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Did crop diversity criterion from CAP green payments affect both economic and environmental farm performances? Quasi-experimental evidence from France

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ABSTRACT

This study aims to shed light on the impact of the crop diversity criterion of green payments on farms' economic and environmental performances, alongside land use practices. In order to provide causal evidence, we exploit the natural experiment from the 2013 Common Agricultural Policy reform, which established stronger crop diversity eligibility criteria for farmers with over 10 ha (and 30 ha) of arable land. More precisely, we use a difference-in-discontinuity design on a sample of French farms and compare those respectively above and below the two thresholds. Our findings suggest that farms around 10 ha experienced significant land reallocation and an increase in crop diversity, while farms around 30 ha increase their number of crops. Interestingly, we also found that the main effects were primarily driven by farms that already met the diversification requirements. This suggests that the crop diversity criterion did not result in much additional change.

1. Introduction

The European Union (EU), through the Common Agricultural Policy (CAP), have aimed to preserve the productive capacity of agriculture, but also the safety and quality of food and its environmental impacts (European Commission, 2010). Indeed, the latter objective is fundamental for policymakers and consumers. Therefore, many reforms have been made to better account for the environmental dimension of the agricultural production. Accordingly, The 2013 CAP reform introduced the so-called greening component to improve environmental performance of farms (European Union, 2013). The main idea is to reward farmers for provision of environmental services that are not paid by the market (European Commission, 2010; European Economic and Social Committee, 2012; European Union, 2013). Farmers receiving green payment should respect "simple, generalized, non-contractual and annual actions that go beyond cross-compliance and that are linked to agriculture, such as crop diversification, the maintenance of permanent grassland, including traditional orchards where fruit trees are grown in low density on grassland, and the establishment of ecological focus areas" (European Union, 2013, Article 37). Therefore, agricultural

practices that are beneficial for the environment and the climate are privileged.

Are green payments sufficient to induce the desired environmental changes, and what impact do they have on farmers' economic performance? This study aims to shed light on these questions. We evaluate the economic, environmental and land use consequences of green payments' crop diversity criterion in France.

The introduction of green payments has generated a substantial body of literature aimed at analyzing their effects on the environment, land use, and economic performance of farmers. The majority of existing studies on green payments are ex-ante evaluations based on simulations and mathematical programming. For instance, Solazzo et al. (2016) found that the green payment reform reduced GHG emissions by 1.5 % in Italy, primarily due to a reduction in maize and dairy cattle production, as well as a shift toward less fertilizer-demanding crops. However, Gocht et al. (2017) found a 2 % reduction in GHG emissions across Europe, but also an increase in ammonia emissions and no significant effect on nitrogen surplus. Moreover, ex-ante studies have also reported an increase in crop diversity and a decline in the share of main crops in Italy (Cortignani et al., 2017; Solazzo et al., 2016), with the latter study

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also showing a limited impact on land use, with a reduction in maize acreage. Furthermore, there is an ongoing debate about the economic impact of the reform. Cortignani et al. (2017) found a reduction in gross margins in Italy due to the convergence criteria and a negative effect on income attributable to coupled payments. Louhichi et al. (2017, 2018) also reported similar effects at the European and Member State level. However, Gocht et al. (2017) found a positive effect on income in the EU, driven by price changes after the reform.

Recently, ex-post studies such as those conducted by Sauquet (2022) and Varacca et al. (2023) have provided complementary insights into the effects of green payments. The former study found that the crop diversity criterion led to an increase in the number of crops grown and a reduction in the share of the two main crops for French farms above 30 ha. The latter study found an increase in the share of leguminous crops, but no significant effects on other environmental indicators or economic performance.

Our study contributes to this ex-post literature on green payments. However, it differs from existing studies in four key aspects. First, this is the first paper, to the best of our knowledge, to analyze the crop diversity criterion effect on technical efficiency (TE) and environmental efficiency (EE) of farms. The impact of Agri-environmental Schemes (AES) on economic and environmental performance has received considerable attention (Arata and Sckokai, 2016; Ait Sidhoum et al., 2023a, 2023b; Baráth et al., 2024). However, none of these studies have analyzed the effect of green payments on crop diversity and their impact on both technical efficiency (TE) and environmental efficiency (EE). Analyzing its effects on both TE and EE is crucial. Indeed, one of the main objectives of the CAP since its inception is to improve agricultural productivity but also the optimal use of production factors (Massot, 2016). TE is recognized as an indicator of competitiveness, but also of productivity and efficiency as it allows measuring the maximum level of production attainable with the minimum level of inputs (Latruffe, 2010). The reform effect on EE is also insightful, as one of the main objectives of green payments is to enhance environmental performance (European Court of Auditors, 2017; European Union, 2013). Studying the effect of the crop diversity criterion on both TE and EE is therefore crucial, as it might bring clarity to the dual objective of recent CAP reforms: promoting agricultural productivity while enhancing environmental performances of farms. Second, this is one of the first attempts to evaluate causal effect of the reform with causal inference methods, with Sauquet (2022) and Varacca et al. (2023) being the exception. Most of the existing literature use simulation based on mathematical programming (Solazzo et al., 2016; Solazzo and Pierangeli, 2016; Gocht et al., 2017; Cortignani et al., 2017; Louhichi et al., 2017, 2018), Markov chain model (Bertoni et al., 2018, 2021) or panel data model (Olagunju et al., 2022). By exploiting the natural experimental setting of the reform, we are able to provide causal effect on the diversification measure. Third, it is the first study to offer a broad view of the green payments' crop diversity criterion effect on three dimensions in France: economic, environmental, and land use. Varacca et al. (2023) offered such a broad view, but their study focused on the EFA criterion and Cortignani et al. (2017) evaluated the entire reform. Some other papers have studied only one (Solazzo et al., 2016; Bertoni et al., 2021; Sauquet, 2022) or two dimensions (Solazzo et al., 2016; Gocht et al., 2017; Louhichi et al., 2017, 2018). Fourth, we go beyond the overall effect by simulating the crop diversity effect on farms that did not comply with requirements before the reform, labeled as "noncompliers". This allows us to know the additionality of the measure, *i.e.*, what would have been the potential effect of this criterion if it was only focused on farms that need to change their agricultural practices.

The rest of this paper is organized as follows. Section 2 presents the core of the 2013 CAP reform and the literature review. The methodology is described in section 3 followed by the description of the data used in the section 4. The section 5 discusses the results of our analysis, section 6 evaluates the robustness of our findings, and section 8 concludes.

2. Background and literature review

2.1. CAP green payments reform

There has been raising concerns about the environmental impact of agricultural practices from the European taxpayers and consumers (European Economic and Social Committee, 2012; Erjavec and Erjavec, 2015). Indeed, fierce societal criticism has emerged on the CAP, especially the first pillar, concerning the environment and food (Erjavec and Erjavec, 2015). Public interventions have been aiming to address these concerns with CAP reforms. The 2013 CAP reform intended to provide a clear switch in the objectives of European agricultural policies (Louhichi et al., 2018).

Traditionally, the first pillar of the Common Agricultural Policy (CAP) consisted of a financial incentive scheme called the Single Payment Scheme (SPS), which aimed to support farm income and market measures (Lécuyer et al., 2021). However, the 2013 CAP reform ended the SPS and replaced it with different payments, such as coupled payments and green payments (Cortignani et al., 2017). This new payment structure was called the Basic Payment Scheme (BPS) (European Union, 2013). Additionally, convergence mechanisms were put in place to redistribute direct support. Specifically, farms with entitlements higher than the national average faced reductions in their payments, that were, in turn, redistributed to farms with entitlements below the average (European Union, 2013; Solazzo et al., 2016).

One of the main stated objectives of the new CAP 2014–2020 was to improve the environmental performances of farms by introducing a 'greening' component (European Union, 2013). Greening payments are part of direct payments from the CAP first pillar. They aim to support provisions of environmental benefit from agricultural practices (European Union, 2013). European Economic and Social Committee (2012) justifies these supports as market returns compensation for provision of environmental services. Therefore, there is a clear inclusion of positive externalities generated on farms (European Court of Auditors, 2017). The objective is to reward farms that meet three criteria beneficial for the environment: (i) crop diversification, (ii) ecological focus areas, and (iii) maintenance of permanent grassland (European Union, 2013). The retribution concerns 30 % of the direct payment (Louhichi et al., 2018).

The crop diversification criterion implies to increase the number of crops on the farm. Farms with arable land lower than 10 ha are exempted from the measure. If farm's arable land ranges from 10 ha to 30 ha, it should have at least two crops in the diversification, and the main crop share should not exceed 75 % (Louhichi et al., 2017; European Court of Auditors, 2017). If the arable land is higher than 30 ha, farms should have at least three crops. Moreover, the share of the main crop share should not exceed 75 %, and the two main crop share should not be higher than 95 % (European Court of Auditors, 2017). Other exemptions have been made, especially farms already applying environmental beneficial practices such as organic farms (European Union, 2013; Massot, 2016). Farms with grassland covering more than 75 % of the total eligible land or farms with forage representing 75 % of cultivated arable area are also out of the scope of the measure (Louhichi et al., 2018). The environmental benefit sought here is mainly the improvement of soil quality (European Economic and Social Committee, 2012). Indeed, intercrops (cultivating two or more crops) may increase the biological nitrogen fixation (legumes for instance) and therefore improve the soil fertility. Moreover, it can ameliorate soil conservation and canopy structure (Lithourgidis et al., 2011).

The ecological focus area (EFA) component exacts farms with arable land higher than 15 ha to dedicate no less than 5 % of it to EFA (European Union, 2013; European Court of Auditors, 2017; Cortignani et al., 2017). This measure aims to improve biodiversity (European Union, 2013), and therefore targets areas directly related to it, such as buffer strips, fallow land, nitrogen-fixing crops, *etc.* (Cortignani et al., 2017; European Union, 2013).

The maintenance of permanent grassland entails that the ratio of grassland/total agricultural area should not be any lower of 5 % than the reference ratio (before greening)¹ (European Union, 2013). If the ratio is worsened by 5 %, the grassland conversion will be forbidden. In France, a derogatory ratio of 2.5 % is made as a warning signal (MAAF, 2021), meaning that when the ratio is worsened by 2.5 % or more, an administrative authorization should be issued to allow further conversions (MAAF, 2021).

The reform came into force in 2014 (European Union, 2013). Therefore, the first payments have been received in 2015 following entitlements of 2014. The next section presents country-specific or EU-wide studies on the potential effects of greening, but also studies of crop diversity effect on productivity and production.

2.2. A short review on the effect of 2013 CAP reform

The effects of the 2013 CAP reform on land use, farm production, income, and the environment have been analyzed in several studies. One such study is the one by Cortignani et al. (2017), who evaluated the potential impact of the overall reform of the first pillar, including the greening component, on land use, environmental indicators, and economic results in three regions of Italy (Lombardia, Marche, and Puglia). They used a Positive Mathematical Programming (PMP) model with two scenarios: (i) the entire reform, and (ii) only greening. Using Farm Accountancy Data Network (FADN) for the 2013 period, their results suggested that the whole reform of the CAP has changed farms' land use aspect. They found a reduction of the main crop in all three regions attributed to a substitution made by farmers, who introduced new crops to fulfill the greening obligation by reducing the main crop area. However, this effect is mainly driven by the coupled payment and less by the greening scheme of the reform. When the greening scenario is only considered, the main crop area reduction is much lower (1/3 of the total reduction). The effect of the greening, *per se*, is either lower than the entire reform or in contradiction to the effect of the reform.

Louhichi et al. (2018) also observed similar patterns when studying the farm-level impacts of greening measures using the Individual Farm Model for Common Agricultural Policy Analysis (IFM-CAP), an EU-wide individual farm-level model. The IFM-CAP is applied with three scenarios: (i) the same support as the greening criterion until 2025; (ii) an inflation rate of 1.9 for input costs, and (iii) adjustment of baseline prices and yields with growth rates. Their results highlighted a relocation of land in EU-27 due to greening measures, where 4.5 % of the total area is relocated. This effect is mainly driven by the Ecological Focus Area (EFA) criterion (2.4 %), while crop diversification and grassland criteria play a secondary role (respectively 1.8 % and 1.5 %). However, the effects are heterogeneous within Member States (MS), with greening measures being more or less important for different countries for area relocation. Similarly, in their ex-post analysis with regression discontinuity design, Varacca et al. (2023) found that the EFA criterion has induced an increase in the leguminous crop area in Italy. Above the EFA criterion, the crop diversity one has also been found to change agricultural practices. Indeed, Sauquet (2022), with an ex-post evaluation based on the difference-in-discontinuity method, found that more than one in eight French farms around 30 ha was able to add a crop.

In addition to the land-use effects, policymakers also sought positive environmental outcomes from the 2013 CAP reform. To this end, Gocht et al. (2017) conducted an analysis of the potential environmental impacts of CAP greening using simulations with CAPRI models. They evaluated five scenarios: (i) no greening reform; (ii) greening; (iii) crop diversification only applied; (iv) EFA only applied, and (v) Permanent grassland only applied. Using data from FSS in 2007 and FADN for the

2007–2009 period at NUTS-2 levels for EU-28, EU-15 and EU-13, their results showed a reduction of GHG emissions of 0.2 %, a positive effect on ammonia emissions, but no significant effect on nitrogen surplus. Similarly, Cortignani et al. (2017) found that new crops introduced affected crop diversification on the farm with an increase of the Shannon Index. This is accompanied by a reduction in nitrogen use. As the main crops (durum wheat and maize) require a large amount of nitrogen, a reduction in the main crop area resulted in a decrease of nitrogen use.

Assessing the economic impact of green payments on farms can offer valuable insights, as these payments are intended to cover the cost of producing environmental goods. In their study, Gocht et al. (2017) found a positive effect on income but a reduction of the production level. This result can be explained by the fact that the reform induced an increase in the output price. As some lands are taken out due to compliance, as shown by Olagunju et al. (2022), there is a reduction of output supply which affects the agricultural goods prices. Even though there is a negative production effect, the price effect outweighed it, resulting in an increase of farm incomes. However, Cortignani et al. (2017) found a reduction of gross margins, although not related to the 2013 CAP reform *per se*. This reduction was mainly due to the convergence aspect within and between states. Therefore, based on their results, the green payment did not influence economic activities of farms.

Louhichi et al. (2017) assessed the consequences of crop diversification measure at farm level using IFM-CAP. Using individual FADN data combined with FSS between 2007 and 2009, their results highlight a decline in the overall production change at EU-27 levels (0.4 %) caused by the crop diversification measure of the greening with a variation between crops is observed, ranging from -1.5 % to 0.11 %. However, as opposed to Gocht et al. (2017), a small decrease of income level is also observed at EU level (maximum -0.35 % in Finland). But more important effect on income is observed by farm specialization and farm size. The results of Louhichi et al. (2018) showed a decline of the total production of 0.9 % at EU level. This decline is mainly attributable to the land reallocation. At Member States (MS) level, there is a variation from 0 to -4.5 %. The production change is higher for more specialized crop, but also for small and larger farms. However, the part of greening measure in the income decline is rather a small (1 %) at EU-level. Finally, Varacca et al. (2023) found no significant effect of the EFA criterion on economic conditions of Italian farms. In summary, while the 2013 CAP reform might have led to a decline in production levels, the impact on farm income is still debated.

Our study focuses exclusively on the crop diversification effect, making it comparable to studies conducted by Louhichi et al. (2017) and Sauquet (2022). However, we differentiate ourselves by analyzing the impact of the crop diversity criterion on the economic and land use dimensions, in addition to the environmental dimension. Moreover, we introduce TE as a measure of productivity to capture the technical capacity and productivity change resulting from crop diversification requirements. TE is widely recognized as a good proxy for measuring farms' competitiveness and productivity (Latruffe, 2010). Lastly, we examine the potential deadweight effect of the crop diversity criterion. In the next section, we will delve into the relationship between crop diversification and crop production, productivity, and input usage.

2.3. How crop diversification impact production and productivity?

In the era of mechanization and modernization of agriculture, agricultural system has been simplified, causing heavy dependence on pesticides and fertilizers, and preference of monoculture (Lithourgidis et al., 2011). These agricultural practices implied biodiversity degradation and environmental concerns (Tamburini et al., 2020). An appropriate management of agricultural systems and crops is sought to solve many of the negative impact on the environment (Power, 2010). Crop diversity, as underlined by Bommarco et al. (2013), can be a key element of crop management intended to reduce negative effect while preserving crop yields. It can increase the efficiency use of inputs and resources at farm

¹ European Union (2013) highlights that Member States (MS) should choose at which territorial level to apply the ratio. In France, the ratio is applied at the regional level (MAAF, 2021).

level *via* complementary of crops (Bommarco et al., 2013; Di Falco et al., 2010), but also constitute a buffer against weeds, diseases and pests (Lechenet et al., 2014).

Studies in France have documented a potential increase in production and yields due to crop diversification. Bareille and Letort (2018) showed that crop diversity increases yields of winter barley and wheat. Similar results have been found by Donfouet et al. (2017) who highlighted positive and significant influence of crop diversity on major crop production. These effects are even more prominent in case of low rainfalls.

Crop diversity has been also identified as a key strategy to reduce price and production risk. Di Falco and Chavas (2009) showed that biodiversity reduces the effect on risk, especially when land is degraded in Ethiopia. Indeed, multiple crop allow farmers to sell their products many times per year. Moreover, as shown also by Donfouet et al. (2017), it can also enhance the agricultural production, especially when rainfall is low. This latter result is confirmed in Italy (Di Falco and Chavas, 2008) and in Ethiopia (Di Falco and Chavas, 2009; Di Falco et al., 2010).

However, the positive effect of crop diversity on production and productivity seems not to be unanimous. Zeng et al. (2020) found an inverted U-shaped effect on crop diversification on agricultural output in China. The effect is even negative for lower and median quartiles of the distribution. Moreover, when it comes to greening crop diversification effect on productivity and income, studies mainly converge toward a reduction of income (Louhichi et al., 2017; Cortignani et al., 2017; Solazzo and Pierangeli, 2016). One exception is the study of Gocht et al. (2017) which found positive effect on income, although a negative effect on production was highlighted.

Our study will evaluate the crop diversity effect on, among others, TE and EE, which are our proxies for economic and environmental productivity. Crop diversity can modify these two outcomes *via* input use, *i. e.*, modification of input quantity and requirement that depend on each crop, or *via* the output level, *i. e.*, different levels of production following the introduction of a new crop. Our estimation strategy will be altogether different from existing studies relying on production function (Di Falco et al., 2010), production function with spatial effect (Donfouet et al., 2017), simulations based on mathematical programming (Solazzo and Pierangeli, 2016; Louhichi et al., 2017; Mahy et al., 2015) or a dynamic acreage model (Bareille and Letort, 2018). The next section presents our empirical strategy.

3. Econometric strategy

The existing literature on greening effects has mainly used simulations based on mathematical programming to assess green payment effects (Gocht et al., 2017; Cortignani et al., 2017; Louhichi et al., 2017). These models are more of an ex-ante methods based on different scenarios. However, our studies rely on ex-post identification strategy. Indeed, we take advantage of the policy design to use a quasi-experimental identification strategy, namely the difference-in-discontinuity, to identify the causal impact of the crop diversity criterion.

The 2013 CAP reform creates a discontinuity around 10 ha and 30 ha that did not exist before 2013.² It acts as a natural experiment, as it is an exogenous variation of the variable (arable land in our case) determining the treatment assignment (Meyer, 1995). Exploiting this setting will allow us to evaluate the causal effect of crop diversity criterion.

² The two thresholds were set by the European Commission during the implementation of the green payments and the CAP reform in 2013.

Thus, we can compare green payment receivers just below and just above the two thresholds.³ Data at hand allow us to identify farms which received green payments each year. We can also identify farms that respect or not the crop diversity criterion, with data on arable land and main crop share. Therefore, our analysis will be focusing on this precise criterion.⁴

We can think of a Regression Discontinuity Design (RDD hereafter) as a natural candidate to identify a causal effect of green payment. Indeed, the greening component of 2013 CAP reform implies different requirements for farmers that are respectively above and below 10 ha and 30 ha of arable land. The conditions for the crop diversity criterion are designed to be increasingly harder with arable land area. Farms above 10 ha have stronger requirements than farms below, same as for farms above 30 ha compared to the one below. Therefore, by comparing farms just below and above thresholds, which are more likely to have similar characteristics, we might be able to evaluate the impact of the crop diversity criterion. Hence, the RDD could be well suited for this case.

However, RDD relies on the continuity assumption meaning that the treatment should be the only source of discontinuity around the thresholds. Since we assume that farms just above cut-offs are similar to farms just below before the treatment, the expected outcomes of the two groups are considered to be the same before treatment (Hahn et al., 2001). To test this assumption, we estimated a RDD in 2012 and 2013 (before the introduction of green payment) on our main outcomes: for the RDD to be valid, there should be no effect on the outcomes (Tables A1 to A9 present the results of these estimations). We can observe a significant difference in terms of outcomes in either one or both year (2012 and 2013), which means that there are unobserved characteristics that differentiate treatment and control groups. These results highlight a threat in the identification strategy if we rely on cross-sectional RDD.

To overcome this issue, we will take advantage of the longitudinal dimension of our database. Indeed, we have data before the CAP reform. This helps us overcome the confounding effect from other sources of discontinuity by combining the Before/After setting with the RDD. This approach has been called the Difference-in-Discontinuity (DD hereafter) (Grembi et al., 2016).

The basic idea of the RDD is to evaluate treatment effect by comparing observations just above and below a known cut-off point (here 10 ha and 30 ha, respectively, of arable land). Indeed, in RDD setting, the assignment to the treatment or control group is determined whether the value of the forcing variable (here the arable land area) is greater than the known cut-off (Lee and Lemieux, 2010). Therefore, the known cut-off creates a discontinuity in terms of probability to be treated or not (Imbens and Wooldridge, 2009). This setup is combined with traditional difference-in-difference methodology. Following Angrist and Pischke (2009), we estimate a diff-in-diff model with ordinary least squared-fixed effects (OLSFE):

$$Y_{it} = \alpha + \beta_1 I[AA_{it} > \bar{X}] \times Post_{2015} + \gamma_t + \mu_i + \epsilon_{it} \quad (1)$$

where Y_{it} is the outcome of interest presented in Table 4, \bar{X} represent the thresholds 10 ha and 30 ha, $I[AA_{it} > \bar{X}]$ is the dummy variable which equals 1 if farm arable land is higher than \bar{X} , $Post_{2015}$ is a dummy

³ We only select farms that receive green payments. Comparing receivers and not receivers of green payments around the cut-off might generate a bias. Indeed, every farm can, in principle, receive the green payments by complying with requirements. Therefore, the CAP reform did not create any “non-receivers” category *per se*.

⁴ The EFA and permanent grassland criteria are hard to measure. Indeed, there is limited data on core elements of the EFA criterion in the FADN database and the maintenance of a permanent grassland criterion is measured at regional level. This impedes the evaluation of the entire green payment system.

variable which equals 1 after the CAP reform, γ_t and μ_i are respectively, time and individuals farms dummies. Finally, ϵ_{it} represents our random error term.

The before/after setting allows removing confounding effects, based on the assumption that the effect of confounding factors are constant over time in the absence of the treatment (Grembi et al., 2016). This assumption can be tested by verifying the local parallel trend for farms just below and above thresholds, had the CAP reform did not take place. We test the local parallel trend as in Sauquet (2022). The results are presented in Table B39 for farms around 10 ha, and Table B40 for those around 30 ha. For farmers around 10 ha, we can see that the absence of a parallel trend can be rejected for all outcomes except from the Shannon Index and the number of crops. For farms around 30 ha, the absence of a parallel trend can also be rejected for all outcomes except from the gross margins per non-workers. Therefore, the results for the above-mentioned outcome should be taken with caution.

Moreover, we also check if there is a balance in covariates between treatment and control groups. Farms between 0 ha and 10 constitute the control group, and farms between 10 and 20 ha are in the treatment group for the 10 ha threshold. Likewise, farms between 20 ha and 30 ha constitute the control group, and farms between 30 and 40 ha are in the treatment group for the 30 ha threshold. The results of this procedure are documented in Table 1 and Table 2.

The normalized mean difference is lower than 0.25 for all variables as in Sauquet (2022). This suggests that there is a balance of covariates between groups and increase the plausibility of our comparison (Stuart, 2010).

A manipulation test can also help check the plausibility of the confounding assumption (McCrary, 2008). Indeed, farms just above the threshold can be reluctant to comply with requirements. Therefore, they might reduce (manipulate) their arable land stated when they are

Table 1
Covariate Balance in RDD for farmers around 10 ha of arable land.

Variables	Below 10 ha		Above 10 ha		Normalized Mean Difference
	N	Mean/ SE	N	Mean/ SE	
Household head age	1075	44.860 [0.247]	649	44.145 [0.326]	0.087
Household head education	1075	1.286 [0.014]	649	1.253 [0.017]	0.074
1 if quality sign is present	1075	0.473 [0.015]	649	0.527 [0.020]	-0.107
Household head experience	1075	18.717 [0.266]	649	18.357 [0.353]	0.041
Number of shareholders	1075	0.710 [0.032]	649	0.673 [0.040]	0.035
Number of farms head and co-head	1075	1.303 [0.018]	649	1.293 [0.022]	0.018
Inheritance	1075	6.353 [0.117]	649	6.248 [0.153]	0.027
1 if activity is diversified	1075	0.148 [0.011]	649	0.151 [0.014]	-0.009
Total paid working labor	1075	101.163 [12.520]	649	110.362 [18.875]	-0.021
1 if farms received young farm aid	1075	0.730 [0.014]	649	0.750 [0.017]	-0.046
Irrigated UUA	1066	0.028 [0.004]	647	0.028 [0.005]	0.001

Note: Standard errors are robust. This table is based on the Agricultural Census data in 2010. It concerned farms both present in this census and in the FADN dataset.

Table 2
Covariate Balance in RDD for farmers around 30 ha of arable land.

Variables	Below 10 ha		Above 10 ha		Normalized Mean Difference
	N	Mean/ SE	N	Mean/ SE	
Household head age	781	43.570 [0.272]	964	44.919 [0.253]	-0.174
Household head education	781	1.264 [0.016]	964	1.214 [0.013]	0.118
1 if quality sign is present	781	0.462 [0.018]	964	0.516 [0.016]	-0.107
Household head experience	781	17.292 [0.293]	964	17.642 [0.277]	-0.042
Number of shareholders	781	0.804 [0.040]	964	0.678 [0.031]	0.120
Number of farms head and co-head	781	1.356 [0.025]	964	1.262 [0.018]	0.149
Inheritance	781	6.668 [0.130]	964	6.709 [0.117]	-0.011
1 if activity is diversified	781	0.102 [0.011]	964	0.088 [0.009]	0.049
Total paid working labor	781	94.270 [9.701]	964	127.853 [14.643]	-0.088
1 if farms received young farm aid	781	0.745 [0.016]	964	0.782 [0.013]	-0.087
Irrigated UUA	781	0.042 [0.006]	964	0.030 [0.004]	0.091

Note: Standard errors are robust. This table is based on the Agricultural Census data in 2010. It concerned farms both present in this census and in the FADN dataset.

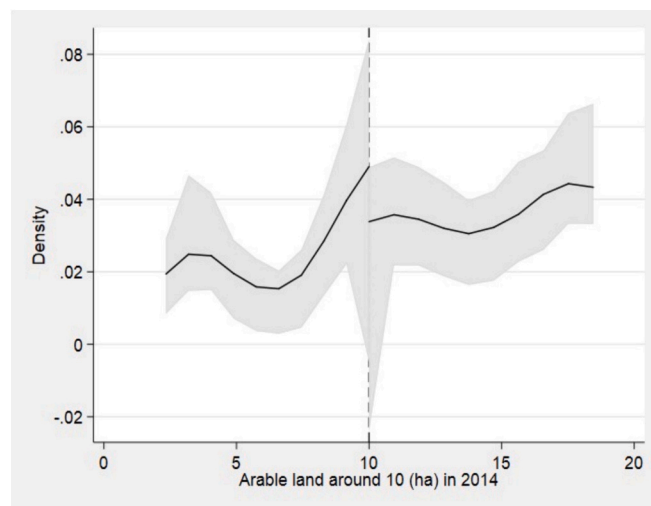


Fig. 1. Manipulation test around 10 ha of arable land in 2014.

surveyed. This will, in turn, reduce the number of farms affected by the policy. In order to verify the threshold manipulation problem, we follow Cattaneo et al. (2020) by estimating density of arable land around 10 ha and 30. The idea is to test whether the densities are continuous around the two thresholds (McCrary, 2008). Fig. 1 and Fig. 2 display, respectively, the density around 10 ha and 30 ha in 2014.

The alternative hypothesis, stating that there is a discontinuity in

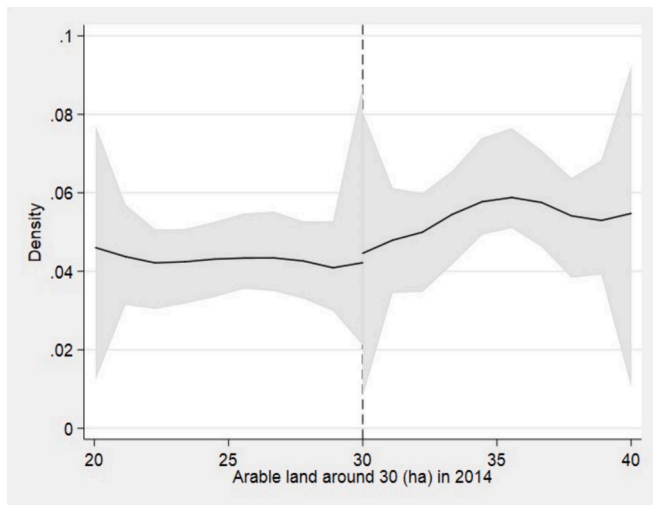


Fig. 2. Manipulation test around 30 ha of arable land in 2014.

densities around the thresholds, is rejected in both cases.⁵ Therefore, these results give credits to our identification strategy. The following section outlines the methodology used to construct our sample.

4. Data

4.1. Data description

In this study, we use the French FADN data, which provides detailed statistical information on farm characteristics and income on an annual basis. It is an unbalanced panel, with around 10 % of the sample being yearly renewed, resulting in farms being observed once or multiple successive years (Piet et al., 2020). The FADN categorizes farms according to their location at a regional level (NUTS2), their type of farms (TF), and their economic dimension (standard gross production). The FADN focuses on commercial farms, excluding economically small farms where farmers have less than 25,000 euros of Standard Gross Production. The total number of farms surveyed ranges from 7000 to 7500 per year, and the data are representative of French commercial farms. It also includes the subsidies received through the CAP 1st pillar, allowing us to identify specifically those who receive green payments, i.e., the compliers with the greening requirements of the 2013 CAP reform. Additionally, we rely on the Agricultural Census of 2010 to have pre-treatment covariates. The two databases are merged by an identification system number (SIRET-Système d'Identification du Répertoire des Etablissements).

Our sample consists of green payment receivers, excluding organic farmers. The latter are excluded because they are exempted from the crop diversity requirement, and therefore, there is no additionality in terms of agricultural practices related to the green payment crop diversity criterion. Data from 2012 to 2016 are used for the analysis and cover metropolitan France. This period allows us to conduct a before-after comparison of the reform that took place in 2013. The final database is a pooled sample of 15,171 farms. Descriptive statistics for our sample are presented in Table 3.

The average amount of green subsidies received by farms in our sample from 2015 to 2016 was 2485 euros. We also observed that farms in our sample tend to be large in terms of both arable land and Utilized Agricultural Area (UAA), with averages surpassing the crop diversity thresholds. The average number of crops (4), the main crop share (0.48),

⁵ The test has also been done in 2015 as in Sauquet (2022), and are presented in Fig. C1 and Fig. C2. The presence of density discontinuity is still rejected.

Table 3
Descriptive Statistics from 2013 to 2016.

Variable	Obs	Mean	Std. Dev.	Min	Max
Arable land	15,171	97.245	78.38	0	718.65
UAA	15,171	130.036	82.506	0	833.94
Gross production	15,171	218,783.62	215,308.77	302	4,027,001
Green payment	15,171	2483.963	1588.825	3.25	15,282
Shannon Index	15,171	0.584	0.327	0	1.061
Crop protection Index	15,165	0.976	0.882	0	15.855
Fertilizer Index	15,165	1.061	0.635	0	13.996
Environmental Efficiency	15,171	0.72	0.135	0.153	0.991
Technical Efficiency	15,171	0.702	0.144	0.107	0.99
Operating Surplus	15,171	571.802	607.219	-5491	1894
Income before tax per unpaid workers	15,171	235.39	490.405	-8567	16,829
Main crop share	15,171	0.484	0.213	0	1
Two Main crop share	15,171	0.699	0.229	0	1
Number of crops	15,171	4.123	1.995	0	16

and the two main crop share (0.69) meet the requirements of the crop diversity criterion. On average, farms in our sample perform relatively well in terms of the environment, as indicated by the crop protection index, the fertilizer index, and the environmental efficiency, although there may be room for improvement. Specifically, farms could reduce their detrimental inputs (crop protection, fertilizer, gas) by an average of 28 % (1-0.72) without compromising their level of production.

Table D41 highlights differences between farms with around 10 ha of arable land (between 0 ha and 20 ha) and farms with around 30 ha of arable land (between 20 ha and 40 ha). Interestingly, farms with less than 10 ha of arable land received, on average, more subsidies than farms with more than 10 ha of arable land and farms with more than 30 ha of arable land. This may be due to exemptions that come with the reform, particularly the crop diversity criterion. Additionally, farms with less than 10 ha of arable land tend to be more efficient both economically and environmentally. Another noteworthy feature is the share of the main crop and the share of the two main crops. For all groups, the share of the main crop is lower than 75 %, which is the criterion of the greening component of the CAP, and the share of the two main crops is also lower than 95 %. The next section will detail the construction of our outcome variable.

4.2. Outcome of interest

In this study we are interested in the economic, environmental and land use effects of the greening crop diversity criterion. We have multiple outcomes for each of these dimensions. Table 4 presents the definition of outcome variable used and the computation methods.

Technical efficiency (TE) and environmental efficiency (EE) indicators are computed following Reinhard et al. (1999, 2002). This method is based on Stochastic Frontier Analysis (SFA) with a production function linking the output produced with inputs used (Battese, 1992). The stochastic production frontier can be written as follows (Reinhard et al., 1999):

$$Y_{it} = f(X_{it}; Z_{it}; \beta) \cdot \exp\{V_{it} - U_{it}\}. \tag{2}$$

A functional form can be specified via a translog function à la Christensen et al. (1973), which gives us the following expression:

$$\ln Y_{it} = \beta_0 + \sum_{j=1}^n \beta_j \ln X_{kit} + \beta_a \ln Z_{it} + \frac{1}{2} \sum_{j=1}^n \sum_{k=1}^n \beta_{jk} \ln X_{jit} * \ln X_{ijk}$$

Table 4
Definition and computation details of outcome variable.

Dimension	Description	Details
Environment	Shannon Index	Shannon Index is computed as follows: $eveness = -\sum_{i=1}^n p_i \ln p_i$ where p_i is the proportion of n_i crop over $i=N$. The lower limit is 0 meaning the total number of crops that there is no diversity in the farm.
	Environmental Efficiency	The Environmental Efficiency is derived from the computation of Technical Efficiency (TE) based on Reinhard et al. (1999) formula. The environmental detrimental input used is the expenses in fertilizers, crop protection and energy.
	Fertilizer use ratio	We compute first fertilizer consumption by deducing inventory change to the fertilizers expenses. Then, we divide this by the UAA to obtain the consumption per ha of the farm. The latter is now compared to the average consumption per ha of the farms' TF. If the ratio is greater than 1, then the farm is using more fertilizer per ha than the average of it peers, suggesting more devastating impact compared to its peers. Midler et al. (2019), Kirsch (2017) and Varacca et al. (2023) used approximately the same method, but they did not divide it by the average of the TF, and Diop et al. (2024) used the same methodology in the case of Agrienvironmental Schemes.
Economic	Crop protection use ratio	Same as the fertilizer use ratio.
	Technical Efficiency (TE)	TE is computed with stochastic frontier analysis (SFA) following Reinhard et al. (1999). We choose a translog (Christensen et al., 1971, 1973) specification over a Cobb-Douglas because of its flexibility (Corbo and Meller, 1979). The agricultural production is the output. Four inputs are chosen: the Utilized Agricultural Area (UAA), the number of Agricultural Working Unit, the fixed assets and the intermediate consumption.
	Operating Surplus per unpaid workers	It is the ratio between operating surplus and unpaid workers. The unpaid workers in the French FADN are the associate of the farm head. Therefore, It is divided by the unpaid workers to account for the real profitability of the farm when the associates are not considered (Piet and Desjeux, 2021).
	Income before tax per unpaid workers	The ratio between income before tax and unpaid workers.
Land Use	Main crop share	The French FADN gives us the area dedicated to each crop. Therefore, we divide each area by the UAA and then derive the main crop share as the maximum.
	Two main crop share	Same procedure as the main crop share, except here it is the share of the two main crop.
	Number of crop	Number of crops cultivated by the farm.

$$\begin{aligned}
 & + \sum_{j=1}^n \beta_{jz} \ln X_{ijt} * \ln Z_{it} \\
 & + \frac{1}{2} \beta_{zz} (\ln Z_{it})^2 \\
 & + \beta_t T + \frac{1}{2} \beta_{tt} T^2 + \sum_{i=1}^n \beta_{it} T * \ln X_{it} + \beta_{it} T * \ln Z_{it} \\
 & + V_{it} - U_i
 \end{aligned} \tag{3}$$

where

- i is for farm, t the year, j and k are the subscripts for classical inputs, z represents the environmental input. The subscript is doubled (*i.e.* zz) when the input is squared;
- Y_{it} is the level of production⁶ for farm i at time t ;
- X_{it} is a vector of conventional inputs, and n the total conventional inputs. The inputs variables are: fixed assets, Utilized Agricultural Area, Agricultural Working Unit⁸ (AWU) and Intermediary Consumption⁸;
- Z_{it} is a environmental detrimental input. It is represented by the sum of expenses in crop protection, fertilizers and energy consumption (electricity, gas, etc);
- β is a vector of technology parameters;
- V_{it} is the random error terms measuring the effects of statistical noise and is assumed to be independently and identically distributed (i.i.d) of $N(0, \sigma_v^2)$ distribution;

⁶ The sum of basic gross products (animals, animal products, crops, crop products, horticultural products) and products from immobilized production, contract work, the sale of residual products, animal boarding, land leased ready to sow, other rentals, agritourism, and products from ancillary activities.

⁷ The output variable is adjusted for inflation using the price indices of agricultural products (base year 2010). The price indices are obtained from The National Institute of Statistics and Economic Studies (INSEE). Each input has a specific index, which is used to adjust the corresponding variable for inflation. Moreover, the output does not account for the green payments or other subsidies. ⁸One unit of AWU amounts to 1600 h.

⁸ We deduce the energy, fertilizer and crop protection expenses as it is included in the intermediary consumption in the French FADN database.

- U_i is the non-negative random error term which measures the inefficiency. It is assumed to be i.i.d. of $N+(\mu, \sigma_u^2)$;
- T are time dummies that account for technological change over year.

From Eq. (3), a technical efficient farm will have $U_{it} = 0$, meaning that he operates on the frontier. From here, the environmental efficiency (EE) can be derived. EE is expressed here as the ratio of minimum feasible quantity of the detrimental input, *i.e.* Z_{it}^F to actual quantity used by the farm Z_{it} ($EE = Z_{it}^F / Z_{it}$) (Reinhard et al., 1999). Therefore, EE is the ability of farm to reach the minimum of crop protection and fertilizer expenses given the level of output. Reinhard et al. (1999) uses a non-radial notion, meaning that it is a single factor measure of farm efficiency in the use of detrimental input. The logarithm of an environmental efficient producer is obtained by replacing $U_i = 0$ and $Z_{it} = Z_{it}^F$ with Z_{it}^F the minimal feasible environmentally detrimental input. It gives us the following translog form:

$$\begin{aligned}
 \ln Y_{it} &= \beta_0 \\
 & + \sum_{j=1}^n \beta_j \ln X_{kit} + \beta_z \ln Z_{it}^F \\
 & + \frac{1}{2} \sum_{j=1}^n \sum_{k=1}^n \beta_{jk} \ln X_{ijt} * \ln X_{ijk} \\
 & + \sum_{j=1}^n \beta_{jz} \ln X_{ijt} * \ln Z_{it}^F \\
 & + \frac{1}{2} \beta_{zz} (\ln Z_{it}^F)^2 \\
 & + \beta_t T + \frac{1}{2} \beta_{tt} T^2 + \sum_{i=1}^n \beta_{it} T * \ln X_{it} + \beta_{it} T * \ln Z_{it} \\
 & + V_{it}
 \end{aligned} \tag{4}$$

The EE can be deduced by setting eqs. (3) = (4), which gives us:

$$\begin{aligned}
 & \frac{1}{2} \beta_{zz} (\ln Z_{it}^F - \ln Z_{it})^2 + (\ln Z_{it}^F - \ln Z_{it}) \left[\beta_z + \sum_{j=1}^m \beta_{jz} \ln X_{ijt} + \beta_{zz} \ln Z_{it} \right] + U_{i,t} \\
 & = 0
 \end{aligned} \tag{5}$$

with $\ln EE = \ln Z_{it}^E - \ln Z_{it}$.

The resolution of Eq. 5 allows us to obtain the final expression of the EE:

$$\ln EE_{i,t} = \left[- \left(\beta_z + \sum_{j=1}^m \beta_{jz} \ln X_{ij,t} + \beta_{zz} \ln Z_{i,t} \right) \pm \left\{ \left(\beta_z + \sum_{j=1}^m \beta_{jz} \ln X_{ij,t} + \beta_{zz} \ln Z_{i,t} \right)^2 - 2\beta_{zz} U_{i,t} \right\}^{0.5} \right] \beta_{zz} \tag{6}$$

whereas the TE is estimated econometrically, the EE is derived from Eq. 5 thanks to parameters already estimated (β_z and β_{zz}), and the inefficiency term U_{it} (Reinhard et al., 1999; Marchand and Guo, 2014). Here, the EE is directly linked to the inefficiency term. The farm is more environmental efficient if there is less inefficiency, and vice versa. Fig. C3 and Fig. C4 shows, respectively, the density of TE and EE for farmers around the 10 ha and 30 ha. We can observe no or small differences in the density of farms around the thresholds, especially for farms around 30 ha.

It is essential to acknowledge that various alternative methods for computing environmental efficiency are present in the literature. For instance, Murty et al. (2012) utilized byproduction systems with Data Envelopment Analysis (DEA), and Cillero and Reaños (2023) employed Stochastic Frontier Analysis (SFA) techniques, considering a detrimental environmental output. Due to data limitation to measure detrimental outputs (such as GHG emissions), this paper focus on the methodology introduced by Reinhard et al. (1999).⁹

Above the TE and EE, other indicators are computed for our three dimensions. For the environmental dimension, we used the Shannon Index as in Varacca et al. (2023), the fertilizer use ratio, and the crop protection use ratio. The last two indicators have also been used by Diop et al. (2024) and are similar to indicators used by Midler et al. (2019), Kirsch (2017), and Varacca et al. (2023). While the average of the TF might not capture the full environmental impact, a value above 1 indicates higher input usage intensity, potentially leading to more environmental damage. For example, high nitrogen surplus, causing increased nitrogen emissions, can result from intense fertilizer use (Ait Sidhoum et al., 2023a, 2023b). Although these measures have limitations and may not fully reflect the environmental footprint (Uthes et al., 2019), we view these indicators as proxies for fertilizer and pesticide usage intensity, partially capturing the farming system’s environmental aspects. For the economic aspect, we used the operating surplus per unpaid worker as in Piet et al. (2020) and the income before tax per unpaid worker. For the land use dimension, we adopted the following indicators: main crop share, two main crop share, and the number of crops, as in Sauquet (2022). The details of their computation can be found in Table 4. The next section will present the results of our estimations.

5. Results

This section presents, first, our results pertaining to the crop diversity effect for the overall sample. Second, we evaluate the potential effect of the crop diversity criterion for farms that did not meet the requirements in 2014.

⁹ Additionally, by using environmentally detrimental inputs rather than environmentally detrimental outputs, this approach aligns better with Reinhard et al. (1999)’s definition of environmental efficiency, and potentially avoiding the issues raised by Färe and Grosskopf (2003) and Førsund (2008) regarding the treatment of bad output as input.

5.1. What is the impact of green payments crop diversity criterion?

We start by presenting the results of crop diversity criterion on different outcomes. Tables 5 to Table 7 highlight, respectively, the impact on the economic, environmental and land use conditions for farms around 10 ha.

For farmers with around 10 ha of arable land, the crop diversity criterion significantly influences the environmental and land-use conditions of farms. There is an increase in the Shannon index, as shown in previous studies such as Cortignani et al. (2017), and a reduction in the share of the main crop and the two main crops for farmers with more than 10 ha. The reduction in the main crop share can be explained by the introduction of new crops to comply with the requirements (Cortignani et al., 2017). The green payments imply land reallocation on farms (Louhichi et al., 2018), and this land reallocation and reduction in main crop shares can significantly increase crop diversity on farms, as shown by the increase in the Shannon index. The results also show that there is no significant effect on economic dimensions, as well as the fertilizer and crop protection index. This latter result is in line with Gocht et al. (2017), who showed that the diversification measure has almost zero effect on environmental measures. Therefore, the land reallocation was not enough to translate into environmental consequences. Moreover, as already mentioned, the results of the Shannon index and the number of crops should be interpreted with caution as the difference existed even before the reform.

Tables 8 to 10 report results for farms with around 30 ha of arable land. We can see that there is a significant increase in the number of crops for farmers with more than 30 ha, which is in line with the results of Sauquet (2022), who also found the same results for French farms.

Our estimate for the number of crops (+0.375), which is somewhat greater than the one found in Sauquet (2022) (+0.12), suggests that, on average, more than one in three farms was able to increase its number of crops in our sample. This might be explained by the possible reallocation of land that occurred after the reform, as found by Louhichi et al. (2017). This reallocation allows some farms to find rooms to introduce more crops in their diversification.

Many studies have highlighted that few farms and lands were really concerned by green payment requirements (Louhichi et al., 2017; European Court of Auditors, 2017; Commission, 2017). Indeed, the green payment component of the 1st pillar was mainly designed to have many compliers (Cortignani et al., 2017; Louhichi et al., 2017). The requirements, especially for the crop diversification, would not be strong enough to impel great changes as many were already complying with requirements. These observations lay the foundation to the following questions: what would happen if green payments were specifically targeted to farms that did not meet the requirements? Would it change anything in term of additionality? The next section tries to provide an answer to these questions.

5.2. Would a change in targeting give a better additionality?

The main results provide some insights about possible reallocation of land in farms and an increase Shannon Index for farms around 10 ha. The number of crops has also seen a significant improvement for farmers around 30 ha. However, these results might be driven by the fact that

Table 5
Green payments effects around 10 ha: Economic outcomes.

	Technical Efficiency	Operating Surplus	Income before tax
	-0.001	-6.015	0.880
LATE	(0.000)	(31.387)	(30.374)
Total.obs	365	293	318
Opt. Band	3.504	2.612	2.839

Note: Robust standard errors in parentheses. * p < 0.10 ** p < 0.05 *** p < 0.01. The optimal bandwidth in the table are bandwidth for one side.

Table 6
Green payments effects around 10 ha: Environmental outcomes.

	Shannon Index	Crop Pro. Index	Fertilizer Index	Environmental Efficiency
LATE	0.044** (0.020)	-0.021 (0.059)	-0.060 (0.099)	-0.001 (0.001)
Total. obs	386	309	319	360
Opt. Band	3.765	2.793	2.866	3.477

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

Table 7
Green payments effects around 10 ha: Land use outcomes.

	Main crop share	Two Main crop share	Number of crop
LATE	-0.062* (0.036)	-0.037* (0.021)	0.091 (0.152)
Total. obs	386	303	375
Opt. Band	3.756	2.757	3.660

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

Table 8
Green payments effects around 30 ha: Economic outcomes.

	TE	Operating Surplus	Income before tax
LATE	0.000 (0.001)	-17.776 (94.033)	-32.211 (93.619)
Total. obs	191	199	168
Opt. Band	2.803	2.981	2.385

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

Table 9
Green payments effects around 30 ha: Environmental outcomes.

	Shannon Index	Crop protection Index	Fertilizer Index	Environmental Efficiency
LATE	0.149 (0.096)	-0.041 (0.072)	-0.038 (0.139)	0.001 (0.001)
Total. obs	222	243	232	194
Opt. Band	3.125	3.487	3.321	2.886

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

most of the green payments receivers might have already met crop diversity requirements (Louhichi et al., 2017; European Court of Auditors, 2017). In this case, the additionality of the crop diversification criterion would be questionable.

Accordingly, this raises an interesting question: would it be different if the crop diversity were only focused on farms that did not meet the requirements before the reform? Indeed, Solazzo et al. (2016) have even argued that stronger requirements from a previous proposal would have delivered better results. This argument might imply that a change of target, i.e. selecting farms which did not meet the criterion, would be more efficient. We intend to verify this stance.

Our sample allows us to identify farms that did not respect the crop diversity criteria in 2014, but receive green payments in the 2015–2016 period. These farms are termed “non-compliers”. Therefore, we restrict our sample to those “non-compliers”, i.e. farms who did not either respect the number of crops, the main crop share or the two-main crop share. Then, we estimate the effect of the crop diversity criterion around the two thresholds. The results will provide an overview of the potential

Table 10
Green payments effects around 30 ha: Land-use.

	Main crop share	Two Main crop share	Number of crop
LATE	-0.002 (0.020)	0.014 (0.021)	0.375* (0.223)
Total. obs	156	158	188
Opt. Band	2.169	2.276	2.742

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

effect of the crop diversity criterion, has it been targeted toward the non-compliers. Tables 11 to Table 13 present findings for farms around 10 ha.

We find no significant effect of crop diversity criterion for any dimension of interest for farmers around 10 ha. It means that if the diversification requirements were only focused on non-compliers, it would not deliver better results as it is designed.

Tables 14 to Table 16 highlighted findings for farms around 30 ha. The results also indicate no significant change in economic, environmental and land use conditions for noncompliers farms around 30 ha.

These results highlight interesting features for a public policy perspective. Indeed, the crop diversity criterion bring substantial change in agricultural practices, only if we include farms that already respect the diversification requirements. Otherwise, it would not deliver better results any additional effect. This puts more weight on the lack of efficiency of the policies and raises concerns for a possible “deadweight” in the design, i.e. meaning farms that received subsidies to adopt practices already adopted or that they would have adopted without the policy (European Court of Auditors, 2017).

6. Robustness checks

To test the robustness of our results, we decided to change some aspects of our main estimation. First, as mentioned by Sauquet (2022), the bandwidth estimators compute different bandwidths depending on the outcome of interest. Therefore, comparing different outcomes might be difficult as we might have different farms for each outcome. Accordingly, we followed Sauquet (2022) by choosing the same bandwidth for all outcomes of interest. We chose three bandwidths (6 ha, 8 ha, and 10 ha) and ran our estimations for each one of them. The choice was based on the average bandwidth of our main estimations (around 6 ha for each of the two thresholds). Table B13 to Table B30 gather all results for each bandwidth and threshold. The findings were qualitatively the same compared to our main estimations.

Second, we chose a different bandwidth following the Imbens and Kalyanaraman (2012) bandwidth estimator (IK, henceforth) instead of the CCT bandwidth estimator for the main results (Calonico et al., 2020). New bandwidths obtained were greater than the CCT bandwidth. Table B31 to Table B36 provide findings related to these estimations. The results were also qualitatively equivalent to our main estimations, except for the Shannon Index for farmers around 30 ha, which is no longer significant. These results support to a great extent our main estimations.

Third, we also propose falsification test of our approach by

Table 11
Green payments effects around 10 ha on non-compliers: Economic outcomes.

	Technical Efficiency	Operating Surplus	Income before tax
LATE	-0.000 (0.001)	-56.816 (69.249)	-4.212 (66.260)
Total. obs	175	173	173
Opt. Band	2.962	2.858	2.873

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

Table 12

Green payments effects around 10 ha on non-compliers: Environmental outcomes.

	Shannon Index	Crop protection Index	Fertilizer Index	Environmental Efficiency
LATE	0.010 (0.026)	0.036 (0.084)	-0.134 (0.224)	-0.000 (0.001)
Total. obs	220	172	151	185
Opt. Band	3.868	2.826	2.466	3.246

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

Table 13

Green payments effects around 10 ha on non-compliers: Land use outcomes.

	Main crop share	Two Main crop share	Number of crop
LATE	-0.037 (0.050)	-0.014 (0.024)	-0.002 (0.234)
Total. obs	204	139	179
Opt. Band	3.656	2.210	3.104

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

Table 14

Green payments effects around 30 ha on non-compliers: Economic outcomes.

	Technical Efficiency	Operating Surplus	Income before tax
LATE	3.10e-05 (0.001)	-31.583 (93.235)	-19.241 (91.286)
Total. obs	258	173	177
Opt. Band	3.818	2.488	2.520

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

estimating outcome discontinuities at different “placebo” thresholds, such as 35 ha and 45 ha of arable land. The estimations are presented, respectively, in Table B37 and Table B38. The results for 35 ha showed no significant effect for any of the outcomes under study, which confirm the appropriate choice of our estimation strategy. As for the results for 45 ha, there was a significant effect only for the main crop share, which might not compromise our main results.

7. Discussion

The primary objective of this study was to assess the impact of green payments on the technical and environmental efficiency of farms. Contrary to our initial expectations, the results indicate that green payments do not have a significant impact on the economic and environmental efficiency of farms.

Several factors could explain the lack of significant impact observed in our analysis. Firstly, the design of green payments under the Common Agricultural Policy (CAP) may inherently limit their effectiveness. The criteria were designed to be broadly applicable (Louhichi et al., 2018), and the vast majority of farms in our sample met these criteria even without the policy. This raises questions about the windfall effects of green payments, similar to issues seen with voluntary measures such as agri-environmental schemes (Chabé-Ferret and Subervie, 2013; Diop et al., 2024). Windfall effects, where farmers adopt practices they would have adopted even without the payments, can significantly limit the additional impact of the policy.

However, as shown in Section 5.2, even when focusing on farmers who did not meet the criteria before (*i.e.*, those who needed to change their practices to receive the payments), the crop diversity criteria did not bring any significant benefits. This suggests that the policy design

Table 15

Green payments effects around 30 ha on non-compliers: Environmental outcomes.

	Shannon Index	Crop protection Index	Fertilizer Index	Environmental Efficiency
LATE	0.170 (0.106)	-0.066 (0.085)	-0.007 (0.131)	-0.001 (0.001)
Total. obs	192	188	263	258
Opt. Band	2.853	2.734	3.986	3.846

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

Table 16

Green payments effects around 30 ha on non-compliers: Land use outcomes.

	Main crop share	Two Main crop share	Number of crop
LATE	-0.002 (0.020)	0.010 (0.019)	0.321 (0.196)
Total. obs	191	238	240
Opt. Band	2.811	3.384	3.392

Note: Robust standard errors in parentheses. * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. The optimal bandwidth in the table are bandwidth for one side.

itself may need to be reconsidered. The criteria might not have been ambitious enough to bring about any substantial changes in the economic and environmental conditions of farms. For instance, European Commission (2017) argued that the original plan of the European Commission in 2011 was more ambitious, with stricter criteria, and Solazzo et al. (2016) showed that this original plan would provide more substantial benefits (a reduction of environmental emissions greater than 5 % for the initial plan compared to 1.5 % in the proposed plan). Our results further support the notion that, while windfall effects can play a role, as mentioned by Louhichi et al. (2018), the policy’s design might not be ambitious enough. This implies that the additionality of green payments is limited, meaning that the dictated practices are not significantly altering farm behaviors to improve economic and environmental efficiency.

It is also important to consider the potential lag between the implementation of green payments and observable changes in efficiency. Environmental and economic efficiencies may require longer periods to manifest significant improvements. Our study period might not have been sufficient to capture these delayed effects, suggesting the need for long-term studies to better understand the impacts.

Moreover, the heterogeneity among farms in terms of size, management practices, and regional environmental conditions might contribute to the mixed results. Farms with different characteristics may respond differently to green payments, and aggregating these varied responses could lead to an overall non-significant impact. Our methodology, which focused mainly on a limited number of farms, reduced the possibility of exploring diverse results within the category, thus failing to capture this heterogeneity fully.

Finally, our results highlight various aspects that need to be considered when evaluating agri-environmental policies. Windfall effects are not the only threat to the effectiveness of these policies, their design is equally crucial.

8. Conclusion

Green payments under the 2013 CAP reform aimed to better account for the environment in the CAP’s first pillar without compromising the economic aspect of farming. Their main objective was to remunerate farms for the provision of environmental services and to support them in the production of environmental goods. The crop diversification criterion introduced different requirements for farms around two thresholds

of arable land. Farms above 10 ha and 30 ha of arable land had higher constraints than, respectively, farms below 10 ha and 30 ha. In this study, we aim to answer two questions. First, what was the effect of the crop diversification criterion on the environmental, economic, and land-use conditions of farms? Second, were the crop diversification criteria designed to fail? We enrich previous studies in this literature in multiple ways. First, to the best of our knowledge, this is one of the first evaluations of the crop diversification criterion using impact evaluation techniques. Second, this is also the first study evaluating the greening crop diversity criterion on technical and environmental efficiency computed *via* SFA methods. Third, this study offers a broad view by analyzing the effects on three dimensions, namely environmental, economic, and land-use. Fourth, this paper is a study that provides evidence of the deadweight or windfall effect of green payments. Finally, this is the first study that we are aware of dealing with the crop diversification effect on farms around 10 ha.

Using an original sample for the 2012–2016 period, we found that the crop diversification criterion did translate into land reallocation and an increase in the Shannon Index for farmers around 10 ha of arable land. An increase in the number of crops has also been noticed for farms around 30 ha. The results are in line with most previous studies on crop diversification (Louhichi et al., 2017; Sauquet, 2022). The results also show no significant effect on the economic conditions of farms around 10 ha and 30 ha.

Second, our results showed evidence of a deadweight effect, meaning a situation where farms receive subsidies to adopt practices that they would have adopted in the absence of the policy. Indeed, we found that the crop diversification criterion would not bring any additional effect if it were entirely focused on non-compliant farms. It means that the green payments serve mainly to reward farms that were already adopting good environmental practices and did not bring additional changes.

In light of these findings, interesting policy implications can be derived. Indeed, if the intention was to provide additional environmental benefit, the design of the crop diversification criterion has shown to have failed to live up to expectations. Therefore, public policies aiming to encourage crop diversity should be more ambitious if they expect to bring additional changes on farms. However, the criterion seems to have succeeded somewhat to reward existing beneficial practices. More precisely, we think that introducing environmental conditionality on payments under the first pillar of the CAP is an excellent way to green the agricultural practices of a large number of farms. The success of this measure hinges on the choice of conditionality criteria. Politically, the conditionality was introduced with a fairly unrestrictive criterion, which has resulted in its lack of effectiveness. The conditionality should have been retained but the environmental criteria tightened up gradually. Progressive programming would have enabled farms to anticipate changes in their practices. We also suggest that recent methodological advances in causal inference and machine learning provide a solid basis for defining this environmental criterion. Firstly, we can identify the conditionality thresholds that allow the best economic and environmental efficiencies by exploiting the Treatment Effect Derivative approach (Dong and Lewbel, 2015). Secondly, by exploiting causal machine learning approach (Athey, 2018), we could target more appropriately farms for which the effectiveness of the policy is maximised (Andini et al., 2022; Esposti, 2024). A potential improvement to the CAP payments could involve a redistribution strategy tied to stricter conditionality, where higher payments are offered to farmers willing to adopt more demanding practices. This will include a differentiated payments systems based on the expected additionality as in Aspelund and Russo (2024). Additionally, a policy differentiation based on expected additionality, as demonstrated by Aspelund and Russo (2024), could be another way to make these measures more ambitious. For instance, payments could be lower for farmers already meeting the criteria and progressively higher for those who meet stronger environmental requirements. This approach would address the heterogeneity among farms and create greater incentives for those who go beyond the

basic standards, thus improving environmental outcomes and aligning payments more closely with additional efforts. These proposals could be the subject of further work.

This paper has some limitations that should be taken into account. For instance, we were not able to evaluate the heterogeneous effect through the types of farming due to a lack of enough observations. Our results also offer local average treatment effect (LATE). Therefore, a generalization of these results, with, for instance, the methodology of Angrist and Rokkanen (2015), could help provide more insights about the proper effect of the crop diversification criterion. Moreover, our sample did not allow us to examine the green payment system entirely. Another caveat of our result is the temporality of our sample. It is possible that the effect could be different in following year due a higher adaptation time for farmers that needed to change their agricultural practices. Finally, a limitation related to our approach is that, due to data availability constraints, we were unable to implement a modeling of bad outputs as proposed by Murty et al. (2012) and discussed by Dakpo et al. (2016). Instead, we focused our analysis on environmentally detrimental inputs. We expect future development merging farm accounting data with practice data to be crucial in overcoming this limitation. Nonetheless, the results of this paper constitute new evidence that can help policymakers, especially for the following CAP reforms.

CRedit authorship contribution statement

Thierno Bocar Diop: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lionel Védrine:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecolecon.2024.108405>.

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