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Between the approved and the actual dose. A diagnosis of pesticide overdosing in French vineyards

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Abstract *– In this article, we explore the factors leading winegrowers to apply pesticide doses exceeding the official recommendations. Our approach is founded on an original methodology that determines practices of overdosing by matching four databases in 2006: the Farm Accountancy Data Network (FADN); the cropping practices survey (PK) in the winegrowing sector; the e-phy database operated by the French Ministry of Agriculture and Food, which identifies authorised doses per input; and climatic data measured by the Météo France meteorological office. Our sample, which contains 105 vineyards throughout France, reveals that 50% of these winegrowers never overdose, while 24% systematically apply excessive doses of pesticides. The latter group benefits from a comfortable financial situation, but suffers from an unfavourable climate.*

Keywords: *pesticides, overdosing, winegrowing, France, FADN*

Entre dose homologuée et dose réellement appliquée. Un diagnostic des exploitations viticoles françaises

Résumé – Dans cet article, nous étudions les facteurs qui conduisent certains viticulteurs à surdoser leur utilisation de pesticides par rapport aux prescriptions règlementaires. Notre approche repose sur une méthodologie originale qui détermine les pratiques de surdosage par un appariement de quatre bases de données de 2006 : le Réseau d'information comptable agricole (RICA), l'enquête des pratiques culturales (PK) en viticulture, la base e-phy gérée par le ministère de l'Agriculture et de l'Alimentation, qui identifie les doses autorisées par intrant et des données climatiques issues de relevés Météo France. Dans notre échantillon de 105 exploitations, 50 % des exploitants ne surdosent jamais alors que 24 % surdosent de façon systématique toutes leurs applications de pesticides. Ces derniers bénéficient notamment d'une situation financière confortable mais souffrent d'un climat défavorable.

Mots-clés : pesticides, surdosage, viticulture, France, RICA

JEL classification: Q14, Q16, Q18

1. Introduction

Reducing the consumption of chemical inputs, fertilisers and pesticides has become a primary objective in France in the wake of the *Grenelle de l'Environment* (2007). The challenge facing the country is considerable as France is the leading European consumer of chemical inputs in terms of volume and the third largest consumer worldwide (Aubertot *et al.*, 2005). In the French agricultural sector, pesticides are not used consistently and major disparities exist between different types of agricultural production. Accordingly, arable crops represent 48% of chemical inputs expenditure yet account for only one third of the land farmed (Baschet and Pingault, 2009). Winegrowing represents 4% of utilized agricultural area (UAA) within the country but accounts for 14% of chemical inputs expenditure, making it a relevant area for our study. In 2009, the legislature set a target of reducing consumption by 50% by 2018, a figure which was then reduced to 37% for vineyards following the "EcoPhyto Report" (Butault *et al.*, 2011).

Vines are perennial crops that suffer from many diseases, such as mildew and powdery mildew, which reduce grape yields. Despite efforts to select resistant grape varieties (Goheen, 1989), favourable weather conditions are conducive to the development of disease (Koleva *et al.*, 2009). In light of this, pesticides remain the main solution used by farmers to reduce the extent of diseases (Houmy, 1994, Mishra *et al.*, 2005), and winegrowers are among those most affected by the targeted reduction (Butault *et al.*, 2011; Carpentier, 2010). The effort required is even greater as pesticides are an integral part of the production processes due to their capacity to accelerate the development of crops while protecting them from biological risks (Just and Pope, 2003). Use of these products nevertheless raises questions concerning the sustainability of an approach relying on these factors of production. Inputs are indeed responsible for environmental pollution affecting both the soil and the water table (Craven and Hoy, 2005). They are also at the root of health problems affecting workers who handle them as well as consumers (Etienne and Gatignol, 2010).

Many avenues exist to reduce pesticides. An analysis of the literature shows that the common approach consists of implementing more environmentally friendly practices. Changes in pest management are generally driven by farm characteristics. Many studies deem education level to be one of the main factors (Dörr and Grote, 2009; Fernandez-Cornejo and Ferraioli, 1999; McNamara *et al.*, 1991; Wu, 1999). Financial characteristics are also cited as key determinants of how pesticide risks are managed. While Chakir and Hardelin (2009) focus on the solvency level, Galt (2008) and Sharma *et al.* (2011) emphasize the role of farm indebtedness. Confronted by climate hazards, farmers can be inclined to replace pesticides by similar products such as insurance policies (Aubert and Enjolras, 2014; Feinerman *et al.*, 1992; Smith and Goodwin, 1996). Structural characteristics also condition pesticide use. Among them, the size of the farm appears to be a key determinant of risk management (Burton *et al.*, 2003; Dörr and Grote, 2009; McNamara *et al.*, 1991).

Efficient pesticide reduction supposes to be in compliance with the regulation and a first step toward more environmental crop protection is to identify growers having overdosing practices. However, the literature lacks analyses on the topic of input overdosing (Bürger *et al.*, 2012; Sattler *et al.*, 2007). The main reason is that identifying and evaluating farmers' practices of overdosing involves finding adequate data sources that provide information not only on pesticide application but also on the structure of the vineyard, its financial situation and climatic conditions. We propose in this paper to identify wine producers who use excessive doses of pesticides in relation to the recommendations from chemical input manufacturers and/or environmental regulation. This approach is then used to determine the factors that lead to overdosing practices. For that, this article adopts the approach of combining existing databases for year 2006, which are commonly used for research in agricultural economics. The data from the Farm Accountancy Data Network (FADN) provide some structural and financial parameters. The "cropping practices survey" (PK) provides details of pesticides—fungicides[1], insecticides and acaricides—applied in each vineyard. To measure overdosing, it is necessary to cross these data with recognised references such as the "e-phy" database, created and published by the French Ministry of Agriculture and Food, which identifies the authorised doses *per* input. The matching performed allows us to identify which pesticide has been overdosed. Finally, meteorological databases of Météo France provide additional climate data. Matching these four databases for the very first time is a key contribution of our paper because it offers the possibility to measure overdosing with a high degree of precision at the plot level and to understand the rationale behind this practice.

Our article is organised in the following manner: in the first section, we present the methodology used for measuring overdosing founded on an original matching of several databases. In the second section, we detail the model with the aim of understanding the practice of overdosing. In the third section, we discuss the results. Finally, we conclude with a summary of the strategies adopted by the vineyard owners and the perspectives offered by our study.

2. Measuring overdosing: a database matching

The methodology for measuring pesticide overdosing calls for an original process of matching databases.

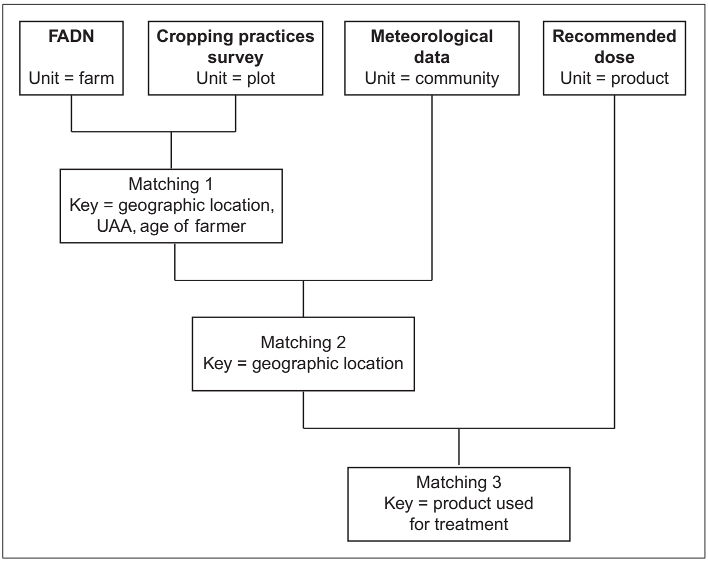
2.1. Database matching

To understand the full complexity of the process of overdosing as experienced by winegrowers, numerous factors must be taken into consideration. Naturally, these concern the farmers' characteristics, the structure of the

[1] Such products represent 80% of the chemicals used on vineyards (Agreste Primeur, 2012).

farm and its financial characteristics but also include climatic factors. In order to incorporate all this information as precisely as possible, we adopted a three-step process to match the data from the FADN databases, the winegrowing "cropping practices survey" (PK), weather forecasts (Météo France) and the doses recommended by both the legislation and the manufacturers (e-phy) as shown in Figure 1.

Figure 1. **Methodology for matching all databases**



Source: Own contribution.

2.1.1. *Step 1: Matching the FADN and the PK databases*

The matching process we undertook involved coordinating databases with their own logic and their own units of measure. While the FADN is representative of the production orientation and the region at the national level of all commercial French farms[2], the PK survey focuses exclusively on farms producing wine, *i.e.* at least two-thirds of the standard gross margin (SGM) results from a winegrowing activity. Whereas the unit of FADN data is the individual farms, the data from the PK survey primarily consider plots of land. Furthermore, the number of plots surveyed for a given farm does not necessarily correspond to the total number of plots, the latter varying among farms. Assuming that the behaviour of winegrowers is similar from one plot to another, we can then match the FADN and PK databases considering variables defined at the farm level, *i.e.* independently of the number of plots.

[2] A farm is said to be commercial if its Standard Gross Margin (SGM) is greater than €9,600 and if it employs at least 0.75 Annual Work Units (AWU).

The availability of data is a crucial factor for the matching process. The last PK surveys on winegrowing plots were conducted in 2006 and in 2010. The FADN data are updated annually but the complete records at our disposal do not go past 2008. Therefore, matching between the two databases can only rely on the year 2006. That year, plots on the PK comprise 5,216 different farms while the FADN only lists 1,043 farms in the winegrowing sector. Matching these two databases involved identifying the common information at farm level, including geographic location, the agricultural area farmed, the age of the farm manager and the Economic and Technological Orientation (OTEX). Considered successively, these elements constituted the matching key necessary to our analysis.

We began by considering a stratification relating to the geographic location and the technical orientation of the farm. We then performed a manual check–case by case–of the matching of the farms identified according to their size and the age of the farm manager. Despite the common units, especially for the agricultural area of the farm (hectares), it was difficult to find perfect matches due to rounding. This crucial step in our analysis required particular attention. Sometimes the incorporation of other factors (such as the area of land allocated to winegrowing as a proportion of total land) was necessary in order to validate each FADN-PK pair of farms definitively.

Using the matching key defined above, we identified 135 farms present in both files. More precisely, we retained 2.97% of the farms present in the PK and 14.86% of the farms in the FADN.

2.1.2. Step 2: Combining with climatic data

Incorporating climatic data meant combining the new file obtained above with the meteorological data collected by Météo France. This second matching exercise was based solely on the geographic location identified at the municipal level. This refined geographic location was not taken into account during the first matching process as the FADN file only mentions the region in which the head office of the farm is located in contrast to the PK, which indicates a municipality-based location.

The data obtained in this step enabled the comparison of the structural, financial and climatic parameters proper to each farm retained. We also gained access to the details of the doses applied for each plot of land.

2.1.3. Step 3: Incorporating the pesticide dosage

The aim of the final step was to determine whether winegrowers applied an overdose of pesticides. To define an overdose, a correspondence was established between the products used (*e.g.* fungicides or insecticides) for each pesticide and the doses authorized by the legislation or, by default, recommended by the manufacturers. In practice, after having identified the different products used by the winegrowers, we established a correspondence with the authorised doses identified in the "e-phy" database of the Ministry of Agriculture and Food in 2006[3].

The PK file lists 677 different products used by the farmers, but we chose to target the products most commonly used in vineyards: 84.8% of farms in our sample use only 20.4% of all products indexed in the PK database. Therefore, we ignored the 30 farms of our sample that applied only other kinds of pesticides. The final database contains 105 farms.

2.1.4. Validation of the final database

Despite its small size, the final database offers the ability to study the behaviour of farms towards pesticide use. By design, the sample cannot pretend to be representative of the wine-growing regions. However, this weakness is compensated by the high degree of precision regarding the structure, financial situation and weather conditions of the surveyed farms.

Given that the final database is generated from FADN data with a unit at the farm scale, we measure its statistical relevance by comparing its characteristics with variables considered for the FADN stratification: the usable agricultural area, the standard gross margin and the OTEX. Results provided in Table 1 show that these two databases present similar characteristics according to these criteria. In addition, expenses in pesticides

Table 1. **Comparison between the newly created database and the FADN**

	Newly created database	**FADN database**	**Equality of means test Pr > |t|**
Usable agricultural area (UAA, in ha)	24.46	27.73	0.1531
Standard Gross Margin (SGM, in €)	162249.93	163334.45	0.9198
Expenditures on fertilizers (€/ha)	104.04	138.38	0.1146
Expenditures on pesticides (€/ha)	526.68	479.66	0.2779

Source: Own contribution, based on Agreste - FADN (2006), PK (2006).
Keys: The null hypothesis considers equality of means between the two populations. Means are significantly different at the 10% (*), 5% (**) and 1% (***) thresholds.

	Newly created database	**FADN database**	**Chi2 test**
OTEX 37 (quality winegrowing)	83.23%	77.66%	0.0956*
OTEX 38 (other winegrowing)	16.77%	22.34%	

Source: Own contribution, based on Agreste - FADN (2006), PK (2006).

Keys: The null hypothesis considers the independence of populations. Independence between the two populations is significantly significant at the 10% (*), 5% (**) and 1% (***) thresholds.

[3] Data were collected from an older version of the e-phy website: http://web.archive.org/web/20060427134323/http://e-phy.agriculture.gouv.fr/ (last checked on March 21, 2014).

and fertilizers are analogous between our database and the FADN for commercial wine growing farms.

2.2. Measuring the practice of overdosing

Dealing with overdosing practices raises several methodological issues in terms of identification and measurement. To the best of our knowledge, few studies have focused on the intensity of pesticide use. Sattler *et al.* (2007) propose and discuss a methodology capable of assessing the intensity of pesticide use in Germany by computing proxies referred to as "Standard Treatment Indices *per* crop" or STIs. This method takes into account the number of active substances *per* application, the number of applications during a single season and the area treated.

$$\begin{aligned} \text{STI} = \text{Active substances per application} \times \frac{\text{Actual application}}{\text{Recommended application}} \\ \times \frac{\text{Treated area}}{\text{Total area}} \end{aligned} \quad (1)$$

This indicator is also known as a Treatment Frequency Index (TFI) when the active ingredients[4] *per* application are not taken into account. Both STI and TFI are synthetic indicators of the intensity of pesticide use.

Bürger *et al.* (2012) used STIs in order to measure the influence of cropping system factors on the intensity of pesticide use. They found that crop management and treatment patterns (*e.g.* sustainable farming) mainly influence pesticide use. These two studies based on STIs went beyond the common measurement of pesticide consumption. However, they were somewhat limited by their inability to measure directly the excess products, molecules and combinations of molecules applied to crops. In reality, they could only compare the individual use of pesticides on each farm with regional references, thereby providing a relative measurement of overdosing.

Considering the data available in our sample, we cannot precisely identify the area treated on a considered plot. Without such information, we can compute neither TFI nor STI indices. Otherwise, such measures would over-represent treatments that are not overdosed. Instead, we propose a more relevant measurement of overdosing that takes into account the product quantities actually applied to the plants. Any overdosing can be measured directly by comparing the doses of the different pesticides applied during a single season with the upper limits recommended by the manufacturers and the health authorities. Let us suppose that, for a given plot k ($k = 1, \ldots, m$),

[4] Active ingredients are the chemicals in pesticide products that kill, control or repel pests. For instance, the active ingredients in a herbicide are the ingredients that kill weeds. Pesticide product labels always include the name of each active ingredient and its concentration in the product.

a farmer i applies pesticides j ($j = 1,\ldots, n$) with a dose $I_{i,j}$ over the course of a season. $I_{i,j}$ is an aggregate value that may include several passes over the plants.

The dose of each product j applied on each plot k is compared to the maximum value recommended by the manufacturer or authorised by the legislation $\overline{\overline{I}}_j$[5] over the course of one season in order to determine a formal record of overdosing:

$$Dose_{k,j} = I_{k,j} - \overline{\overline{I}}_j \tag{2}$$

If equation (2) provides a positive result, a case of overdosing of product j on plot k has been detected.

The measurement can also be standardised as a percentage of the dose:

$$\%Dose_{k,j} = \frac{I_{k,j}}{\overline{\overline{I}}_j} \times 100 \tag{3}$$

We can thus directly identify farmers who occasionally apply excessive doses of pesticides j, for one or more plots k, or more systematically, for all surveyed plots; and farmers who comply with the recommendations or regulation in treating their plots.

Given that our database is constructed at the farm level, the salient question is how to define a synthetic indicator of overdosing at this scale. Because the doses of pesticides are expressed in different units (kg/ha, l/ha, kg/hl, l/hl) depending of the availability of products in solid or liquid form, we are not able to calculate an aggregate measure of overdosing.

Due to this constraint, the only reliable way to obtain a synthetic indicator of overdosing at the farm level involves counting pesticide applications for which an overdose has been observed. On the basis of the distribution of this percentage, we observe highly polarised behaviour: while 55% of farmers never overdose on their plots, around 20% of them overdose systematically. Such behaviour advances the hypothesis that any overdosing observed on a farm's plots of land reflects the global overdosing behaviour of the farm. Yet, the count for overdosed applications cannot be used in the upcoming analysis because all plots of a farm are not systematically surveyed in the PK and because the number of applications varies depending on the plots.

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[5] One should note that thresholds indeed differ depending on the type of chemical input. For instance, Sekoya® is prohibited for treating mildew but authorised for treating grey rot. Similarly, Cabrio Top® is limited to 1 kg/ha when it is used to treat powdery mildew whereas it is limited to 2 kg/ha for mildew. Insofar as we do not know the precise reasons for winegrowers applying chemical inputs, we have to consider the maximum authorised threshold.

Therefore, given the dichotomy observed between farmers who overdose all their applications and farmers who never overdose, we consider overdosing a dichotomous behaviour. As soon as a product is overdosed on a plot, we consider that the farmer overdoses. Although simplified and imposed by the data set, this distinction has the advantage of being clear and directly usable in a model aimed at understanding the determinants of overdosing behaviours.

3. Explaining overdosing: a model

Once measured, the overdosing behaviour needs to be interpreted. In this section, we propose a theoretical model of overdosing based on the existing literature and the possibilities offered by our database.

3.1. A theoretical model of overdosing

Farmers apply pesticides with the goal of protecting their income. This practice is part of a global production strategy, the aim of which is to maximize a farmer's production and profit. By using a general formulation adapted from Rahman (2003), the profit of a farm Π_i which the farmer wishes to maximise is:

$$\begin{aligned} &\Pi_i = \sum_{k=1}^{m} p_{i,k} Y_{i,k} - q I_i - r F_i \\ &\text{with : } Y_{i,k} = f\left(I_{i,k}, F_{i,k}, S_{i,k}, E_i\right) \text{ for } \mathrm{k} = 1 \ldots \mathrm{m}, \text{ and} \sum_{k=1}^{m} S_{ik} \leq S_i \\ &\text{where : } I_i = I_{1i} + \cdots + I_{mi} \text{ and } F_i = F_{1i} + \cdots + F_{mi} \end{aligned} \tag{4}$$

Equation (4) reflects the individual profit function of each farm *i*. $Y_{i,k}$ is the yield of each plot *k* and *m* is the total number of plots. It depends on the application of chemical inputs, I_i, the use of other production factors (either structural, *e.g.* land and workforce, or financial, *e.g.* capital), F_i, the relative area allocated to each plot, $S_{i,k}$, and a set of individual and exogenous parameters (*e.g.* risk-awareness of the farmer and weather conditions), E_i, which modify the production function. p, q and r represent the output prices, the input prices and the other production factors prices, respectively.

The first-order conditions determine the demand functions for inputs:

$$I_i = I_i\left(p_1, \ldots.., p_m, q, r, S_1, \ldots.., S_\mathrm{m}, E_i\right) \tag{5}$$

Use of inputs beyond the recommended or authorised thresholds can be modelled as:

$$Overdose_i = Overdose_i\left(p_1, \ldots\ldots, p_m, q, r, S_1, \ldots.., S_\mathrm{m}, E_i\right) \tag{6}$$

Equations (5) and (6) show that (over-) consumption of inputs depends on several parameters, such as the structure of the farm, its financial situation and certain exogenous factors.

3.1.1. Structural parameters

Farm size would appear to be an indicator of prime importance in explaining pesticide use, although its impact is debatable. According to Burton *et al.* (2003), size has a positive impact on the way pesticide risks are managed. Dörr and Grote (2009) find its impact to be negative, and McNamara *et al.* (1991) present evidence showing that this parameter has no influence. In the context of winegrowing, we establish the hypothesis that the influence of the size of the farm is negative with regard to pesticide use, assuming that it is more crucial for small farms to protect yield and income.

Overdosing is also conditioned by the fact that the farmer may benefit from another source of income (Dörr and Grote, 2009; Fernandez-Cornejo, 1996; Fernandez-Cornejo and Ferraioli, 1999; Galt, 2008; McNamara *et al.*, 1991). These papers highlight the fact that a farmer who has another source of income is less likely to use pesticides. Usually, the degree of dependence on an activity is measured through the share of income coming from this activity. Because we do not dispose of such information in our database, we calculate a proxy measuring the share of labour realized by the workforce inside the farm. More people work on the farm, more their income depends on the farm. In this context, preserving revenues of the farm is more likely to be associated with a pesticide use.

3.1.2. Financial parameters

Chemical inputs imply a cost compared to all the expenses a farm must bear. According to Tables 3a and 3b, pesticides account for 8.2% of total expenses for farmers who do not overdose while they represent 7.3% for farmers who do overdose. More precisely, in 2006, chemical inputs represent a quarter of the procurement costs for quality wine-making farms (OTEX 37) and 45% for the other wine-making farms (OTEX 38) (Agreste Primeur, 2009). Payment of this charge is conditioned by cash flows generated by the farm presupposing good financial health reflected by a high turnover and short-term cash reserves (Chakir and Hardelin, 2009). A farmer benefiting from comfortable revenue will not seek to protect the yields at all costs and therefore will not overdose applications. This would be the case for farmers exhibiting Decreasing Absolute Risk Aversion (DARA), meaning that their risk aversion decreases with their wealth, which is a common characteristic among the population of farmers.

However, when confronted by difficulties, *e.g.* a high level of long-term indebtedness, the farmer may prioritize pesticide use compared to other operations in order to insure a certain level of turnover and income. Galt

(2008) highlighted the fact that indebtedness has a positive impact on the consumption of pesticides used *per* hectare while Sharma *et al.* (2011) showed this effect is not significant. Testing the influence of financial parameters on overdosing practices requires the use of lagged variables because only past financial conditions can influence the level of pesticide use and not those directly present in the FADN data, because they are measured at the end of a given fiscal year.

There are also certain substitutes for pesticides identified in the literature. With regard to risk reduction, crop insurance plays a similar role to that of pesticides. In exchange for payment of a premium, the contract gives the farmer the right to receive compensation if the effective yield falls below the threshold stipulated in the contract. In France, these policies cover a wide range of climatic hazards affecting crop yields, *e.g.* drought and rainfall excess (Enjolras and Sentis, 2011). Vineyard diseases such as mildew, powdery mildew or botrytis bunch rot are not covered unless they are the consequence of one of the climatic hazards covered in the contract. Crop insurance can thus be used as an indirect instrument to hedge against diseases affecting vineyards.

Insurance can play the role of a substitute for pesticides (Babcock and Hennessy, 1996), thereby reducing the probability of overdosing. Nevertheless, the substitutability between crop insurance and pesticides does not seem to apply if the farmer is highly risk-averse (Feinerman *et al.*, 1992). Moreover, Horowitz and Lichtenberg (1993 and 1994) show that pesticide use is ambiguous: on one hand, pesticides reduce disease risks but on the other hand they also increase the range of yields the farm produces. Consequently, the authors show that pesticides may contribute to increase yield volatility, *i.e.* the overall risk of the farm. In these two specific cases, the farmer could combine a high consumption of pesticides with insurance coverage.

3.1.3. Individual and exogenous parameters

The farmer's awareness towards risks induced by pesticide use is also considered a fundamental variable in the literature (Baumgart-Getz *et al.*, 2012). The characteristics of the farm manager are crucial in choosing the production approach, which means taking the farmer's age and education level into account (Wu, 1999). Young and educated farmers are more sensitive to pesticides impacts on health and environment and more likely to manage risk using fewer pesticides (Dörr and Grote, 2009; Fernandez-Cornejo and Ferraioli, 1999; McNamara *et al.*, 1991). The consumption of pesticides and the associated risk may also be optimised if the equipment is modern and the pesticide consumption is monitored (Arcury *et al.*, 2002; Lichtenberg and Zimmerman, 1999). We incorporate this by considering whether an individual farmer uses recent sprayers, stores his chemical inputs in a dedicated room, or records his input applications.

Climate is also one of the most important factors justifying the use of phytosanitary products. Houmy (1994) and Koleva *et al.* (2009) assert that both rainfall and temperatures are the most relevant parameters explaining the prevalence of diseases. Specifically, an absence of sunshine and excess rain are factors conducive to the development of diseases, such as mildew. Furthermore, vines are highly sensitive to major climatic changes over the course of a season (Rosenzweig *et al.*, 2001). Most existing studies do not offer a precise analysis of the influence of weather on pesticide application because they do not have access to such information (Fernandez-Cornejo, 1996; Galt, 2006; Galt, 2008; Sharma *et al.*, 2011). Consequently, they include location in their model to offer a rough differentiation of the population. In our database, climate conditions can be assessed on a very small scale (municipality), thereby avoiding the need to control explicitly for the location effect.

Moreover, we can assume that farmers take seasonal climatic data into account and the variations from one season to another in order to adjust the intensity of the pesticides they apply. While the literature traditionally limits the incorporation of the climate to annual rainfall levels (Horowitz and Lichtenberg, 1993; Mishra *et al.*, 2005), we also take into consideration the temperature and wind deviations from the average calculated on the five previous years because of their potential influence on the development of diseases.

All the variables used in this analysis as well as their expected influence on the probability of overdosing pesticides are defined and summarized in Table 2. These different hypotheses will be tested within the methodological framework presented in the following section.

3.2. Econometric model

Considering the constraints described above on the aggregate measure of overdosing, we consider a synthetic model, which distinguishes farmers who never overdose from other farmers. Consequently, the model implemented is a logit model, such that:

$$\mathrm{OD}_{\mathrm{it}} = 1 \ \text{ if } \ \mathrm{OD}_{\mathrm{it}}^{*} \geq 1\text{; otherwise } 0. \tag{7}$$

$$\mathrm{OD}_{\mathrm{it}}{}^{*} = \alpha + \beta' \ \mathrm{CSit} \ + \ \gamma' \ \mathrm{CFi}\,(\mathrm{t}-1) + \theta'\mathrm{Ait} \ + \ \delta \ '\mathrm{Mit} \ + \ \varepsilon\mathrm{it} \tag{8}$$

Where:

$\mathrm{OD}_{\mathrm{it}}$ corresponds to a practice of overdosing on farm *i* in year *t* if at least one of the farmer's applications exceeded the recommended dose.

$\mathrm{OD}_{\mathrm{it}}{}^{*}$ corresponds to the number of input applications where the doses applied are greater than the recommended doses.

$\mathrm{CS}_{\mathrm{it}}$ is the matrix of structural characteristics of the farm.

$\mathrm{CF}_{\mathrm{i(t-1)}}$ is the matrix of lagged financial characteristics of the farm.

A_{it} is the matrix of farmers' awareness of risks induced by pesticides.

M_{it} is the matrix relating to the meteorological data.

ϵ_{it} is the error term.

Table 2. **Description of main variables**

Variables	**Definition**	**Expected influence on the probability of overdosing pesticides**
Usable Aagricultural Aarea (UAA)	Area (hectares)	–
Winegrowing area/UAA	Share of the area dedicated to winegrowing (%)	–
Agricultural education	In years	–
General education	In years	–
Production value	Turnover *per* hectare (€/ha)	+
Labour done in the farm	Share of the labour done by waged employees in the farm (%)	–
Indicator of liquidity	Cash ratio (cash and invested funds/current liabilities)	+
Indicator of indebtedness	Financial leverage (debt-to-asset ratio)	–
Insured	1 if the farmer is insured; 0 otherwise	–
Practices recorded	1 if farmer records inputs applied; 0 otherwise	–
Product storage room	1 if the farmer has a storage room; 0 otherwise	–
Age of the sprayer	In years	+
Temperature deviation	Deviation of annual temperature (in °C) compared to the mean computed over 5 years	?
Rainfall deviation	Deviation of annual rainfall (in mm) compared to the mean computed over 5 years	?
Rainfall deviation	Deviation of annual rainfall (in days) compared to the mean computed over 5 years	?
Wind deviation	Deviation of annual wind (number of days wind speed is greater than 100 km/h) compared to the mean computed over 5 years	?

This model explains the determinants of overdosing behaviour by considering the structural and financial particularities of the farms as well as the farmers' sensitivity to pesticide risks and the influence of the climate.

Due to the assumed co-determination between the consumption of pesticides and the financial parameters of the farm, we explicitly take the risk of endogeneity into account. Pesticides purchases directly reduce the farm's cash funds while indirectly impacting its turnover. To overcome this problem, we opt to lag the financial variables.

4. Results

In this section, we present the main descriptive statistics and the results of the econometric model.

4.1. Descriptive statistics

The first outstanding result of our analysis is that 52 farms (50%), have never practised overdosing when applying pesticides. Therefore, only half of the vineyards comply with the requirements in force concerning the use of phytosanitary products. Our own calculation on the PK survey for 2006 finds that 59% of farmers have never overdosed their pesticides applications; so our data set slightly over-represents overdosing farmers.

We notice that the structure of the farms does not differ between those that never overdose and the others (Table 3a). The physical size is somewhat comparable, around 25 hectares on average, though they are identically specialized in winegrowing production with more than 90% of their area dedicated to vines. Lastly, the share of labour realized by the workforce within the farm is close to 50% in both cases. This result denotes the fact that overdosing is not systematically associated with a particular structure of farms organized around this behaviour.

Table 3a. **Structural characteristics of the farms according to their pesticide dosage**

Structural variables		**Overdosing**		**Total**	**Equality of means test**
		No	**Yes**		
Count	Number	52	53	105	
	Distribution (%)	49.52	50.48		
Usable agricultural area (UAA, in ha)	Mean	28.21	21.63	24.92	0.1372
Winegrowing area/total area (%)	Mean	91.17	89.16	90.16	0.6323
Labour done in the farm (%)	Mean	45.34	49.77	47.57	0.4103

Source: Own contribution, based on Agreste – FADN (2006), PK (2006).

Keys: The null hypothesis considers equality of means between the two populations. Means are significantly different at the 10% (*), 5% (**) and 1% (***) thresholds.

Given the fact that farms have a similar structure whatever their dosing practices, they share, on average, the same standard gross margin (Table 3b). Yet, the other financial indicators reveal a contrast between the two groups of farms. Farms that overdose benefit from a higher turnover, turnover *per* hectare, and production value *per* hectare. Such results reveal a higher productive intensity on overdosing farms that use pesticides heavily as a way to protect their yield and their revenue. By contrast, being insured does not have an influence on overdosing pesticides: roughly 40% of the farmers are insured, whatever their practices.

Table 3b. **Financial characteristics of the farms according to their pesticide dosage**

Financial variables	**Overdosing** No	**Overdosing** Yes	**Total**	**Equality of means test**
Turnover (€)	20129.60	70632.19	45621.38	0.0003***
Turnover (€/ha)	13.37	97.36	55.76	0.0018***
Standard gross margin (SGM, in €)	189364.74	173115.13	181162.56	0.5240
Production value/ha (€/ha)	98.11	285.03	192.46	0.0002***
Chemical inputs charges/global charges (%)	8.20	7.30	7.75	0.3860
Pesticides charges/global charges (%)	7.07	6.02	6.54	0.2498
Fertilizers charges/global charges (%)	1.14	1.28	1.21	0.7011
Indicator of liquidity (cash ratio)	0.04	0.04	0.04	0.8998
Indicator of indebtedness (financial leverage)	0.68	0.48	0.58	0.3343
Insured (%)	42.31%	39.62%	40.95%	0.7797

Source: Own contribution, based on Own contribution, based on Agreste - FADN (2006), PK (2006).

Keys: The null hypothesis considers equality of means between the two populations. Means are significantly different at the 10% (*), 5% (**) and 1% (***) thresholds.

We note that the farmers' age, 47 years old on average, does not lead to distinct behaviours regarding pesticide use. There is also no difference considering the farmers' level of education, either "agricultural" or "general" (Table 3c).

We consider the farmer's behaviour towards pesticide risk through the effective use of the following protections: boots, gloves, masks, goggles and waterproof clothing. Farmers who overdose their pesticide applications do not use significantly more protection tools (Table 3d). Perhaps these farmers are not aware of overdosing consequences on health or, alternatively, this practice does not justify an additional protection in their point of view. It is also possible that nearly all producers are confident in the way they apply pesticides.

Table 3c. **Individual characteristics of farmers according to their pesticide dosage**

Individual variables		Overdosing No	Overdosing Yes	Total	Equality of means test
Agricultural education of the farmer	No education	5.77	11.32	8.57	0.2454
	Primary	25.00	9.43	17.14	
	Secondary short	50.00	54.72	52.38	
	Secondary long	15.38	16.98	16.19	
	Superior	3.85	7.55	5.71	
General education of the farmer	No education	5.77	5.66	5.71	0.3117
	Primary	26.92	22.64	24.76	
	Secondary short	55.77	43.40	49.52	
	Secondary long	7.69	20.75	14.29	
	Superior	3.85	7.55	5.71	
Age of farm manager (years)	Mean	47.23	46.38	46.80	0.5893

Source: Own contribution, based on Agreste – FADN (2006), PK (2006)

Keys: The null hypothesis considers equality of means or independence between the two populations. Means are significantly different at the 10% (*), 5% (**) and 1% (***) thresholds. The two populations are independent at the 10% (*), 5% (**) and 1% (***) thresholds.

We notice the same phenomenon when considering recording practices: on average, 62% of the farmers assert that they record all their applications, while 65% of the farmers use a room dedicated to the storage of phytosanitary products whatever the dosage they apply. Farmers who overdose their pesticides seem to use older sprayers, on average 11 years against 9 years for farmers who never overdose.

4.2. Determinants of overdosing

In this section, we examine the results of our econometric model (equation 9), which are presented in Table 4. The main result of the analysis is that the factors considered to be decisive in the practice of overdosing allow the observed behaviour to be correctly predicted in 83.6% of the cases. The key factors of overdosing essentially correspond to financial variables, farmers' awareness towards pesticides risks and climatic conditions.

The econometric model indicated that none of the structural or individual factors identified in the literature has an impact on the probability of overdosing. Consequently, the level of dosage of pesticides depends neither on the size or level of specialisation of the farms nor on the proportion of wage labour done by employees in the farm. Hence, our results confirm the results of McNamara *et al.* (1991) in that the farm's size has no impact on its pesticide use.

Key factors of overdosing practised by the farmers are more related to short-term financial factors. Any increase in production *per* hectare in the business year, and correlatively in the company's cash flow, observed one

Table 3d. **Conditions for phytosanitary operations according to their pesticide dosage**

Conditions of phytosanitary operations	**Overdosing**			**Equality of means test/Chi2 test**
	No	**Yes**	**Total**	
Observation of diseases on the plots of land in progress (%)	90.38	92.45	91.43%	0.7051
Practices recorded (%)	67.31	58.49	62.86%	0.3498
Storage room for phytosanitary products (%)	71.15	58.49	64.76%	0.1744
Average number of pieces of protective equipment	1.79	1.83	1.81	0.9097
Average age of sprayer (years)	9.42	10.98	10.21	0.3083

Source: Own contribution, based on Agreste – FADN (2006), PK (2006).

Keys: The null hypothesis considers equality of means or independence between the two populations. Means are significantly different at the 10% (*), 5% (**) and 1% (***) thresholds. The two populations are independent at the 10% (*), 5% (**) and 1% (***) thresholds.

year is reflected by a greater probability that overdosing will be practised the following year. This result goes hand in hand with Chakir and Hardelin (2009). Conversely, the long-term indebtedness resulting from the company's investment decisions play absolutely no role in overdosing practices, which is in line with Sharma *et al.* (2011). Being insured does not explain overdosing to any significant extent although the literature shows that pesticides-dosing practices are closely linked to the subscription of crop insurance policies (Aubert and Enjolras, 2014).

The farmer's awareness of the risks induced by pesticides measured by practices recorded and the existence of a product storage room could be seen as having a positive effect on overdosing, which is rather counterintuitive, but this effect is not statistically significant. While an agricultural education has no influence on overdosing, farmers who received a high level of general education are more likely to practise overdosing. This counterintuitive result contradicts the literature (Wu, 1999), which reveals that more the farmer is educated, less pesticide applications will be applied. However, educated farmers may also assess with a high degree of accuracy the cost-benefit consequences of overdosing and decide to overdose in full knowledge (Cooper and Dobson, 2007).

As expected, weather conditions affect the applied doses of pesticides. Any temperature or rainfall deviation from the average observed over the five previous years results in less intensive use of pesticides. More precisely, the increase of the temperature by one degree Celsius leads to a decrease of the probability of overdosing by 1.30% while the increase of rainfall by one millimetre leads

Table 4. **Results of the econometric model**

Parameter	Estimation	Marginal effect	Standard error	z	Pr > |z|
Usable agricultural area (UAA)	0.0041	0.0010	0.0188	0.05	0.83
Winegrowing area/total (%)	−1.3943	−0.3485	1.5703	−0.79	0.37
Agricultural education	−0.0786	−0.0196	0.3091	−0.06	0.80
General education	0.5920*	0.1480*	0.3362	3.10	0.08
Production value (€/ha) −1	0.0048**	0.0012**	0.0022	4.78	0.03
Labour done in the farm (%)	−0.0006	−0.0002	0.0121	−0.01	0.96
Indicator of liquidity (cash) −1	0.7384	0.1845	1.4079	0.27	0.60
Indicator of indebtedness (leverage) −1	0.1171	0.0293	0.2476	0.22	0.64
Insured (Y/N) −1	0.1281	0.0640	0.2690	0.23	0.63
Practices recorded (Y/N)	0.1927	0.0959	0.2642	0.53	0.47
Product storage room (Y/N)	0.2826	0.1399	0.2814	1.01	0.31
Age of the sprayer (years)	0.0663*	0.0166*	0.0405	2.68	0.10
Temperature deviation (°C)	−5.2358**	−1.3086**	2.4683	−4.50	0.03
Rainfall deviation (mm)	−0.0179**	−0.0045**	0.0078	−5.22	0.02
Rainfall deviation (days)	0.0285	−0.0539	0.0260	1.20	0.27
Wind deviation (days)	−0.2158	0.0071	0.2000	−1.16	0.28
Intercept	3.3888		2.6519	1.63	0.20

Likelihood ratio: 38.9349 (p-value = 0.0011)
Percentage concordant: 83.6%
Number of observations: 105

Source: Own contribution, based on Agreste – FADN (2006), PK (2006) and meteorological data.
Keys: Estimates significant at the 10% (*), 5% (**) and 1% (***) thresholds. −1 denotes a lagged variable.

to a decrease of the probability of overdosing by 0.01%. Year 2006 was indeed considered as an average year regarding phytosanitary pressure. Starting from 2004, a favourable climate led to a continuous decrease in pesticide use. As a result, expenses in phytosanitary products followed the same trend (Butault et *al.*, 2011). Years 2007 and 2008 were characterized by climatic conditions more favourable to diseases, which led to an increased consumption of pesticides. Therefore, the intensity of the relationship between weather conditions and pesticide overdosing needs to be assessed on an annual basis.

We also observe that the age of the spraying equipment is positively linked to the practice of overdosing pesticides. The poor state of repair or obsolescence of the equipment might be reflected by less precision in the applications, resulting in a practice of overdosing. Our analysis supports the need for an equipment modernization policy in order to improve the practices of applying pesticides. Article 41 of law no. 2006-1772 dated 30 December 2006 concerning water and aquatic environments has made the technical inspection of sprayers obligatory since January 1, 2009. This constraint is intended to improve the reliability of the distribution of chemical inputs. An analysis of more recent data should highlight its potential effectiveness.

4.3. Discussion

The results appear to show that overdosing practices result from short-term calculations of the farms linked to their financial situation and to the climate more than from long-term considerations linked to their structure. This outcome indicates that farmers applying excessive pesticides are not structured around an overdosing behaviour. On the contrary, pesticides are a response adaptated to pests and diseases and to the necessity of preserving yields and, consequently, the value of the production.

Naturally, the results need to be viewed in the light of the dependent variable, which is dichotomous. The logit model distinguishes farmers who never overdose their applications from farmers who made at least one overdosed application during the season. This innovative choice is motivated both by constraints on the database and by the polarized behaviour of farmers. However, such a formulation can hide dynamics along the year: many applications of a given pesticide may be done during the season, some respecting the regulations and some being overdosed, *e.g.* to provide a quick response to diseases. Our model does not take into account any form of "compensation" between low-dosed and over-dosed treatments. Nor does it take into account continuous indicators, such as the Treatment Frequency Index (TFI) over the season, which makes the comparison with other studies difficult.

The limited size of the sample (105 observations) does not affect the quality of the econometric model (percentage concordant = 83.6%). However, the number of observations does not allow us to consider a regional effect in overdosing. Instead, we measure the influence of the production value *per* hectare, which is a proxy for *grands crus*, on the probability to overdose. The results indicate that the production value has a positive effect on overdosing, which is not surprising because, at the same time, the most important wine producing regions (Champagne, Bourgogne, Bordeaux) perform the most significant pesticides applications (Agreste Primeur, 2009). Availability of more recent FADN data would permit us to realize a new matching for year 2010 that would take into account some advances in pesticide regulations and changes in agricultural practices. For instance, the PK survey performed in 2010 indicates a change in behaviours towards chemical herbicides that leads to a better valorisation of wine production (Agreste Primeur, 2012). Therefore, a comparison between years 2006 and 2010 would be of great interest to measure both the evolution of overdosing and potential changes in its determination.

5. Conclusion

This study focused on the practice of overdosing pesticide applications in the French winegrowing sector. Despite its primary importance, very little academic research was found that addressed this issue, probably due to lack of appropriate data.

Our contributions are twofold: first and foremost, we propose and apply a methodology able to identify and to measure overdosing in wine-producing farms. Our approach is founded on the creation of an original database by matching four separate sources mainly used in French agricultural research (FADN, PK, recommended doses and climate for year 2006). A farmer is said to overdose if at least one of his pesticide applications during the season is overdosed according to the regulations.

Our second contribution uses the new database as well as the indicator of overdosing in order to determine factors that lead to this practice. We show that overdosing is not linked to the structure of the farm or to the individual characteristics of the farmer but rather to the value of the production. Moreover, being insured is not significantly associated with a practice of overdosing. At last, temperature and rainfall variations, which explain the development of diseases affecting the vines, would also appear to be key factors.

These results aim at filling a significant gap in the literature. Only the determinants of input consumption had been studied previously in different countries and in different contexts. The study of agricultural practices using an economic or managerial approach supposes to rely on complete data sets at the farm level. Such databases should include variables as basic as the structure of the farm and its financial situation (based on the FADN model) and combine these with more precise data concerning the farm at the plot level (based on the PK model). Only by combining such data can we increase our knowledge of input overdosing practices. Given the current state of the databases, we were obliged to restrict our analysis to a sample, which, while sufficient, was nevertheless small. Similarly, we were unable to perform panel analyses. A suggestion would be to survey the same farms in the FADN and PK databases.

There are numerous prospects afforded by our work. In particular, the database obtained should continue to be used. As we did not differentiate the inputs according to their nature (insecticide, fungicide, *etc.*), and behavioural differences probably exist here, too. Similarly, field surveys have to be conducted with farmers in order to identify more precisely the motivations of the input applications. These surveys could be appropriate to understanding whether farmers are aware or not when they are overdosing chemical inputs. Exploring these different elements would help to improve our knowledge of overdosing practices with a view to ensuring the global reduction of input consumption in the field of agriculture.

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