.26)	(0.26)	(0.22)	(0.22)	(0.22)	(0.22)
Share of forest area	−0.28	−0.27	−0.22	−0.22	0.04	0.04	0.09	0.11
	(0.22)	(0.22)	(0.23)	(0.23)	(0.18)	(0.18)	(0.18)	(0.18)
Share of nonproductive land	0.29	0.29	0.26	0.27	0.20	0.19	−0.01	−0.01
	(0.17)	(0.17)	(0.17)	(0.17)	(0.16)	(0.16)	(0.16)	(0.16)
Observations	**10,599**	**10,599**	**10,599**	**10,599**	**11,463**	**11,463**	**11,463**	**11,463**

Note: Year and commune fixed effects estimation. Robust standard errors clustered at commune level in parenthesis. *p $<$ 0.1; **p $<$0.05; ***p $<$ 0.01.

Table 8: DID-FE Results: Same Sample of Communes

	Placebo Test (1993-1997)				**Treatment Effect (2000-2007)**			
	No DEPxTIME FE		With DEPxTIME FE		No DEPxTIME FE		With DEPxTIME FE	
	No controls	With controls	No controls	With controls	No controls	With controls	No controls	With controls
Outcome Variables: Panel A								
Share of permanent grassland area	0.03	0.06	0.18	0.19	0.25	0.38	0.31	0.44
	(0.39)	(0.38)	(0.40)	(0.39)	(0.32)	(0.31)	(0.32)	(0.31)
Share of crop area	0.45	0.48	0.22	0.21	−0.32	−0.31	−0.36	−0.38
	(0.28)	(0.27)	(0.29)	(0.28)	(0.23)	(0.22)	(0.24)	(0.23)
Share of fodder area	0.11	0.10	0.08	0.07	0.09	0.06	0.13	0.11
	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)
Specialization rate	0.50	0.54	0.58	0.60	0.18	0.29	0.26	0.36
	(0.34)	(0.33)	(0.34)	(0.34)	(0.30)	(0.29)	(0.30)	(0.30)
Loading ratio	−0.01	−0.01	−0.01	−0.01	0.01	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Outcome Variables: Panel B								
Share of utilised agricultural area	0.15	0.16	0.07	0.07	−0.31	−0.30	−0.23	−0.24
	(0.27)	(0.27)	(0.28)	(0.28)	(0.23)	(0.23)	(0.23)	(0.23)
Share of forest area	−0.19	−0.20	−0.09	−0.10	0.07	0.06	0.13	0.14
	(0.24)	(0.24)	(0.25)	(0.25)	(0.20)	(0.20)	(0.20)	(0.20)
Share of nonproductive land	−0.01	0.00	−0.04	−0.03	0.32	0.31	0.18	0.19
	(0.18)	(0.18)	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)
Observations	**7,808**	**7,808**	**7,808**	**7,808**	**7,808**	**7,808**	**7,808**	**7,808**

Note: Year and commune fixed effects estimation. Robust standard errors clustered at commune level in parenthesis. *p $<$ 0.1; **p $<$0.05; ***p $<$ 0.01.

Table 9: Elasticity Estimate

Outcome	ITT estimate	% change	Elasticity
Additional hectares of grassland	3.73±7.31	0.76%±1.49%	**0.02±0.04**
Additional monetary transfers (in euro)	5,000±513	42.46%±6.21%	

Note: Estimate of the elasticity of the additional supply of grassland with respect to the additional amount of the subsidy per treated communes as a result of the French Grassland Conservation reform in 2000. The confidence interval around the estimated values is given by the formula: point estimate ± value from the standard normal distribution for the selected confidence level (i.e. 1.96) x standard error of the point estimate (computed using the Delta Method).

Table 10: Cost-Benefit Analysis

Study	**Benefits**			**Costs**	**Benefit-Cost Ratio**	**Break-even SCC**
	ITT estimate (ha)	Benefits per ha (euro/ha)	Total (euro)	ITT estimate (euro)		(euro/tCO_2eq)
Chabé-Ferret and Voia						
Climate benefits only	3.73±7.31	162.54±45.51	606±1,200	5,000±513	**0.12±0.24**	198±392
All benefits	3.73±7.31	961.90±45.51	3,588±7,033	5,000±513	**0.72±1.41**	80±389
Chabé-Ferret and Subervie						
Climate benefits only	1.4±2.7	162.54±45.51	228±444	3500±513	**0.07±0.13**	369±721
All benefits	1.4±2.7	961.90±45.51	1,347±2,598	3500±513	**0.38±0.74**	251±717
Gallic and Marcus						
Climate benefits only	1.2±0.35	162.54±45.51	195±79	2622±513	**0.07±0.03**	323±145
All benefits	1.2±0.35	961.90±45.51	1,154±341	2622±513	**0.44±0.16**	205±127

Note: The costs of the Grassland Conservation Program reform compared with the social benefits at commune level. The confidence interval around the estimated values is given by the formula: point estimate ± value from the standard normal distribution for the selected confidence level (i.e. 1.96) x standard error of the point estimate (computed using the Delta Method). The literature estimates come from Arrouay et al. (2002) for the climate benefits and from Puydarrieux and Devaux (2013) for the other ecosystem services.