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

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**Abstract**

In 2008, the French government announced an important shift in agricultural policy, calling for halving the use of pesticides in the next ten years. Since then, it has spent 40 million euros a year on implementing the so-called Ecophyto plan. In this paper, we evaluate the success of this program, focusing on its flagship scheme, which has provided technical assistance to 3,000 volunteer pilot farms since 2011. To do so, we use panel data collected from a representative sample of vineyards: the agricultural systems known as the largest users of pesticides. We use a slate of quasi-experimental approaches 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 while others seems to have maintained yields. Although below the expectations of the French government, these results seem rather encouraging, as they suggest that technical assistance alone can be effective in reducing significantly pesticide use in the agricultural sector.

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

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

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# 1 Introduction

With an agricultural sector particularly developed, France is the first user of pesticides in ton per year in Europe. To lose 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 has been 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 (Stokstad, 2018).

We 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.

We 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 (as in Europe) or in return for retiring environmentally sensitive land from farming activity (as in the US). On the one hand, there are reasons to be pessimistic on the efficiency of such disposal, since the program does not impose any quantified target to participating farms, contrary to most conditional payment programs. Furthermore, previous studies are 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 whole production process, while conditional payment programs 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, and DID-matching.[1] Taken together, our observational approaches all point

[1]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

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 pesticides use reductions 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 those involved in the application of pesticides (Wilson and Tisdell, 2001).[2] 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).[3] Jacquet et al. (2011) have constructed

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.

[2]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).

[3]The literature addressing reductions in pesticide use is generally based on specific areas (Nave et al., 2013; Petit et al., 2015), on 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 sustain-

cropping system prototypes[4] 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 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.[5]

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 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

ability indicators.

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

[5]Our work differs from theirs along several dimensions. First, they focus on field crops while we focus on vineyards. Second, they use only data on farms engaged in the Dephy program, so cannot determine what would have happened in the absence of the program, and thus the proper impact of the program on pesticide use and yields. For a more general critical view on Lechenet et al. (2017) we refer the reader to Frisvold (2019).

[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).

(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]

Nevertheless, the literature is mitigated on the capacity of agricultural extension services to induce change in practices.[9] A main reason in developed countries is that farmers get information from many sources (Anderson and Feder, 2004). Yet, extension is expected to have its greatest impact in the early stage of the dissemination of a practice, such the ones promoted through the Dephy network. Finally, attributing the impact on agricultural performances of extension services is complex due the numerous factors affecting agricultural performances. The lack of evidence on the impact of extension services and the ambiguity on its real capacity to make a difference in the important topic of pesticide use reductions stress the need to lead the subsequent impact analysis.

## 2.2 The Dephy program

In this context and issuing from the Grenelle consultation process on environmental issues, the Ecophyto 2008 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, 1,900 farms enrolled in the Dephy program between 2011 and 2012. In 2016, an extension of the program was implemented and the network today gathers 3,000 farms from field crops, to industrial crops, to orchards, to wineyards. 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

[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).

[9]See Anderson and Feder (2007) for a general review, or Marsh and Pannell (2002) and Tamini (2011) and for case studies in developed countries

a collective project for 5 years. First-wave 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. In practice, engineers conduct an initial 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.[10] The network shares its experience and results with farms outside of the program through local communications outlets and practical demonstrations.

# 3 Data

## 3.1 Data sources

To lead the analysis, we used two sources of data on phytosanitary practices of vineyards: three national surveys carried out by the Department of Statistics of the French Ministry of Agriculture (MA) and the Agrosyst database that describes the cropping systems implemented on Dephy farms and documents their development over time. The surveys were run in 2010, 2013, and 2016, on a sample of 9,369 wine farmers, who were each interviewed at least once about their practices on randomly chosen parcels. Among these, 3,984 parcels were investigated in the three surveys. The Agrosyst database records all phytosanitary product applications of Dephy vineyards, at the cropping system level, from 2011 to 2016.[11]

We used the Agrosyst data in two ways. First, we matched the Agrosyst database to the national surveys to determine how many Dephy farms had been surveyed in 2010, 2013 and/or 2016. We combine these two databases on the basis of a common identifier (the farm business identification number) and found that 182 Dephy farms had been surveyed at least once in 2010, 2013, or 2016. Most of them (63 percent) were enrolled in the program in 2011, 2012 or 2013, while the others were enrolled much later (in 2016). In our analysis, we thus distinguish early participants from second-wave participants. At the end, we end up with 45 farms from first-wave participants and 36 farms from the second-wave participants, who were surveyed three times.

[10]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).

[11]A cropping system is series of plot homogeneously managed, i.e., all organic vineyards, or all under a common certification mark.

Second, we used the Agrosyst database to gather information on the use of phytosanitary products by all the Dephy vineyards (not only those that appeared in the national surveys). In particular, we were able to retrieve comprehensive information on phytosanitary product use in 2016 for 125 of the 207 cropping systems that entered the Dephy network between 2011 and 2012 (first-wave participants) .

Finally, we used the 2010 agricultural census to gather information on socio-economic and production characteristics of farms before the program starts.

## 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.[12] 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.[13] 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 the Agrosyst database. It also reports mean values of the yield as measured by the amount of wine (in hectoliters) that is produced per hectare of vineyard.

Table 1 calls for three comments. First, looking at participating farms for which two values of the TFI are provided, we observe that the average value of the chemical TFI computed from Agrosyst data (11.14) is lower than that provided by the surveys (11.96). This is consistent with the fact that the TFI recorded in the surveys does not systematically reflect the practices used on the parcel enrolled in the program, but could reflect the practices used on another parcel of

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

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

the farm, one that is likely farmed under a conventional cropping system and therefore a higher TFI.[14] Second, the use of biocontrol products increases over time in both groups, – from 0.77 to 2.27 among participants and from 1.17 to 2.11 among non-participants – which suggests a general tendency towards improved farming practices over the period. Third, Dephy farms and non-Dephy farms differ in many ways. The use of pesticides is different across groups throughout the period, especially in 2016, when Dephy farms have a significantly lower TFI (11.14 according to Agrosyst data) than non-Dephy farms (14.2), something that is also clearly displayed in Figure A1. The use of biocontrol pesticides is different across groups as well in 2016, when the TFI equals 4.20 among Dephy farms according to Agrosyst data versus 2.11 among non-Dephy farms (see also  A2). Also, according to the MA surveys Dephy farms recorded lower yields in 2016 (45.02 lh per ha) than non-Dephy farms (54.94 hl per ha). This is not confirmed by Agrosyst data,as shown in Figure A3 as well. Our goal is to assess the extent to which these gaps can be attributed to the program. We come back to the discrepancy between MA surveys and Agrosyst data on yields in 2016 in Section 5.4 and 6.

### 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.

[14] Although 70% of the Dephy farms identified in the MA surveys enrolled 100% of their utilised agricultural area (UAA) in the program.

# 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, which 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).[15] In practice, we regress the change in the outcome between 2010 and 2016 on the treatment variable $D$, using first-wave participants as treated group and non-participants as untreated group.

[15]This identification strategy relies on the stable unit treatment value assumption (SUTVA, which implies here that the practices of non-participants have not been altered by the Dephy program (Rubin, 1978). Although that we cannot exclude that some Dephy winegrowers had shared their experiences and results with non-Dephy winegrowers, it is reasonable to assume that this sharing of experience is unlikely to be sufficient to modify the practices of non-Dephy farms at this stage of the program.

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. 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).

Following Ferraro and Miranda (2017) and Haninger et al. (2017), we moreover 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. This strategy allows us to perform an exact matching procedure on the wine-growing basins, which ensures that control and treated parcels are subject to similar agronomic and meteorological constraints, a very important condition when dealing with agricultural outcomes.

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 should be considered a lower-bound estimate of the program's impact.

We then turn to the Agrosyst data, which accurately reflect the phytosanitary practices implemented by the enrolled farms on the enrolled plots. Since they do not provide information about the phytosanitary practices implemented by the enrolled farms during the pre-treatment year 2010, the DID approach cannot be applied to these data. We thus opt for a simple matching approach, which relies on the selection on observable assumption.[16] In prac-

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

tice, we compare the level of the outcome in 2016 between first-wave participants and their $X$-matched untreated counterparts, using the Agrosyst data to compute 2016 outcome levels among treated farms and the MA surveys to compute 2016 outcome levels among untreated farms. This can be done through a harmonization of TFI formulas in both datasets (see details in Appendix).

Running simple matching estimates is likely to lead to overestimation of the impact of the program on participants' TFI since the DID-matching approach usually outperforms the simple matching approach, meaning that the simple matching estimates may suffer from a (positive) selection bias. In this case, the estimate generated by the simple matching approach would reflect the maximum impact of the scheme. Therefore, using both methods (DID-matching using MA surveys and simple matching using Dephy reports) enables us to provide the likely bounds of the effects of the Dephy program.

# 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.[17] Examining the disaggregated TFI, we moreover find that this improvement is driven by a significant decrease in the fungicide TFI in particular. This has important consequences since fungus fight is the main source of pesticide use in winegrowing, contributing to 85% of the total TFI.

## 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.[18]

Turning to the disaggregated TFI, the results show that this drastic change in practices is driven by biocontrol products used as fungicides mainly.

## 5.4 Impacts on yields

Table 5 reports estimates of the impact of the program on the yields of first-wave participants in 2016. The two DiD estimators converge suggesting a decrease in yields by 19 to 22%. The Matching estimator (Col. 1) lead to a different conclusion; that the Dephy program did not have any significant impact on yields (coefficient non significantly different from 0). The discrepancy between the conclusions of the two estimators call for further investigation. The source of data for yields in 2016 in the treated group are different. Looking at the distribution of yields in the two database for the treated group is illuminating. Figure 2, shows that even if the general distribution is similar in the Agrosyst and MA surveys data, there is no yields below 30 HL/ha in the Agrosyst database. Combined to the fact that numerous data on yields are missing in the Agrosyst database (information available for only 47 farms), it leads us to

[17]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.

[18]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.

suspect that the database does not contain cases of very low yields observed in the program. By chance, in this project, we evaluate the impact of the program using two different sources of data : one that is built from the data collection from the technical engineers working in the program (Agrosyst) and the other that comes from regular surveys from the Ministry of agriculture (MA surveys). Available information leads us to conclude that even if a fraction of farms maintained yields, some suffered severe losses, leading us to find a negative impact of the Dephy program on yields in the DiD regressions.

### 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 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[19] for 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 several 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

[19] A reduction in yields does not necessarily imply a decrease in profitability. In recent years, organic viticulture has gained more and more importance in Europe, with double-digit growth rates achieved annually since 2008, according to FiBL survey (Willer et al., 2013). This suggests that organic viticulture has become profitable.

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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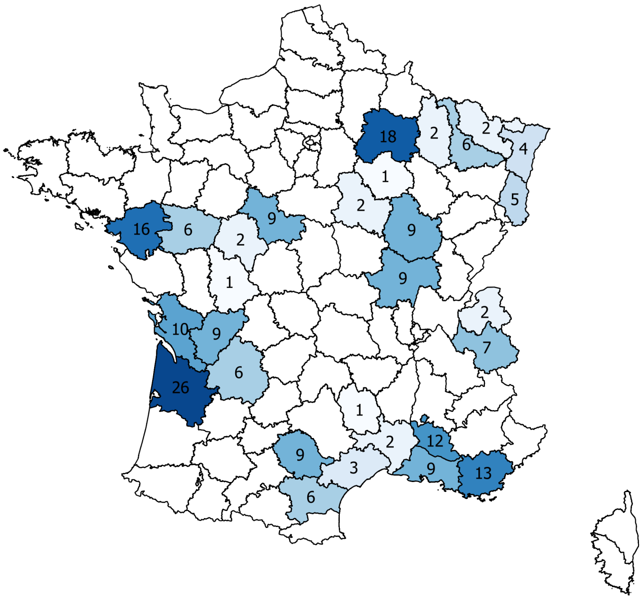
# Figures and Tables

Figure 1: Location of the DEPHY vineyards




Source: Authors using Agrosyst data.

Figure 2: Distribution of yields in 2016 for Dephy farms in the two databases

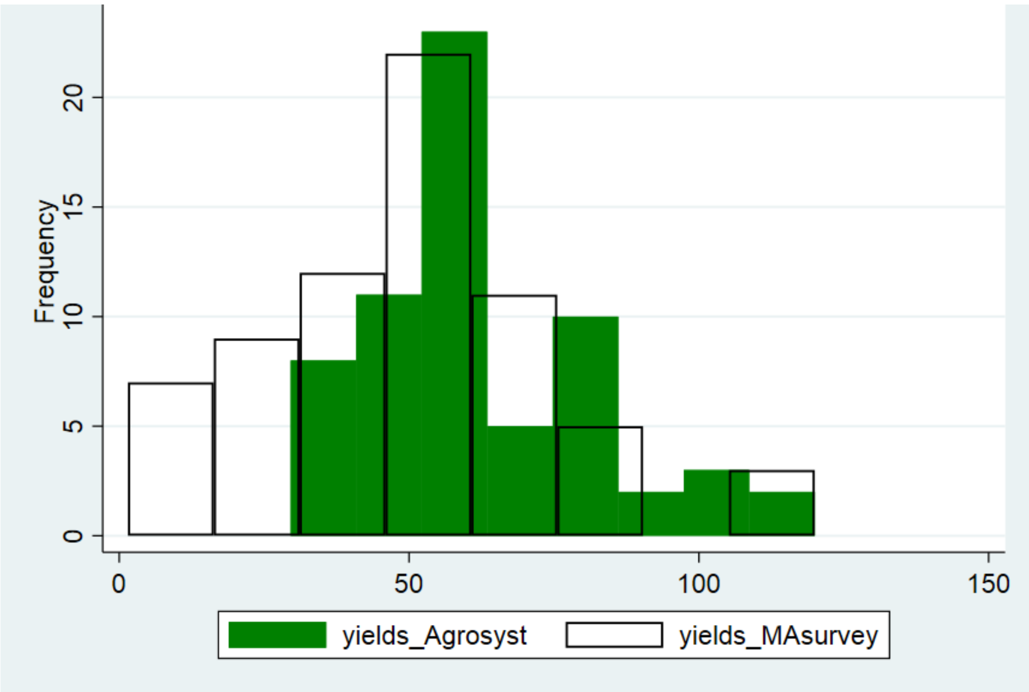


Table 1: Treatment Frequency Index and yields: Descriptive statistics by group

| | non-Dephy farms (from MA surveys) | | Dephy farms (from MA surveys) | | Dephy farms (from Agrosyst) | |
|---|---|---|---|---|---|---|
| Chemical pesticide use | Obs. | Mean | Obs. | Mean | Obs. | Mean |
| TFI in 2010 | 3957 | 12.13 | 45 | 11.02 | n.a | n.a |
| TFI in 2013 | 3957 | 14.07 | 45 | 12.02 | n.a | n.a |
| TFI in 2016 | 3957 | 14.2 | 45 | 11.96 | 124 | 11.14 |
| Biocontrol pesticide use | | | | | | |
| TFI in 2010 | 3957 | 1.17 | 45 | 0.77 | n.a | n.a |
| TFI in 2013 | 3957 | 1.6 | 45 | 1.89 | n.a | n.a |
| TFI in 2016 | 3957 | 2.11 | 45 | 2.27 | 123 | 4.2 |
| Yields (hl per ha) | | | | | | |
| Yields in 2010 | 3957 | 64.87 | 45 | 61.23 | n.a | n.a |
| Yields in 2013 | 3957 | 59.12 | 45 | 53.35 | n.a | n.a |
| Yields in 2016 | 3957 | 54.1 | 39 | 43.47 | 64 | 61.60 |

Note: This table provides the mean value of the TFI and the yields in the two groups, as computed from the two sources of data, namely the surveys run by the French Ministry of Agriculture and the Agrosyst database.

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

| | | | Untreated | | | Treated | |
|---|---|---|---|---|---|---|---|
| Variable | Unit | Obs | Mean | Std. Dev. | Obs | Mean | 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 | $\natural$ | 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 $\natural$ 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) | (2) | (3) | | (4) | (5) | | (6) |
| | ATT | Y_1 | ATT | | Y_1 | ATT | | Y_1 |
| Yield | 5.24 | 64.50 | -8.68 | * | 37.44 | -10.47 | *** | 43.47 |
| | 3.66 | | 4.82 | | | 3.85 | | |
| n_1 | 47 | | 27 | | | 39 | | |
| n_0 | 2485 | | 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 $\natural$ 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

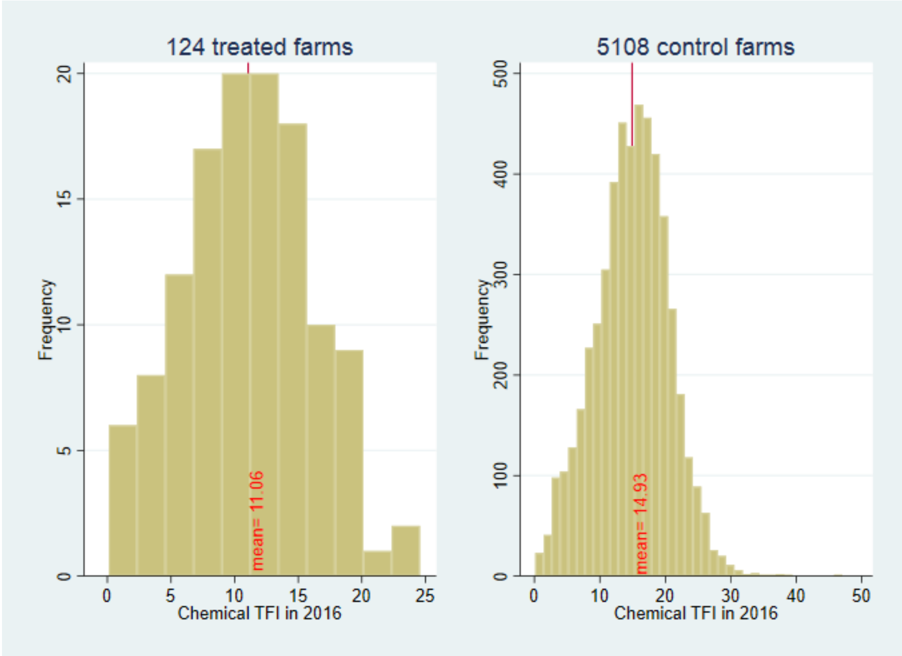


Figure A2: Distribution of the Biocontrol TFI

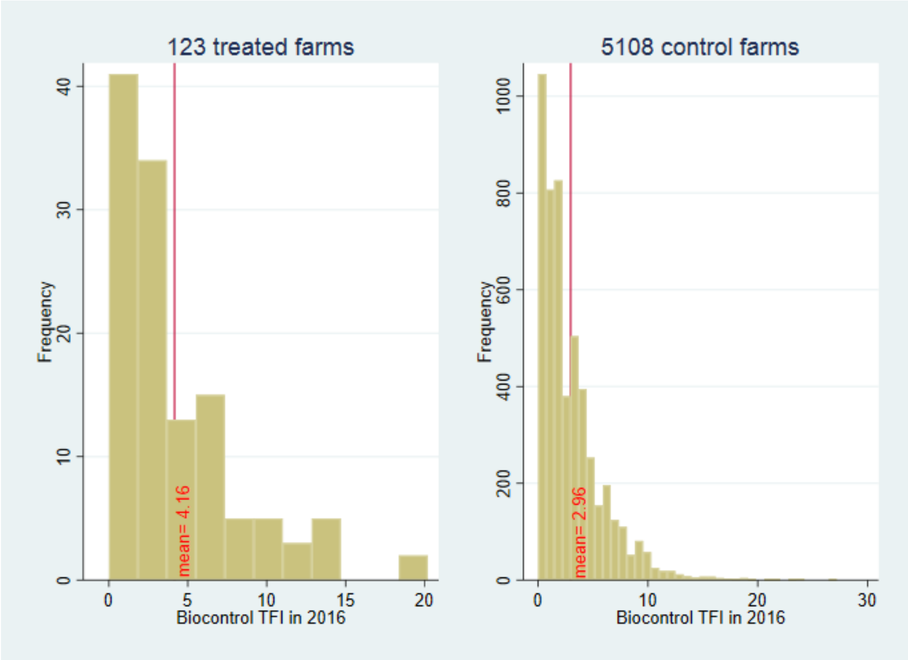


Figure A3: Distribution yields (in hl/ha)

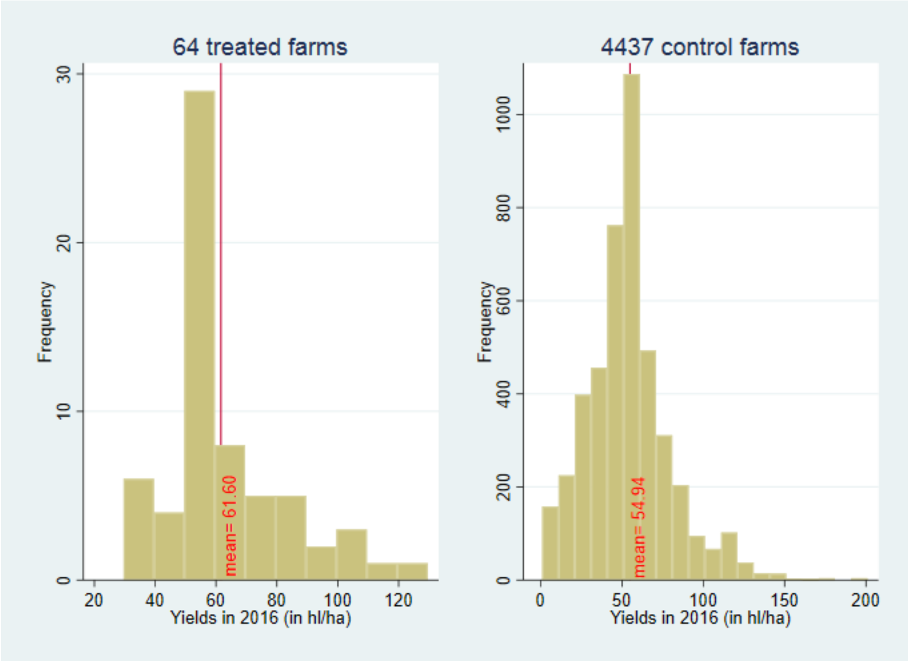


Table A1: Impacts of the program on second-wave treated units (placebo test)

| | 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 | | 1505 | |

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 | -0.031 | 0.033 |
| Climate insurance | 0.236 | 0.213 |
| Share of sales in short circuit | 0.125 | 0.169 |
| Vinayard surface area | 0.009 | 0.031 |
| Diversification of activities | 0.332 | 0.047 |
| Calibration of pesticide sprayer | -0.013 | 0.137 |
| Sex of head of the farm | 0.021 | 0.173 |
| Year of birth of head of the farm | 0.389 | 0.339 |
| Head of the farm got bachelor's degree | 0.400 | 0.048 |
| Spouse has agricultural activity | 0.143 | 0.000 |
| Spouse has non-agricultural activity | 0.038 | 0.000 |
| Wine production | 0.037 | -0.008 |
| PDO and PGI production | -0.298 | 0.010 |
| Utilised agricultural area (UAA) | -0.016 | 0.070 |
| Participation in farmer association | 0.120 | -0.047 |
| UAA without pesticides | 0.134 | 0.034 |
| UAA under organic farming | 0.218 | 0.037 |
| Surveyed plot is cultivated as organic | 0.255 | 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 simple matching. The total number of treated is 47.

## 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.

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