Improving Farm Environmental Performance through Technical Assistance: Empirical Evidence on Pesticide Use

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Abstract

The Ecophyto plan is a high stake program implemented in France since 2008 with the aim to halve pesticides use in the farming sector in 10 years. A central disposal of the program is the dephy network. It consists in providing technical assistance to groups of volunteer farms. Furthermore, the French government is currently trying to scale-up the program, which calls for the evaluation of its impacts on pesticide use and yields. Coupling Dephy data and national surveys from 2010 to 2016, we use a slate of quasi-experimental approaches - Matching, Difference-in-difference matching, Difference-in-difference, and quantile regressions to estimate the impact of participation in the program on pesticide use and crop yields on enrolled vineyards. We find that participants have achieved reductions in pesticide use that ranges from 8 to 22 percent, thanks to the program. We moreover find that the reduction in the use of chemicals was accompanied by an increase in the use of biocontrol products. Finally, we find that this change of practices resulted in a reduction in yields for a fraction of enrolled farms. Our study provides new evidence regarding the effectiveness of technical assistance alone in reducing pesticide use in the agricultural sector. It shed lights on potential beneficial impacts as well as warnings of the effects of such programs.

Keywords: Technical assistance; Farming practices; Pesticides; Treatment effect.

JEL: Q15; Q18; Q25; Q28; Q53.

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1 Introduction

In 1962 Rachel Carson revealed to the international community the hazards of the DDT pesticide, an event that marks a change in the status of environmental issues for voters and politicians. Consequences of pesticide use on biodiversity, water quality and human health have constantly been revealed by scientific studies since (Aktar et al., 2009). Naturally, since the 60's we assist to a constant process of creation followed by bans of pesticides products on the market (Zilberman et al., 1991). The only option to break the cycle seems to be avoiding the use of pesticides. Hence ambitious plans to drastically reduce pesticide use raises in several regions (Eyhorn et al., 2015).

With an agricultural sector particularly developed, France is the first user of pesticides in ton per year in Europe. To loose this grim status, the country launched in 2008 the French Ecophyto plan 1 which aims at a reduction by 50% of pesticide use. Reaching such an ambitious goal demands profound changes in production processes. In many cases, however, farmers are not aware of the most advanced techniques regarding sustainable agricultural practices that would be relevant for their particular situation. For this reason, the core disposal of the plan is the creation of a network of 1,900 pilot farms to which the government provides free technical assistance with the aim of decreasing pesticide use while maintaining yields. In 2016, the French authorities increased the network from 1,900 to 3,000 farms, and created a secondary network of 30,000 farms (Stokstad, 2018).

The first contribution of this article is to use a slate of quasi-experimental approaches to estimate the impact of participation in this technical assistance program - called Dephy - on pesticide use and crop yields on enrolled vineyards. We focus on viticulture because the Department of Statistics of the French Ministry of Agriculture carried out three surveys on phytosanitary practices from a representative sample of about 4,000 vineyards since 2010, providing a unique opportunity to assess the effectiveness of the Dephy program. Wine growing is, moreover, an agricultural system characterised by the highest level of pesticide use per hectare (Agreste, 2012) and for which conversion to integrated farming represents a formidable challenge.

The second contribution is to provide evidence on the effects of a program that provides technical assistance only, which makes it very different from previous programs that offer compensation in return for adopting green practices .[1] On the one hand, there are reasons to be pessimistic on the efficiency of such disposal, since contrary to most AES, the program does not impose any quantified target to participating farms. Furthermore, the literature is rather pessimistic on the effect of extension services in general (Anderson and Feder, 2007). On the other hand, the presence of the technical expert allows a profound redefinition of the

[1] The current literature on extension services in developing countries focuses on social networks, collaboration between extension workers and farmers, and experimentation (BenYishay and Mobarak, 2018; Conley and Udry, 2010; de Janvry et al., 2016)

production process, while AES usually target specific practices. Finally permanence issues might be a lesser concern with technical assistance than with conditional payments, since multiple aspects of the production process are supposed to have been affected. As a result, judging the effectiveness of such program requires careful empirical examination.

Distinguishing the effects of enrolling some particular farms from the effects of the technical assistance itself remains a challenge. Given that farmers were not randomly selected for participation in the Dephy program, the third contribution of this article is to combine a variety of quasi-experimental approaches to identifying the effect of the program, including matching procedures, difference-in-differences (DID) estimation, DID-matching, and quantile regressions.[2] Taken together, our observational approaches all point to the same conclusion – that the Dephy program was successful in reducing chemical pesticide use. In particular, we find that participating farms have achieved reductions in chemical pesticide use that ranges from 8 to 22 percent, thanks to the program. We moreover find that the reduction in the use of chemicals was accompanied by an increase in the use of biocontrol products. Finally, we find that the switch from chemicals to biocontrol products resulted in a reduction in yields for a fraction of enrolled farms. Our study thus provides new evidence regarding the effectiveness of technical assistance alone in reducing pesticide use among French farmers, and presumably among farmers in developed countries more generally.

The rest of the paper is organized as follows. Section 2 provides a background on the Ecophyto plan and the Dephy program. Section 3 describes the data and Section 4 presents the estimators we use. The results of the various estimations are presented in Section 5 and discussed in Section 6. Finally, Section 7 emphasises the policy implications of our results and provides directions for further research.

2 Background

2.1 Context

Pesticides were developed to preserve crop yields through the management of agricultural pests (pathogens, animal pests and weeds). Herbicides, for example, are used to control weeds that compete with crops for soil nutrients, water, light, and space. However, the extensive and continuous use of pesticides can threaten agricultural production and sustainability (Wilson and Tisdell, 2001), as suggested by the stagnation and even decline in yields that has occurred in some areas (Ray et al., 2012). Moreover, pesticides are able to spread from the site of application, contaminating air, soil and water alike and causing adverse effects on quality of ground and surface waters, soil fertility, biodiversity and human health, particularly for

[2] In an ideal research environment, one would randomly select farms for the technical assistance program and estimate the effects of the program by comparing the pre-and post-intervention practices of selected farms to those of non-selected farms. Randomization would ensure that unobservable determinants of changes in farmers' practices would not be correlated with changes that are induced by technical assistance.

those involved in the application of pesticides (Wilson and Tisdell, 2001).[3] Despite these developments, pesticide use has not decreased. Instead, the volume of pesticides sold between 2011 and 2016 increased in 16 EU countries (Eurostat, 2018).

A growing number of studies have demonstrated that the use of pesticides is generally not optimal (Gaba et al., 2016; Mailly et al., 2017; Nave et al., 2013), that alternatives do exist (Lamichhane et al., 2015; Andert et al., 2016; Petit et al., 2015; Reau et al., 2010) and that substantial reductions in pesticide use can be achieved without impacting productivity (Jacquet et al., 2011; Lechenet et al., 2017; Frisvold, 2019).[4] Jacquet et al. (2011) have constructed cropping system prototypes[5] based on the results of agronomic trials and expert knowledge, and have simulated the economic effects of different degrees of pesticide reduction in France. They found that decreasing pesticide use by up to 30 percent at the national level could be possible without reducing farmer incomes. Using field data collected from pilot farms in the Dephy network, Lechenet et al. (2017) examined the link between pesticide use and yields. They did not able to detect any positive correlation between pesticide use intensity and productivity in 77 percent of Dephy farms. By comparing each of these farms to a reference farm that shared the same constraints and opportunities but used less pesticides, they demonstrated that pesticide levels could be reduced by 42 percent without any losses in productivity or profitability in 59 percent of pilot farms.

Today, Precision pest management, Integrated Pest Management (IPM) and organic farming are seen as credible alternative solutions for decreasing reliance on pesticides. The IPM system, which often relies heavily on biological pest control products,[6] appears particularly promising. By taking advantage of a range of pest management options (including, but not limited to pesticide use), IPM can often be more profitable than organic farming. IPM moreover enables greater reductions in pesticide use than Precision pest management (which optimizes pesticide use based on field observations and the use of specific decision-making tools).

Although a wide range of IPM-based methods are available today, only partial or step-wise adoption is typically used by farmers (Bailey et al., 2009). One reason for this is that farmers have little guidance for strategically implementing it given climatic and crop-specific growing conditions. Furthermore, they often perceive the adoption of new practices as risky, due to the inherent uncertainty surrounding crop output and the time investment required in order to

[3] In France it is estimated that 10 to 70 percent of the pesticides sprayed on foliage is lost to the soil and 30 to 50 percent is lost to the air (Aubertot et al., 2007).

[4] The literature addressing reductions in pesticide use is generally based on data from a small number of farms (Nave et al., 2013; Petit et al., 2015) or from agronomic experiments (Hossard et al., 2014; Petit et al., 2015; Reau et al., 2010; Jacquet et al., 2011), and analyses the effectiveness of innovative low-pesticide cropping systems via a range of sustainability indicators.

[5] A cropping system is defined by the crops, crop sequences and the management techniques implemented on a field.

[6] Biological pest control is a method of controlling pests such as insects, mites, weeds and plant diseases using other organisms. It relies on natural mechanisms, but typically also involves an active human management role. IPM systems may also rely on diversifying crop rotations, which can interrupt disease cycles and reduce the abundance of dominant weed species (Andert et al., 2016).

learn how to manage new systems (Musser et al., 1981). IPM is indeed more time-consuming and requires more knowledge than conventional methods (Beckmann and Wesseler, 2003; Waterfield and Zilberman, 2012). A lack of field evidence exists regarding the impacts of IPM-based practices on management and labour costs, especially in the European context, which is likely to attenuate the pace of its adoption. In this context, the massive uptake of IPM systems is unlikely in the absence of any public intervention.

For many years now, programs and policies designed to reduce pesticide use have featured prominently on the EU political agenda. Since the mid 1980's, a number of pesticide reduction programs have been implemented in several European countries with mixed results (Neumeister, 2007; Gianessi et al., 2009; Chabé-Ferret and Subervie, 2013; Lefebvre et al., 2015; Kuhfuss and Subervie, 2018). In recent years, EU legislation has been modified and various new regulations have been released, including restrictions on the use of certain pesticides.[7] Since 2009, the European Union Directive 2009/128/EC on the Sustainable Use of Pesticides (EU, 2009b) has mandated all professional pesticide users to adopt IPM principles and calls on Member States to ensure the adoption of IPM through crop-specific guidelines. Agricultural extension services are expected to play a central role in its implementation, as Member States must provide farmers with the necessary information, tools and advisory services for adopting IPM.[8]

2.2 The Dephy program

In this context and issuing from the Grenelle consultation process on environmental issues, the Ecophyto 2018 plan emerged with the objective of cutting the nationwide use of pesticides by 50 percent in the space of ten years. At the time of this writing, this outcome has not been yet been achieved, and the end of the plan was postponed until 2025. A central component of the Ecophyto plan is the creation of the so-called Dephy network of pilot farms that is intended to demonstrate the feasibility of its objective.

Created in 2010, the Dephy network is constituted of local groups of a dozen farmers. Each group is supported by an engineer who provides technical assistance in implementing cropping systems that require using fewer pesticides. Following a test phase that began in March 2010, the Dephy program has gathered about 3,000 farmers since 2011. To join the Dephy network, a farmer must apply to an organization in charge of the formation of Dephy groups and commit to participating in a collective project for 5 years. Dephy farms are located in all wine regions across the country (see Figure 1).

Dephy engineers assist with both individual farmers' projects as well as the collective group project for which the farmers are responsible. In practice, engineers conduct an initial

[7]These restrictions relate to the maximum levels of pesticide residues in food (EU, 2005, 2009c) and safety requirements on technologies (e.g. spraying materials) used by farmers (EU, 2009a).

[8]Educational programs, training activities and advisory services offered to farmers have indeed proved effective (Kudsk and Jensen, 2014; Bailey et al., 2009).

diagnosis of farmers' practices and then work with farmers to draw up a plan to reduce their pesticide use over five years. They then support the farmer in implementing the project and monitor its progress through campaign reviews and annual documentation. A specific aim of the Dephy program is to create a catalogue that describes the functioning and evolution of the performance of certain low-pesticide and economically-efficient cropping systems such as IPM systems. Collective farmer projects are carried out through meetings and demonstration days.[9] The network shares its experience and results with farms outside of the program through local communications outlets and practical demonstrations.

3 Data

3.1 Sample

To lead the analysis, we use three sources of data. The first is the Agrosyst database which records all phytosanitary product application of farms within the Dephy network (the treated observations). Data are recorded at the cropping system level from 2011 to 2016.[10] We are able to retrieve comprehensive information on phytosanitary product use in 2016 for 125 of the 200 cropping systems that entered the dephy network in 2011. Secondly, to build the control group, we use data from the cultural practices surveys. Three surveys on phytosanitary practices were carried out by the Department of Statistics of the French Ministry of Agriculture (MA) in 2010, 2013, and 2016, on a sample of 9,369 French vineyards that were each interviewed at least once. Among these 9369 vineyards, 3984 were interviewed for the three years of the panel. Data are available at the agricultural parcel level. Finally, we use the 2010 agricultural census to gather information on socio-economic and production characteristics of farms. We combined these three databases on the basis of a common identifier (the farm business identification number). To complete we found 45 dephy farms that were interviewed in the cultural practices surveys in the three years of the panel. This provides us with information on phytosanitary product use and yields for 45 treated farms before (2010) and after the program (2013 and 2016).

[9] Collective approaches for the implementation of new techniques are often seen as the gold standard in improving farming practices (Reau et al., 2010; Kudsk and Jensen, 2014), since they facilitate the identification of common problems and can influence farmers' perceptions of the risks associated with alternative practices as well as their confidence in their ability to implement these practices(Lamichhane et al., 2015).

[10] Agrosyst is an information system that describes the cropping systems on Dephy farms and documents their development over time. It was developed by the French National Institute for Agricultural Research (INRA) as part of the Ecophyto plan. A cropping system is series of plot homogeneously managed, i.e., all organic vineyards, or all under a common certification mark.

3.2 Pesticide use and yields

The MA surveys and Agrosyst database provide information on the quantity of pesticides used by winegrowers on the surveyed parcel, as measured through the Treatment Frequency Index (TFI). This index represents the number of so-called reference doses of pesticides applied during a farming year.[11] The reference dose is often considered the normal dose, as it corresponds to the efficient dose of a product for a specific culture and pest:

$$\text{TFI} = \sum \frac{\text{applied dose}}{\text{reference dose}} * \frac{\text{treated area}}{\text{total area}}.$$

For example, if the reference dose of an herbicide is spread over the entire area of a plot, then the TFI of the plot equals one. If the herbicide is spread at its reference dose but only under the vine rows, the TFI of the plot equals one third, because the space between vine rows is roughly twice as wide as the vine row itself (Kuhfuss and Subervie, 2018). The annual TFI of the entire parcel is the sum of the TFI calculated for each treatment carried out on the parcel during a crop season.

These surveys provide a range of disaggregated indicators, including the Herbicide TFI, the Insecticide TFI, the Fungicide TFI and the Total TFI.[12] Moreover, each TFI can be disaggregated so that the chemical compounds can be distinguished from the biological compounds.

Table 1 reports the average value of the TFI for Dephy farms and non-Dephy farms in 2010, 2013 and 2016, as provided from the MA surveys and Dephy reports. It also reports mean values of the yield as measured by the amount of wine (in hectoliters) that is produced per hectare of vineyard. Data use for the cross-sectional estimations are different from the ones in difference-in Difference estimations. Indeed, for the difference in difference estimations we used only data from the cultural practices surveys. Thus we directly report TFI provided by the surveys. For the cross-section, we use Agrosyst data for the treated farms and cultural practices data for the control farms. Consequently, we used data at the product-parcel level to compute TFI using the exact same rules, as explained in the Appendix. This explains a first difference in TFI level between the cross-sectional and DiD data. A second source of difference for treated observations is that in the cultural practices surveys, the observation unit is the agricultural parcel not the entire farm. This is an important consideration since participating farms in the Dephy network are not required to enrol all of their parcels of land in the program. Consequently, information about the phytosanitary practices of these farms collected during the surveys may not refer to a parcel that is enrolled in the program (even if 70% of participating enrolled 100% of their farms in the dephy program). This explains why the 2016 Chemical TFI is slightly higher for treated farms in the DiD estimations compare to the cross-sectional

[11] In viticulture, the 2010 crop year begins during after the harvest in September 2009 and ends with the harvest in September 2010.

[12] Herbicide, insecticide and fungicide are the main component of the total TFI, a few sanitary products concern other pests such as acarids.

ones. Table 1 calls for two other comments. First, the use of biocontrol products increases over time in both groups, which suggests a general tendency towards improved farming practices over the period. Second, the use of pesticides is different across groups throughout the period, especially in 2016, when Dephy farms have a significantly lower TFI than non-Dephy farms, whichever the data source used to calculate the TFI. Our goal is to assess the extent to which this gap can be attributed to the program. These differences are also highlighted by the histograms describing the distribution of yields and TFI build using data for the cross-section figures A2, A2 , and A3 in the Appendix. Also, remark that a significant number of dephy farms have really low yields in 2016 which suggest a failure of some strategies to control pests.

3.3 Winegrowers' characteristics

Winegrowers' characteristics are taken from the French Agricultural Census that was conducted in 2010 by the Ministry of Agriculture. The census data contains detailed descriptions of French farmers from the 2009-2010 farming year, i.e. before the Dephy program began. Specifically, it provides information on a range of agronomic, social and economic variables likely to influence both the use of pesticides and the decision to participate in the Dephy program, including the characteristics of the farm (land use, labour force, insurance, diversification activities, ownership), the head of the farm (age, sex, education, spouse's main activity), the production of the farm (quantity of wine produced, quality labels, sales), and the farming practices employed (spraying of pesticides, land area without pesticides, organic farming if any).

To this data we added two information from the MA survey and Agrosyst database: whether the plot is cultivated as organic, and the wine-growing basin of the plot. This last information is very important since pest pressure and diversity is very different depending on which area of France the parcels are located.

Table 2 provides summary statistics for the Dephy farms (referred as to participants in the table) and the non-Dephy farms (referred as to non-participants) in 2010. Dephy farms are larger on average, they more often calibrate their pesticide sprayer and sell their wine in short circuits. The head of a Dephy farm is more likely to have a bachelor's degree, be a member of a farmer organization, and to diversify his farming activities, indicating that the Dephy program attracted a particular type of farmer. To deal with this selection issue, we make use of a variety of quasi-experimental approaches, including matching, difference-in-differences (DID) and DID-matching estimations.

4 Empirical strategy

4.1 Parameters of interest

Our objective is to estimate the causal effect of participation in the Dephy program on the amount of pesticides used by participants, or the Average Treatment effect on the Treated (ATT). The ATT is defined as the mean difference between the level of the outcome considered (here, the TFI or the yield) among vineyards involved in the Dephy network and what this level would have been in the absence of the program (the counterfactual scenario):

$$\text{ATT} = E[Y^1 - Y^0|D = 1] = \underbrace{E(Y^1|D = 1)}_{\text{observable}} - \underbrace{E(Y^0|D = 1)}_{\text{unobservable}}$$

where Y^1 is the level of the outcome in the presence of the Dephy program, Y^0 is the level of the outcome in the absence of the program and D is the treatment variable that is equal to 1 for Dephy winegrowers and 0 otherwise. Since the counterfactual level $E(\text{TFI}^0|D = 1)$ is not observable, it must be estimated. To do this, we follow a quasi-experimental approach that uses non-participating farms from the MA surveys to construct valid control groups.

Since the Dephy program started in 2011, data on the phytosanitary practices measured in the 2010 survey are considered as pre-treatment outcomes, while data on the phytosanitary practices measured in the 2016 survey can be considered as post-treatment outcomes. Technically, data on the phytosanitary practices measured in the 2013 survey should be seen as post-treatment outcomes as well, although the time required to implement new farming techniques makes effects of the program unlikely to be detected at this early stage.

Note that we do not have post-treatment data on phytosanitary practices for farms enrolled during the second wave of participation in the program. Consequently, these farms are considered as untreated in our framework. They can, however, be used to test our identification strategy, as we will see in the following section.

4.2 Average treatment effects

To estimate the ATT in 2016, we first apply the Difference-In-Difference (DID) treatment effect estimator by regressing the change in the outcome between 2010 and 2016 on the treatment variable D, using first-wave participants as the treated group and non-participants as the untreated group. The DID estimator is commonly used in evaluation work and measures the impact of the program intervention by comparing the difference between pre- and post-intervention outcomes across the treated and untreated groups (Todd, 2007).

Using DID requires a parallel trend assumption, which assumes that in the absence of the treatment, the difference between the treated and the untreated groups would have been constant over time. In the present study, this assumption can be tested using a placebo test that applies the DID estimator to the change in the outcome between 2010 and 2016 among second-wave participants, for whom no effect should be detected over this period (since they are not yet participants). If the testing procedure fails to reject the null hypothesis of no impact, we would conclude that the parallel trend assumption holds.[13]

As a robustness check, we then use the DID-matching estimator. The DID matching estimator tackles the issue of self-selection in two steps: first, it deals with selection on observables by comparing treated farms to untreated farms having the same observable characteristics X before the program begins; second, it addresses selection on time-invariant unobservables by subtracting the difference in the pre-treatment outcomes from the difference in post-treatment outcomes between the two groups. Therefore, the DID-matching estimator essentially compares changes in the outcomes over 2010-2016 between first-wave participants and their X-matched untreated counterparts. The set of observable factors X includes a large range of variables extracted from the 2010 census and displayed in Table 2.

Remember that the TFI information recorded in the MA surveys does not necessarily reflect the practices implemented on the parcel enrolled in the Dephy program, and could instead reflect the practices of another parcel on which no special effort was made to reduce chemical pesticides. Using these data in a DID(-matching) estimation is thus likely to lead to underestimation of the impact of the program on the TFI levels of participating farms. As such, the estimate produced by the DID(-matching) approach could be considered a lower-bound estimate of the program's impact.

Although the Dephy reports accurately reflect the phytosanitary practices implemented by the enrolled farms on the enrolled plots, they do not provide information about the phytosanitary practices implemented by the enrolled farms during the pre-treatment year 2010, implying that the DID approach cannot be applied to these data. In this case, one could consider applying the simple matching approach, which relies on the selection on observable assumption[14] and consists in comparing the level of the outcome in 2016 between first-wave participants and their X-matched untreated counterparts. Using these data in a simple matching estimation is likely to lead to overestimation of the impact of the program on participants' TFI for two reasons. First, the DID-matching approach usually outperforms the simple matching approach, meaning that the simple matching estimates may suffer from a (positive) selection bias. Second, the TFI levels on enrolled plots are likely to be higher than those on unrolled plots, as suggested in Table 1. In this case, the estimate generated by the simple matching approach would reflect the maximum impact of the scheme. Estimating the impact using both methods (DID(-matching) using MA surveys and simple matching using Dephy reports) enables us to

[13] If the testing procedure rejects the null hypothesis, this could be interpreted as an anticipation effect, suggesting that the program has an effect even before it starts (Chabé-Ferret and Subervie, 2013). Then, if it is possible to rule out an anticipation effect among second-wave participants, rejection of the null hypothesis could be interpreted as weakening the evidence for the parallel trend assumption (Imbens and Wooldridge, 2009).

[14] The validity of the simple matching estimator also relies on the common support assumption and the stable unit treatment value assumption.

provide the likely bounds of the effects of the Dephy program. Finally, for both the DiD matching and simple matching estimators we impose exact matching on the wine-growing basin. It ensures the control and treated parcel face similar agronomic and meteorological constraints.

4.3 Quantile treatment effects

The heterogeneity of Dephy farms, as shown by the standard deviations of the variables in Table 2, suggests that the impact of the program may vary across participants. In this case, examining the quantile treatment effects would seem to make sense. However, the final sample used for the evaluation of the program using a DID approach is inevitably much smaller than the original sample. For example, considering the sample of farms that were surveyed twice (in 2010 and 2016), we end up with a total number of 3,986 farms, among which 45 entered the program during the first wave of enrolment and 35 during the second wave of enrolment. This sample is too small to explore the potential heterogeneity of program impacts. On the contrary, we can do so using data cross-sectional data, which tell us about the practices of all program participants (rather than just a subset) in a quantile regression model.

5 Results

5.1 Preliminary tests

We first check the parallel tend assumption using a placebo test that applies the DID and DiD matching estimators to the change in the outcome over the 2010-2016 period among second-wave participants, for whom no effect should be detected. Results are reported in Table A1 in the appendix. In all cases, the null hypothesis of no impact cannot be rejected at the standard significance level. This tends to support to the validity of our identification strategy for generating a lower-bound estimate of the impacts of the program.

Then we compare the degree of balance between the treated and untreated groups before and after the matching procedure, for each sample when applying the DID-matching estimator and the simple matching estimator. To do so, we calculate the normalized difference between the two groups for each pre-treatment covariate X. The normalized difference is the difference in means divided by the square root of the sum of variances for both groups, and is the most commonly accepted diagnostic used to assess covariate balance (Rosenbaum and Rubin, 1985). Tables A2, A3, A4, and A5 in the appendix provide the results of the balancing tests for our preferred estimator, the nearest neighbour estimator based on mahalanobis distances. Since the normalized difference is considered negligible when it is below the suggested rule of thumb of 0.25 standard deviations (Imbens and Wooldridge, 2009), we conclude in all cases that the matching procedure was successful in constructing a valid control group.

5.2 Impacts on chemical product use

Table 3 reports our estimates of the impact of the program on the use of chemical products by first-wave participants during the 2016 crop year. The ATT represents the difference between the TFI among participant farmers in 2016 and the TFI they would have obtained had they not participated. In all cases, the impact of the program on the total TFI is estimated with precision. The DID (resp. DID-matching) estimate suggests a significant decrease of about 1.12 points (resp. 2.73 points) in the total TFI, as shown in Col.5 (resp. Col. 3). The simple matching estimate of the ATT moreover indicates that the decrease in the TFI due to the program should not be larger than 3.28 points (Col. 1).

Taken together, these results suggest that the likely impact of the program ranges between 8 and 22 percent.[15] Examining the disaggregated TFI, we moreover find that this improvement is driven by a significant decrease in the the fungicide TFI in particular. Finally, the quantile regression results indicate that the impact of the program does not differ significantly across quantiles, as shown in Figure 2.

5.3 Impacts on the use of biocontrol products

Table 4 reports estimates of the impact of the program on first-wave participants' use of biocontrol products during the 2016 crop year. Here again, the impact of the program on the total TFI is estimated with precision in all cases. The DID (resp. DID-matching) estimate suggests a significant increase of about 0.56 points (resp. 0.71 points) in the total TFI, as shown in Col.5 (resp. Col. 3).

This indicates that the program triggered an increase in the use of biocontrol products of at least 24 percent among participants.[16]

Turning to the disaggregated TFI, the results show that this drastic change in practices is driven by biocontrol products used as fungicides mainly. Figure 3 suggests that the program reinforced existing patterns : those that most increased biocontrol product use are those that had the highest use of biocontrol products.

5.4 Impacts on yields

Table 5 reports estimates of the impact of the program on the yields of first-wave participants in 2016. All three estimator converge suggesting a decrease in yields by 19 to 22%. The quantile regression results show that there is a large heterogeneity in the impact of the program. As shown in Figure 4, we indeed find a significant negative effect on the yields of those who would have had the lowest yield in the absence of the program. In contrast, for the 60 percent

[15] This impact is expressed as a percentage of the estimated counterfactual TFI, which equals 13.08 points $(11.96 + 1.12)$ using the DID approach and 14.72 points $(11.44 + 3.28)$ using the simple matching approach.

[16] This impact is expressed as a percentage of the counterfactual TFI estimate, which equals 1.71 points $(2.27 - 0.56)$ using the DID approach.

of the sample whose yields are the highest in the absence of the program, there appears to be no statistically significant impact.

5.5 Early impacts of the program

Next we use data on phytosanitary practices as measured in the 2013 survey to test for the presence of impacts that materialise at an early stage of participation in the program. Table 6 reports the results of the DID estimates. Quite surprisingly, we do find a significant negative impact of the program on the use of chemical insecticides, and a significant positive impact on the use of biocontrol insecticides and fungicides in 2013, though similar effects were not detected for fungicide in 2016 (see Section 5.2). In contrast, we fail to detect any significant impact on the use of chemical fungicides in 2013 (though we do find significant impacts for the year 2016). These results very likely have to do with the experimental protocol implemented by the Dephy technicians as part of the program. They suggest that switching from chemical to biocontrol products involves a process of trial-and-error that focuses on one product at a time (apparently starting with insecticides).

6 Discussion

As in many empirical studies, our findings are to some extent specific to the period analysed. As such, it is difficult to determine whether the effects we estimate can be generalized to other situations. For example, one may question to what extent the weather conditions during the study year (2016) may have influenced the results. Does technical assistance work best during relatively easy farming years in which there are fewer weeds? Only a replication of the estimates in different contexts would be able to answer this question. We nevertheless believe there are several takeaways from our main findings for the years 2013 and 2016.

First, our main result is quite clear and robust: vineyards participating in the Dephy network were able (on average and by quantile) to reduce their use of chemical products, especially fungicides. Given that viticulture is heavily reliant on pesticides, the impact of the program is quite large – 8 to 22 percent less pesticides compared to the counterfactual scenario in which no program is implemented.

Second, our results indicate that the reduction in the use of chemicals was accompanied by an increase in the use of biocontrol products. On the one hand this can be seen as a positive impact of the program, since switching from traditional phytosanitary products to biocontrol products is an express intention of the French government. On the other hand, biocontrol substances are known to have negative environmental impacts of their own. While more environmentally friendly than their conventional substitutes, some biocontrol still have the potential to degrade the environment, as illustrated by the Asian Ladybird invasions (Turgeon et al., 2011), and only a portion of these products are officially classified as environmentally innocuous (cf.

the "NODU vert" products).

Third, our results also suggest that the switch from chemicals to biocontrol products resulted in a reduction in yields for only a fraction of enrolled farms. This result should be seen as encouraging news given that reducing chemical use while maintaining yields was the main objective of the program. It seems that a in a majority of cases agronomic choices were relevant since they did not affected yields while allowing to decrease pesticide use. These cases can be use as examples of good practices to adopt for other farmers, which was one purpose of the program. Additional estimates are, however, obviously needed in order to confirm that these results hold under a variety of weather conditions.

7 Conclusion

The purpose of this work was to estimate, at the most disaggregated level, namely that of the parcel-level, the effects of participation in the Dephy program. We focused on the emblematic case study of pesticide use in French viticulture. We utilised an approach that addresses the problem of self-selection into the network using a slate of quasi-experimental estimators applied to original data on pesticide use and yields. The main results of our analysis suggest that the program, which provides free technical assistance to participating farms, indeed succeeded in triggering a switch from chemical pesticides to biocontrol products, as well as a decrease in total product use.

More research is needed to strengthen our conclusions regarding the effectiveness of providing free technical assistance to farmers as a strategy for encouraging improved farming practices. The first direction for further research is to clarify the crucial role played by technicians in the success of such programs. In particular, further analysis on potential heterogeneity in the treatment effects depending on technician characteristics is needed. Another direction for further research is the estimation of diffusion effects to evaluate the capacity of the network in disseminating information about new cropping systems and triggering changes in farmer behaviour. In addition, and perhaps more urgently, it seems important to enrich the analysis by estimating the effects of the program on the profitability of enrolled parcels. Such a study would take into account the effects of the change in phytosanitary practices (e.g. lower expenses for chemicals but higher expenses for biocontrol products) as well as the implications for farmers' revenue (possibly lower yields but better quality wine that could be sold at a higher price).

Finally, this paper contributes to the debate about the ability of public policies to play a role in reducing the negative environmental impacts of agricultural activity through the provision of technical assistance rather than conditional compensation schemes. Our findings can be compared to the effectiveness of other agri-environmental schemes targeting the use of pesticides in French vineyards. While Kuhfuss and Subervie (2018) find that the quantity of herbicides used by participants in such schemes are about 40-50 percent lower than they would otherwise have been, we found that the Dephy program generates a 8 to 20% reduction in total pesticide use. The complementarity or substitutability between technical assistance and conditional payments could be of interest in the continued refinement of more effective agri-environmental programs and ultimately for the pursuit of a transition to sustainable agro-ecological systems in the near future.

Acknowledgments

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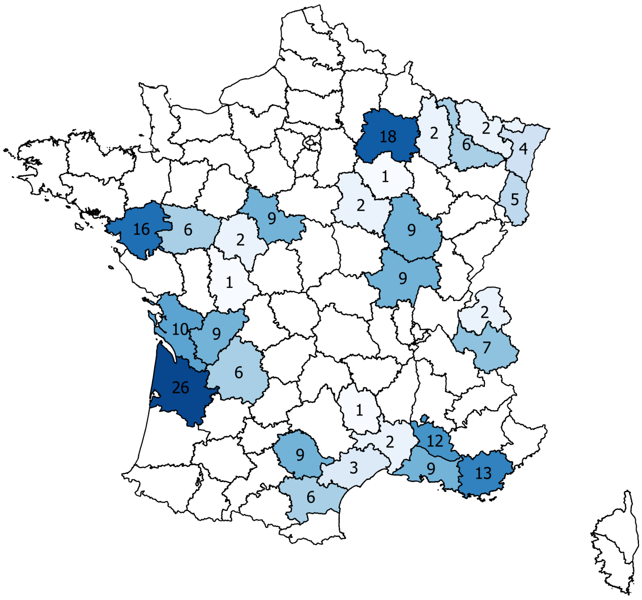
Figures and Tables

Figure 1: Location of the DEPHY vineyards



Source: Authors using Agrosyst data.

Figure 2: Quantile treatment effects on chemical TFI in 2016

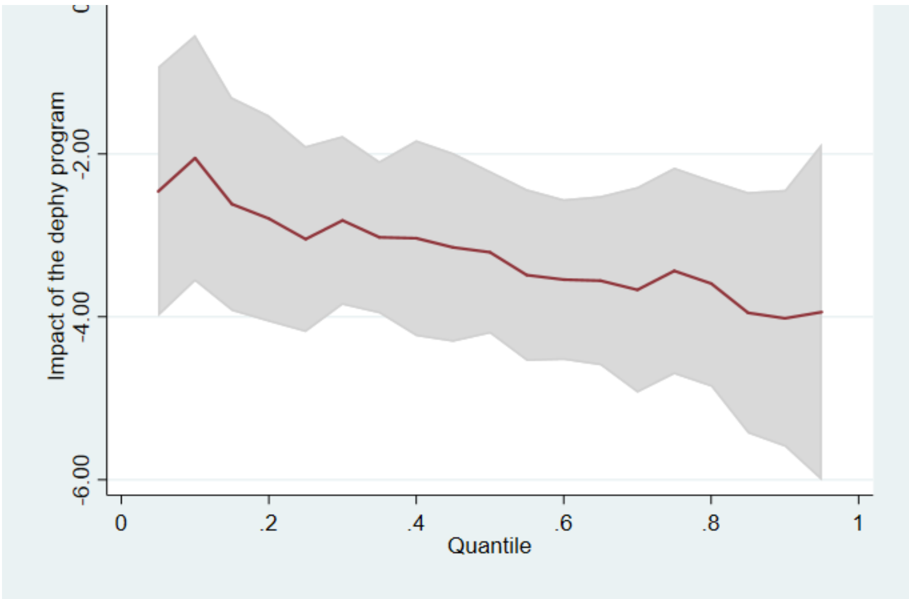


Figure 3: Quantile treatment effects on biocontrol TFI in 2016

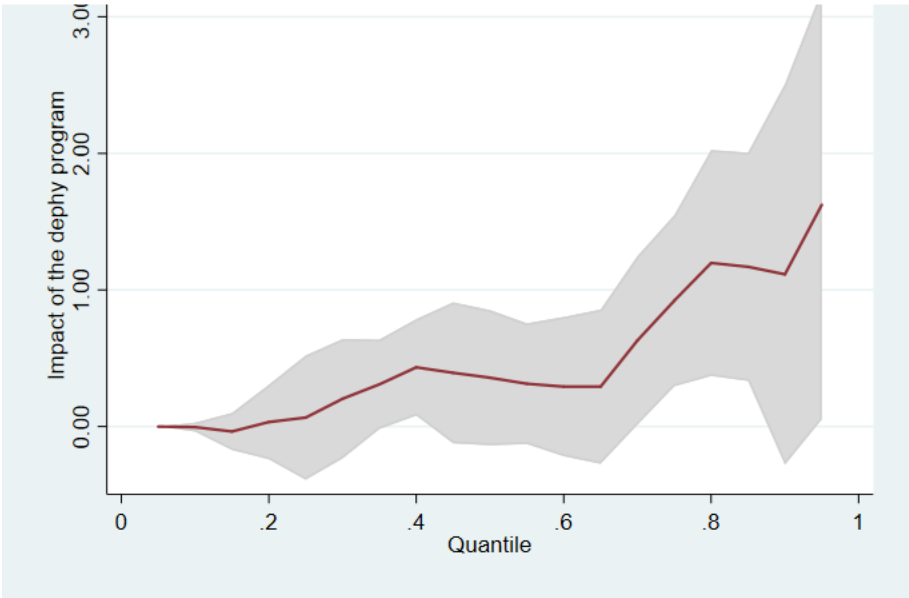


Figure 4: Quantile treatment effects on yields in 2016

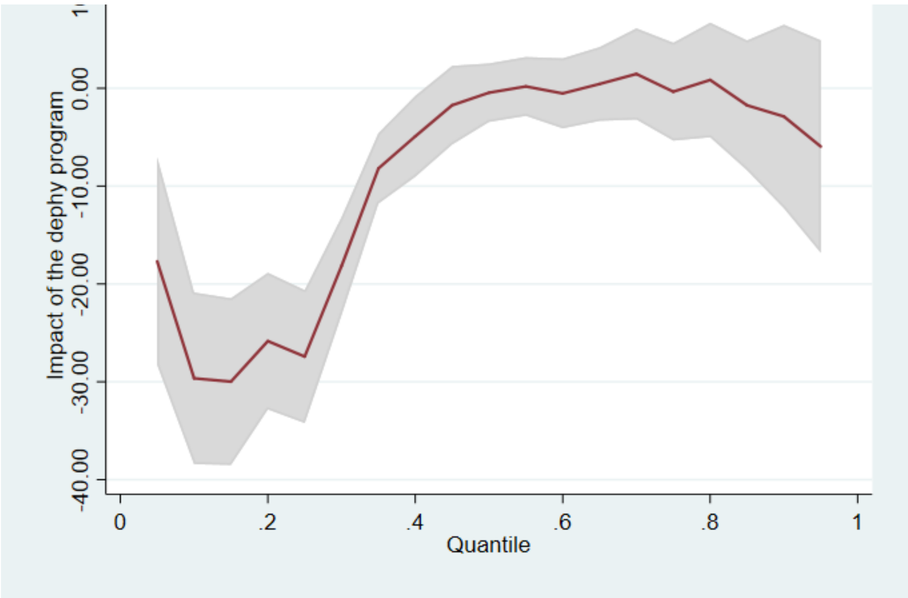


Table 1: Treatment Frequency Index and yields: Descriptive statistics by group

Outcome	Year	Non-participants Obs	Non-participants Mean	Participants Obs	Participants Mean
		Cross-sectional estimations			
TFI Biocontrol	2016	5108	2.96	122	4.20
TFI Chemical	2016	5108	14.93	125	11.14
Yield	2016	4437	54.94	78	45.02
		Difference-in-difference estimations			
TFI Biocontrol	2010	3957	1.17	45	0.77
TFI Chemical	2010	3957	12.13	45	11.02
TFI Biocontrol	2013	3957	1.60	45	1.89
TFI Chemical	2013	3957	14.07	45	12.02
TFI Biocontrol	2016	3957	2.11	45	2.27
TFI Chemical	2016	3957	14.20	45	11.96
Yield	2010	3957	64.87	45	61.23
Yield	2013	3957	59.12	45	53.35
Yield	2016	3957	54.10	39	43.47

Note: This table provides the mean value of the TFI in the two groups, as computed from the two sources of data, namely the survey run by the French Ministry of Agriculture and the reports collected from Dephy network. Treated units refers to the farms enrolled in the programme while untreated units refer to other farms.

Table 2: Main characteristics of farms: Descriptive statistics by group

Variable	Unit	Untreated Obs	Untreated Mean	Untreated Std. Dev.	Treated Obs	Treated Mean	Treated Std. Dev
On-farm labour	annual work units	6105	5322.01	18661.60	161	5548.76	5609.00
Climate insurance	yes=1	6105	0.49	0.50	161	0.50	0.50
Share of sales in short circuit	%production	6105	0.48	0.50	161	0.67	0.47
Vinayard surface area	ares	6105	3116.50	6225.12	161	3208.81	4069.06
Diversification of activities	yes=1	6105	0.17	0.38	161	0.26	0.44
Calibration of pesticide sprayer	yes=1	6105	0.30	0.46	161	0.37	0.48
Sex of head of the farm	1=men, 2=women	6105	1.16	0.37	161	1.17	0.38
Year of birth of head of the farm	year	6105	1961.89	10.39	161	1965.15	8.81
Head of the farm got bachelor's degree	yes=1	6105	0.53	0.50	161	0.73	0.44
Spouse has agricultural activity	yes=1	6105	0.28	0.45	161	0.35	0.48
Spouse has non-agricultural activity	yes=1	6105	0.27	0.44	161	0.28	0.45
Wine production	hectoliters per ares	6105	0.57	0.70	161	0.51	0.25
PDO and PGI production	%production	6105	0.85	0.32	161	0.85	0.32
Utilised agricultural area (UAA)	ares	6105	4990.58	7639.53	161	4372.24	5073.53
Participation in farmer association	yes=1	6105	0.63	0.48	161	0.80	0.40
UAA without pesticides	%UAA	6105	0.15	0.27	161	0.18	0.33
UAA under organic farming	%UAA	6105	0.06	0.22	161	0.12	0.30
Surveyed plot is cultivated as organic*	yes=1	6105	0.07	0.26	161	0.16	0.36

Note: This table provides the mean value of the main characteristics in the two groups, as computed from the census run by the French Ministry of Agriculture in 2010. Only the variable with a star (*) is from the 2010 Farm Practices survey.

Table 3: Impact on chemical product use in 2016

	Simple Matching			DID-matching			DID		
			(2)	(3)		(4)	(5)		(6)
	ATT		Y_1	ATT		Y_1	ATT		Y_1
Herbicides	-0,08		0,64	-0,14		0,45	-0,21	**	0,46
	0,10			0,15			0,096		
Fungicides	-2,49	***	9,62	-2,80	***	10,83	-0,87		10,34
	0,46			0,97			0,71		
Insecticides	-0,31	**	1,07	0,09		1,31	-0,13		1,07
	0,12			0,34			0,22		
All products	-3,28	***	11,44	-2,73	**	12,70	-1,12	♮	11,96
	0,54			1,11			0,76		
n_1	107			35			45		
n_0	3852			2142			3939		

Note: This tables provides the results of the estimates of the impact of the Dephy program on the TFI in 2016 among treated farms, using three different estimators. ATT refers to the average treatment effect on the treated units. Robust standard-errors are in parentheses below the coefficients. Y_1 is the mean value of the TFI of the surveyed plots in the treated group. DID-matching and simple matching estimators rely on a Mahalanobis-distance-matching procedure based on the best matched untreated unit for each treated unit. n_1 (resp. n_0) refers to the number of treated (resp. untreated) units in the sample. Dependent variables for DID and DID-matching estimates rely on survey data (where the plots considered are not necessarily enrolled in the program). Dependent variables for simple matching estimates rely on Dephy data (where the plots considered are enrolled in the program).***, **, *, and ♮ denote rejection of the null hypothesis of no impact at the 1%, 5%, 10% and 15% significance levels, respectively.

Table 4: Impact on biocontrol product use in 2016

	Simple Matching			DID-matching			DID		
	(1)		(2)	(3)		(4)	(5)		(6)
	ATT		Y_1	ATT		Y_1	ATT		Y_1
Fungicides	0,68	♮	3,94	0,89	**	2,36	0,53	*	2,09
	0,46			0,37			0,31		
Insecticides	-0,01		0,00	-0,18		0,23	0,03		0,18
	0,01			0,18			0,07		
All products	0,80	*	4,08	0,71	**	2,59	0,56	*	2,27
	0,46			0,33			0,29		
n_1	105			35			45		
n_0	3852			2142			3939		

Note: This tables provides the results of the estimates of the impact of the Dephy program on the TFI in 2016 among treated farms, using three different estimators. ATT refers to the average treatment effect on the treated units. Robust standard-errors are in parentheses below the coefficients. Y_1 is the mean value of the TFI of the surveyed plots in the treated group. DID-matching and simple matching estimators rely on a Mahalanobis-distance-matching procedure based on the best matched untreated unit for each treated unit. n_1 (resp. n_0) refers to the number of treated (resp. untreated) units in the sample. Dependent variables for DID and DID-matching estimates rely on survey data (where the plots considered are not necessarily enrolled in the program). Dependent variables for simple matching estimates rely on Dephy data (where the plots considered are enrolled in the program).***, **, *, and ♮ denote rejection of the null hypothesis of no impact at the 1%, 5%, 10% and 15% significance levels, respectively.

Table 5: Impact on yields in 2016

	Simple Matching			DID-matching			DID		
	(1) ATT		(2) Y_1	(3) ATT		(4) Y_1	(5) ATT		(6) Y_1
Yield	-13,02	***	45,37	-8,68	*	37,44	-10,47	***	43,47
	4,61			4,82			3,85		
n_1	62			27			39		
n_0	2,833			1527			3137		

Note: This tables provides the results of the estimates of the impact of the Dephy program on the TFI in 2016 among treated farms, using three different estimators. ATT refers to the average treatment effect on the treated units. Robust standard-errors are in parentheses below the coefficients. Y_1 is the mean value of the TFI of the surveyed plots in the treated group. DID-matching and simple matching estimators rely on a Mahalanobis-distance-matching procedure based on the best matched untreated unit for each treated unit. n_1 (resp. n_0) refers to the number of treated (resp. untreated) units in the sample. Dependent variables for DID and DID-matching estimates rely on survey data (where the plots considered are not necessarily enrolled in the program). Dependent variables for simple matching estimates rely on Dephy data (where the plots considered are enrolled in the program).***, **, *, and ♮ denote rejection of the null hypothesis of no impact at the 1%, 5%, 10% and 15% significance levels, respectively.

Table 6: Early impacts of the program (ATT in 2013)

	(1)		(2)
Outcomes	ATT		Y_1
Chemical (TFI)			
Herbicides	0.00		0.51
	(0.09)		
Fungicides	0.37		10.94
	(0.56)		
Insecticides	-0.19	*	0.85
	(0.1)		
All products	0.17		12.3
	(0.61)		
Biocontrol (TFI)			
Fungicides	0.53	*	1.81
	(0.28)		
Insecticides	0.11	*	0.23
	(0.06)		
All products	0.64	**	2.04
	(0.31)		
Yield (hl/ha)	-1.91		50.7
	(1.87)		

Note: This table provides the estimates of the effects of Dephy program on the TFI and yield in 2013 among treated units, using the DID estimator. ATT refers to the average treatment effect on the treated units. Robust standard-errors are in parentheses below the coefficients. Y_1 is the mean value of the outcome of the surveyed plots in the treated group. In all estimates the sample size is 4,819, including 62 treated units. DID estimates rely on survey data (where the plots considered are not necessarily enrolled in the program). Asterisks ***, **, and * denote rejection of the null hypothesis of no impact at the 1%, 5% and 10% significance levels, respectively.

Appendix

Additional figures and tables

Figure A1: Distribution of the Chemical TFI

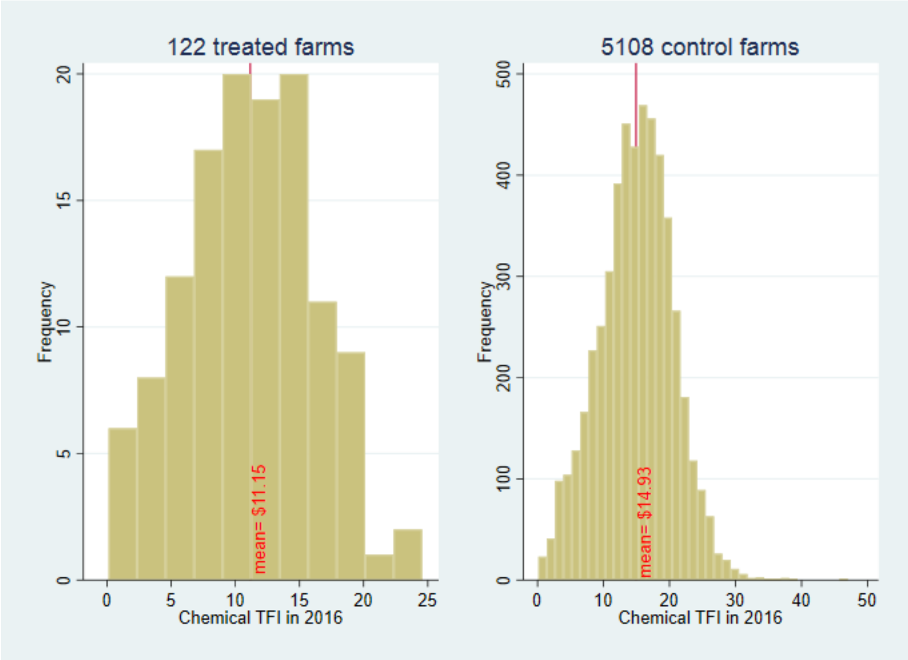


Figure A2: Distribution of the Biocontrol TFI

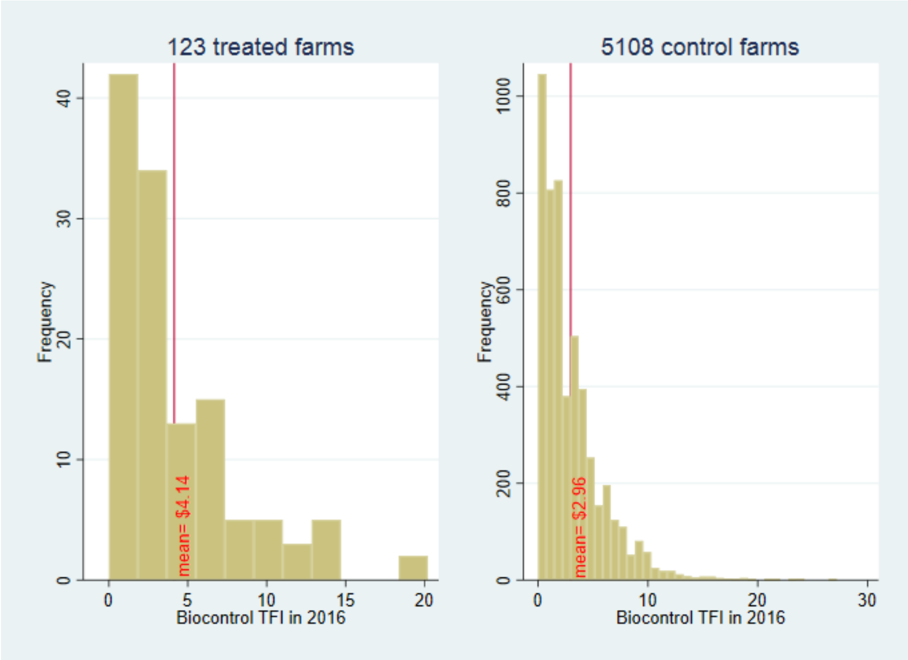


Figure A3: Distribution yields (in hl/ha)

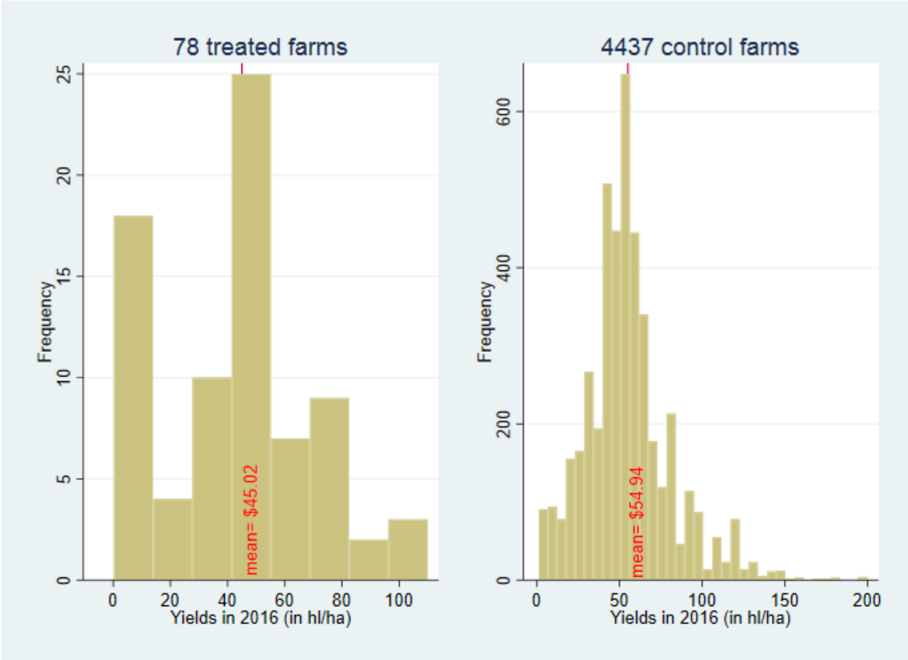


Table A1: Impacts of the program on second-wave treated units (placebo test)

	DID		DID-matching	
	(3) ATT	(4) Y_1	(1) ATT	(2) Y_1
Chemical (TFI)	-0,74	12,57	-0,82	12,93
	0,86		1,59	
Biocontrol (TFI)	0,56	2,32	0,27	1,79
	0,40		0,54	
Yield (hl/ha)	-4,83	44,67	7,96	44,17
	3,96		8,24	
n_1	36		28	
n_0	3957		1,505	

Note: This table provides the estimates of the effects of Dephy program on the TFI and yield in 2016 among second-wave treated units using the DID and DID-matching estimators. ATT refers to the average treatment effect on the treated units. Robust standard-errors are in parentheses below the coefficients. Y_1 is the mean value of the outcome of the surveyed plots in the treated group. n_1 refers to the number of treated units in the sample. DID estimates rely on survey data (where the plots considered are not necessarily enrolled in the program). Asterisks ***, **, and * denote rejection of the null hypothesis of no impact at the 1%, 5% and 10% significance levels, respectively.

Table A2: Balancing test for the estimation of the impacts on TFI using DID-matching

	Standardized Differences	
	Before	After
On-farm labour	0.493	0.193
Climate insurance	-0.126	0.114
Share of sales in short circuit	0.615	-0.069
Vinayard surface area	0.458	0.127
Diversification of activities	-0.068	0.000
Calibration of pesticide sprayer	0.611	0.171
Sex of head of the farm	-0.117	0.000
Year of birth of head of the farm	0.128	0.071
Head of the farm got bachelor's degree	0.382	0.063
Spouse has agricultural activity	-0.110	-0.129
Spouse has non-agricultural activity	0.028	0.000
Wine production	-0.104	-0.140
PDO and PGI production	-0.104	-0.140
Utilised agricultural area (UAA)	0.208	0.119
Participation in farmer association	0.570	0.178
UAA without pesticides	-0.118	0.041
UAA under organic farming	0.122	-0.013
Surveyed plot is cultivated as organic	-0.017	0.000

Note: This table gives the standardized difference in means between the treated and the untreated groups, before and after the matching procedure undertaken to estimate the impact of the program on the TFI using DID-matching. The total number of treated is 46.

Table A3: Balancing test for the estimation of the impacts on yields using DID-matching

	Standardized Differences	
	Before	After
On-farm labour	0.532	0.266
Climate insurance	-0.102	0.110
Share of sales in short circuit	0.894	0.066
Vinayard surface area	0.481	0.158
Diversification of activities	-0.285	0.000
Calibration of pesticide sprayer	0.589	0.333
Sex of head of the farm	-0.115	-0.108
Year of birth of head of the farm	0.064	-0.029
Head of the farm got bachelor's degree	0.260	0.039
Spouse has agricultural activity	-0.024	0.042
Spouse has non-agricultural activity	-0.012	0.000
Wine production	-0.104	-0.140
PDO and PGI production	-0.395	-0.295
Utilised agricultural area (UAA)	0.221	0.138
Participation in farmer association	0.776	0.333
UAA without pesticides	-0.077	-0.011
UAA under organic farming	0.190	-0.117
Surveyed plot is cultivated as organic	0.020	0.000

Note: This table gives the standardized difference in means between the treated and the untreated groups, before and after the matching procedure undertaken to estimate the impact of the program on the yields using DID-matching. The total number of treated is 34.

Table A4: Balancing test for the estimation of the impacts on TFI using simple matching

	Standardized Differences	
	Before	After
On-farm labour	0.001	0.186
Climate insurance	0.179	0.206
Share of sales in short circuit	0.283	-0.019
Vinayard surface area	0.038	0.094
Diversification of activities	0.212	0.109
Calibration of pesticide sprayer	0.167	0.176
Sex of head of the farm	-0.042	0.136
Year of birth of head of the farm	0.341	0.129
Head of the farm got bachelor's degree	0.541	0.087
Spouse has agricultural activity	0.113	-0.020
Spouse has non-agricultural activity	0.044	0.086
Wine production	-0.225	0.005
PDO and PGI production	-0.027	-0.016
Utilised agricultural area (UAA)	-0.045	0.102
Participation in farmer association	0.355	0.067
UAA without pesticides	0.194	0.091
UAA under organic farming	0.269	0.063
Surveyed plot is cultivated as organic	0.159	0.070

Note: This table gives the standardized difference in means between the treated and the untreated groups, before and after the matching procedure undertaken to estimate the impact of the program on the TFI using simple matching. The total number of treated is 107.

Table A5: Balancing test for the estimation of the impacts on yields using simple matching

	Standardized Differences	
	Before	After
On-farm labour	0.088	0.055
Climate insurance	0.369	0.232
Share of sales in short circuit	0.194	0.128
Vinayard surface area	0.131	0.035
Diversification of activities	0.290	0.073
Calibration of pesticide sprayer	0.134	0.133
Sex of head of the farm	-0.090	0.096
Year of birth of head of the farm	0.378	0.323
Head of the farm got bachelor's degree	0.450	0.073
Spouse has agricultural activity	0.149	0.034
Spouse has non-agricultural activity	0.009	0.077
Wine production	0.062	-0.062
PDO and PGI production	-0.231	0.036
Utilised agricultural area (UAA)	0.124	0.042
Participation in farmer association	0.166	-0.036
UAA without pesticides	0.070	0.057
UAA under organic farming	0.113	0.094
Surveyed plot is cultivated as organic	0.128	0.049

Note: This table gives the standardized difference in means between the treated and the untreated groups, before and after the matching procedure undertaken to estimate the impact of the program on the yields using simple matching. The total number of treated is 62.

Details on the construction of the TFI using Dephy reports

This section describes the methodology for calculating TFI from the information collected in Dephy reports. We apply the main rules coming from the TFI methodological handbook of the Ministry of Agriculture.

General principles

The first step to calculate the TFI for each of the treatments declared by the winegrower i.e., for each application of a product during a passage. TFI of a treatment is obtained by dividing the actual applied dose by the reference dose for the product in question, taking into account the proportion of area treated:

$$\text{TFI}_{\text{treatment}} = \frac{\text{applied} \quad \text{dose}}{\text{reference} \quad \text{dose}} * \frac{\text{treated} \quad \text{area}}{\text{total} \quad \text{area}}.$$

Adjuvants, BC products and product that can be used in organic farming without a marketing authorization are not taken into account in the calculation of TFI. The TFI of a space unit is the sum of the TFI performed on that space unit during a given period, usually the crop year. TFI can be spatially aggregated to obtain, for example, a TFI representative of a farm. Whatever the level of aggregation, the principle is the same: the TFI is a weighted average of the TFI of space unit.

Reference doses

Reference doses are established on the basis of information on authorized products and uses, for each crop year. There are two types of reference doses:

- Reference doses for the target: defined for each product, crop, pest or function to be treated (herbicide, fungicide etc), and correspond to the maximum authorized dose for each product and use.
- Reference doses for the crop : defined for each product and crop, and correspond to the minimum of the reference doses defined for the target for the product and crop in question.

Here we consider this latter reference dose because Dephy records of pesticide application do not provide information on the target. Conversions are made when the applied dose is not expressed in the same unit as the reference dose.

Adjustments

The adjustments concern three types of situations: - TFI of a treatment can not be calculated because one or more necessary information is missing (e.g. the reference dose) or the units are incompatible. - TFI of a treatment is considered abnormal i.e., it is not included between 0.1 and 2. In the first case, the adjustments consist in substituting the ratio of doses by 1 if a dose is missing or units incompatible and substituting the proportion of surface treated by 1 if missing. In the case of an abnormal TFI, its value is substituted by 1.