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► **To cite this version:**

Basak Bayramoglu, Raja Chakir. The impact of high crop prices on the use of agro-chemical inputs in France: a structural econometric analysis. Land Use Policy, 2016, 55, pp.204-211. 10.1016/j.landusepol.2016.03.027 . hal-01330042

**HAL Id: hal-01330042**

**<https://hal.science/hal-01330042>**

Submitted on 27 May 2020

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1 The impact of high crop prices on the use of agro-chemical  
2 inputs in France: a structural econometric analysis

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4 March 30, 2016

5 **Abstract**

6 World crop prices increased dramatically during the period 2006–2009. In this context  
7 of high crop prices, farmers may tend to increase the amount of agro-chemical inputs they  
8 use in order to increase yield and manage risks related to crop production. These practices  
9 could, however, have potentially adverse environmental effects in terms of loss of biodiversity  
10 and increased water and air pollution. This study uses a structural econometric model to  
11 measure the effects of crop prices on demand for agro-chemical inputs and land allocation.  
12 We study individual farms observed in the period 2006 to 2009 in the French *Département*  
13 *de la Meuse*. We estimate a multi-output profit function using farm-level panel data. Our  
14 results show that an increase in the rapeseed price, which is the principal feedstock for the  
15 production of biodiesel in France, has a positive and significant effect on demand for agro-  
16 chemical inputs. Higher rapeseed prices also induce an expansion in the land area allocated  
17 to rapeseed at the expense of barley and set-aside. These results suggest that changes in  
18 the rapeseed price, partly driven by biofuel policies, induce changes in demand for chemicals  
19 and land allocation which may have potentially adverse effects on the environment.

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‡We thank the Editor of the journal for his help and his overall contribution to the paper, and two anonymous referees for their very detailed and helpful comments. We thank the *Centre de Gestion et d'Economie Rurale de la Meuse/CER* for providing the data and Jean-Pierre Butault, Nathalie Delame and Guy Millet for their helpful comments and suggestions. This research was supported by the European Union's Seventh Framework Programme FP7/2007-2011 under Grant Agreement n° 290693 FOODSECURE (see GA Article II.30). The authors only are responsible for any omissions or deficiencies. Neither the FOODSECURE project and any of its partner organizations, nor any organization of the European Union or European Commission are accountable for the content of this paper.

20            *Keywords:* Pesticide demand, fertilizer demand, agro-chemical inputs, land allocation,  
21 rapeseed price, fertilizer tax, biofuel policies, panel data model.  
22            *JEL codes:* Q12, C33.

## 23 1 Introduction

24 World crop prices increased dramatically in 2007. For example, in France during the period  
25 2006–2010, the rapeseed price increased by 60%, going from €261 up to €416 per ton. This  
26 period of high crop prices was not limited to France; it was observed in all world cereal markets.  
27 Three principal factors have been identified as the drivers of this worldwide increase in food  
28 prices: rising demand from emerging markets for key commodities, dollar depreciation, and  
29 biofuel policies (Abbott et al., 2009). The first two factors are cyclical variations; the last relates  
30 to policies encouraging production and use of biofuels. According to Baier et al. (2009), for the  
31 period 2006-2008, the increase in world biofuel production induced increases in corn, soybean,  
32 and rapeseed prices by 27%, 21% and 18% respectively.

33 High crop prices can encourage farmers to change their agricultural practices, which in turn  
34 may induce potential adverse effects for the environment. For instance, it has been shown that  
35 higher crop prices due to the biofuel production lead to nitrogen runoff and water pollution  
36 problems (Secchi et al., 2011; Langpap and Wu, 2011), induce losses in biodiversity (Secchi  
37 et al., 2007), and exacerbate the climate change problem due to greenhouse gas (GHG) emissions  
38 from land-use changes (Searchinger et al., 2008). The objective of this study is to measure  
39 how increased crop prices affect demand for agro-chemical inputs among French farmers. More  
40 specifically we test the hypothesis that an increase in crop prices increases demand for chemical  
41 inputs (fertilizers and pesticides). We estimate a multi-output profit function based on a panel of  
42 individual farms in France observed from 2006 to 2009. Using the estimated value of the demand  
43 elasticity of pesticides and fertilizers with respect to the rapeseed price, rapeseed being the  
44 principal feedstock for biodiesel production in France, we simulate the effects of European Union  
45 (hereafter denoted as EU) biofuel policy on the use of agro-chemical inputs. These estimates  
46 provide a basis for discussion of a policy instrument, namely a fertilizer tax, in France to limit  
47 the use of fertilizers which may affect surface water and groundwater quality.

48 France is particularly appropriate for analysing demand for agro-chemicals because water  
49 pollution by nitrates and pesticides, mainly due to agricultural and livestock production, is a  
50 major issue there. France is the world's third largest user of pesticides and the seventh largest  
51 consumer of fertilizers. In September 2014 the European Court of Justice ruled that France  
52 had failed to fulfill its obligation to comply with the EU Water Framework Directive. After its  
53 previous judgments of March 2001 (too many nitrates in Brittany catchments) and June 2013  
54 (incomplete designation of "vulnerable" areas of water pollution by nitrates), the decision of  
55 September 2014 was thus the third time the European Court had ruled against France. On this  
56 occasion it was censured for the insufficient measures taken.

57 The EU Water Framework Directive specifies the objective of good or very good surface water  
58 quality by 2015 for all member states. In France in 2013, only 48.2% of surface water resources  
59 are in a good situation regarding the chemical status. The situation is better for groundwater  
60 resources as 67% of them are in a good situation in 2013. The main causes of the bad status  
61 of the remaining 32.8% of groundwater resources are nitrate pollution (17% of water resources)  
62 and pesticide pollution (15.8% of water resources) (Katell and Michon, 2015).

63 The French Ministry of Agriculture recently implemented the Ecophyto Plan aimed at reduc-  
64 ing agricultural pesticide use by 50% by 2018. Environmental taxes on sales of pesticides (“*rede-*  
65 *vances pour pollutions diffuses*”) have been introduced in order to achieve this objective. The tax  
66 rate varies depending on the type of phytosanitary product: it is €2 per kg for environmentally-  
67 harmful organic substances, €0.90 per kg for mineral substances, and €5.10 per kg for toxic  
68 substances. Despite the extent of nitrogen pollution, there is no tax on fertilizers in France.

69 The paper is organized as follows. Section 2 provides a brief overview of the literature on the  
70 estimation of multi-output models and the literature on the environmental impacts of biofuel  
71 production. Section 3 presents the empirical model and the estimation method. Section 4  
72 discusses the data, and the estimation results. We provide a simulation exercise to assess the  
73 impact of alternative crop price scenarios, found in the literature, on the use of agro-chemical  
74 inputs, and discuss a policy instrument to limit their use. Section 5 concludes by discussing how  
75 our estimates could contribute to the ongoing debate on the potential adverse effects of biofuel  
76 development on the environment.

## 77 **2 Literature**

78 Our paper is related to two strands in the literature. The first strand deals with the estimation  
79 of multi-output models to measure how crop prices affect farmers’ production decisions. Multi-  
80 output models are able to take into account cross-price elasticities between different products  
81 (see, among others, Moro and Sckokai (1999); Williams and Shumway (2000); Arnade and Kelch  
82 (2007); Fezzi and Bateman (2011); Lacroix and Thomas (2011); Laukkanen and Nauges (2014)).  
83 Arnade and Kelch (2007) propose a method to estimate individual crop areas and output re-  
84 sponses to a change in prices, by including in the estimations shadow price equations for each crop  
85 area allocation. The estimation method is applied to aggregate data for the state of Iowa during  
86 the period 1960–1999. Lacroix and Thomas (2011) estimate a multi-output model for a panel  
87 of French farmers during 1995–2001. They incorporate a crop-selection mechanism which allows  
88 them to control for the influence of crop rotation on land use and output decisions. The study  
89 most closely related to ours is Laukkanen and Nauges (2014) which estimates a multi-output

90 profit function in order to assess the effects of agri-environmental payments on agro-chemical  
91 inputs and land-use decisions. The estimations are based on a sample of individual Finnish grain  
92 farmers over the period 1996–2005. The estimation results show modest reductions in fertilizer  
93 use in response to agri-environmental payments, which however increase the area allocated to  
94 grain and reduce the area of set-aside land. The authors combine these estimates with envi-  
95 ronmental production functions in order to assess the damage costs associated with nutrient  
96 pollution.

97 The second strand in the literature focuses on changes in intensive and extensive margins of  
98 production following an increase in energy crop prices. The adverse environmental effects due to  
99 higher crop prices could come either from changes in the intensive margin of production, through  
100 the increased use of agro-chemical inputs, or from changes in the extensive margin of production  
101 through land-use changes. In relation to cropping intensification, Louhichi and Valin (2012)  
102 estimate that for France higher rapeseed prices driven by EU biofuel policies will increase by  
103 2020 pesticide use by 5% and  $N_2O$  emissions by 2.5%. Lankoski and Ollikainen (2011) show in  
104 the case of Finland that biodiesel based on rapeseed and ethanol produced from wheat and barley  
105 lead to nitrogen and phosphorus runoff. For the extensive margin, Hausman (2012) estimates  
106 the impact of sugarcane and soybean prices on acreage conversion in Brazil. High corn prices  
107 in the United States (hereafter denoted as US) are estimated to induce nitrate runoff, nitrate  
108 percolation, and soil water erosion (Langpap and Wu (2011)), and to have adverse effects on water  
109 quality (Secchi et al. (2011)). Langpap and Wu (2011) estimate the environmental impacts of  
110 higher commodity prices driven by ethanol mandates in the US, by combining economic and  
111 physical models. The economic models provide information on the changes in crop mix and land  
112 use allocation (cropland vs. noncropland). These estimated changes are then used to evaluate  
113 local environmental impacts such as nitrate runoff, nitrate percolation, and soil water erosion.  
114 Following a \$3 increase in the corn price in the Corn Belt and Lake States, fertilizer use is  
115 estimated to increase by 18% and 18.7%, and pesticide use by 23.1% and 27.5% respectively.  
116 With regard to the climate change problem, Timilsina and Mevel (2013) forecast the impacts  
117 of worldwide biofuel mandate policies on the extent of GHG emissions triggered by land-use  
118 changes.

119 To the best of our knowledge, there has been no econometric assessment of the effects of  
120 crop prices on cropping intensification and land allocation decisions for the case of France in  
121 the recent context of high agricultural commodity prices, partly driven by biofuel policies. Our  
122 study aims to fill this gap and to shed some light on this question. The structural econometric  
123 approach presented below, allows us systematically to estimate the effects of crop prices on both

124 cropping intensification and land allocation decisions.

### 125 3 The empirical model

126 We consider a risk-neutral farmer who uses  $K$  variable inputs and one fixed but allocatable factor  
 127 (land) to produce  $C$  different crops, where  $c$  is the crop index,  $c = 1, \dots, C$ ;  $p_c$  is the price of  
 128 crop  $c$ ;  $y_c$  is the output level of crop  $c$ ;  $x$  is a  $K$  vector of variable inputs;  $w_k$  is the price of input  
 129  $k$ ;  $l_c$  is the land allocated to crop  $c$  and  $L$  is the total available land ( $\sum_{c=1}^C l_c = L$ ).

130 Following Chambers and Just (1989), the multi-crop profit function for a joint input tech-  
 131 nology given the fixed factor allocation (land) can be written as:

$$\Pi(p, w, \tau, L) = \max_{y, x, l} \left\{ \sum_{c=1}^C p_c y_c - \sum_{k=1}^K w_k x_k + 0.25 * \sum_{c=1}^C \tau_c l_c + SFP; \sum_{c=1}^C l_c = L \right\} \quad (1)$$

132 where  $\tau_c$  is the subsidy rate per hectare for crop  $c$ . The *SFP* or single farm payment is  
 133 calculated on a historical basis independent of actual production, and was introduced by the  
 134 2003 reform of the Common Agricultural Policy (CAP). Decoupling refers to the removal of  
 135 the link between receipt of a direct payment and production of a specific product. Prior to  
 136 the reform, farmers received a direct payment only if they produced the specific product with  
 137 which the direct payment was associated. The 2003 CAP reform permitted member states to  
 138 continue to couple a small number of direct payments to production (in the case of France, 25%  
 139 of production).<sup>1</sup>

140 Following Lacroix and Thomas (2011) and Laukkanen and Nauges (2014), the normalized  
 141 quadratic profit function is written as:

$$\begin{aligned} \bar{\Pi} = & \alpha_0 + \sum_{c=1}^C \alpha_c \bar{p}_c + \sum_{k=1}^{K-1} \beta_k \bar{w}_k + \sum_{c=1}^C \gamma_c \bar{\tau}_c + \frac{1}{2} \sum_{c=1}^C \sum_{c'=1}^C \alpha_{cc'} \bar{p}_c \bar{p}_{c'} + \frac{1}{2} \sum_{k=1}^{K-1} \sum_{k'=1}^{K-1} \beta_{kk'} \bar{w}_k \bar{w}_{k'} + \frac{1}{2} \sum_{c=1}^{C-1} \sum_{c'=1}^C \gamma_{cc'} \bar{\tau}_c \bar{\tau}_{c'} \\ & + \sum_{k=1}^{K-1} \sum_{c=1}^C \delta_{ck}^{pw} \bar{p}_c \bar{w}_k + \sum_{c'=1}^C \sum_{c=1}^C \delta_{cc'}^{p\tau} \bar{p}_c \bar{\tau}_{c'} + \sum_{k=1}^{K-1} \sum_{c=1}^C \delta_{ck}^{w\tau} \bar{w}_k \bar{\tau}_c + \sum_{c=1}^C \lambda_c^{pL} \bar{p}_c L + \sum_{c=1}^C \lambda_c^{\tau L} \bar{\tau}_c L + \sum_{k=1}^{K-1} \lambda_k^{wL} \bar{w}_k L, \end{aligned} \quad (2)$$

142 where  $\bar{\Pi} = \frac{\Pi}{w_K}$ ,  $\bar{p}_c = \frac{p_c}{w_K}$ ,  $\bar{w}_k = \frac{w_k}{w_K}$ ,  $\bar{\tau}_c = \frac{\tau_c}{w_K}$  indicate respectively normalized profit, output  
 143 price, input price, and subsidy rate, and  $w_K$  is the price of the numeraire.

144 Differentiating the profit in (2) with respect to output prices  $\bar{p}_c$  yields the output level of  
 145 crop  $c$  (Hotelling Lemma):

<sup>1</sup>For more details on 2003 CAP reform, see Butault (2004), chapter 3.

$$y_c = \frac{\partial \Pi}{\partial \bar{p}_c} = \alpha_c + \sum_{c'=1}^C \alpha_{cc'} \bar{p}_{c'} + \sum_{k=1}^{K-1} \delta_{ck}^{pw} \bar{w}_k + \sum_{c'=1}^C \delta_{cc'}^{p\tau} \tau_{c'} + \lambda_c^{pL} L, \quad \forall c = 1, \dots, C, \quad (3)$$

146 Differentiating the profit in (2) with respect to input prices  $\bar{w}_k$  yields the variable input  
147 demand equation (Hotelling Lemma):

$$-x_k = \frac{\partial \Pi}{\partial \bar{w}_k} = \beta_k + \sum_{k'=1}^{K-1} \beta_{kk'} \bar{w}_{k'} + \sum_{c=1}^C \delta_{ck}^{pw} \bar{p}_c + \sum_{c=1}^C \delta_{ck}^{w\tau} \bar{\tau}_c + \lambda_k^{wL} L, \quad \forall k = 1, \dots, K-1, \quad (4)$$

148 We follow the paper of Lacroix and Thomas (2011) and derive optimal land allocations by  
149 computing the derivatives of the profit function in (2) with respect to the crop area subsidies<sup>2</sup>  
150  $\bar{\tau}_c$ :

$$0.25 * l_c = \frac{\partial \Pi}{\partial \bar{\tau}_c} = \gamma_c + \sum_{c'=1}^C \gamma_{cc'} \bar{\tau}_{c'} + \sum_{k=1}^{K-1} \delta_{ck}^{w\tau} \bar{w}_k + \sum_{c'=1}^C \delta_{cc'}^{p\tau} \bar{p}_c + \lambda_c^{L\tau} L, \quad \forall c = 1, \dots, C, \quad (5)$$

151 The profit function properties imply that the profit function is (1) non-decreasing in output  
152 prices  $p$ , non-increasing in input prices  $w$ , (2) homogeneous of degree 1 in prices  $(p, w, \tau)$ , (3)  
153 convex in prices  $(p, w)$ , (4) continuous in prices  $(p, w)$ . These properties imply that some con-  
154 ditions need to be imposed on the parameters, such as symmetry. With the normalized form of  
155 the profit, the condition of linear homogeneity is automatically satisfied.

156 We need also to impose the land adding-up condition  $\sum_{c=1}^C l_c = L$ , which in our case imposes  
157 the following conditions on the parameters:

$$\begin{aligned} \sum_{c'=1}^C \gamma_{cc'} &= \sum_{c'=1}^C \delta_{ck}^{w\tau} = \sum_{c'=1}^C \delta_{cc'}^{p\tau} = \sum_{c'=1}^C \gamma_c = 0; \quad \forall k, \forall c \\ \sum_{c'=1}^C \lambda_c^{L\tau} &= 0.25 \end{aligned}$$

158 We calculate the elasticities of inputs, output, and land allocation with respect to prices and  
159 subsidies. They are computed by multiplying the corresponding parameter (coefficient of price  
160 or subsidy rate in the land, output or input equation) by the ratio of the normalized price (or

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<sup>2</sup>This approach has some limitations which are important to be acknowledged. The first is that land equations for crops which do not receive arable area payments are not identified. The second is that this creates a separation between the crop production function and the land production function, which means that the only rationale for allocating land to a certain crop is the associated arable area payment, and not the fact that a crop can be sold for a certain price and produce revenues. The third limitation is that in the land use, output and input equations the impact of prices is assumed to not depend on the size of the farm and, therefore, one can obtain misleading results if farm size differ significantly within the sample.



161 subsidy rate) and land area, output level or input level. For example, the elasticity of input  
 162 demand with respect to its own price, output price, and subsidy rates, can be calculated as  
 163 follows:

$$\varepsilon_{x_k \bar{w}_{k'}} = \frac{\partial x_k}{\partial \bar{w}_{k'}} \times \frac{\bar{w}_{k'}}{x_k} = -\beta_{kk'} \times \frac{\bar{w}_{k'}}{x_k} \quad (6)$$

$$\varepsilon_{x_k \bar{p}_c} = \frac{\partial x_k}{\partial \bar{p}_c} \times \frac{\bar{p}_c}{x_k} = -\delta_{ck}^{pw} \times \frac{\bar{p}_c}{x_k} \quad (7)$$

$$\varepsilon_{x_k \bar{\tau}_c} = \frac{\partial x_k}{\partial \bar{\tau}_c} \times \frac{\bar{\tau}_c}{x_k} = -\delta_{ck}^{w\tau} \times \frac{\bar{\tau}_c}{x_k} \quad (8)$$

164 We estimate simultaneously the system of equations (3-4-5) after imposing symmetry restric-  
 165 tions and land adding-up conditions. The explanatory variables are output prices, input prices,  
 166 the vector of subsidy rates and total land. All prices and subsidies are normalized by the price  
 167 of seed. Since we observe panel data, we control in our model for unobserved individual hetero-  
 168 geneity. From an econometric standpoint, individual effects can be assumed to be either random  
 169 or fixed. The choice between the random-effect (RE) or fixed-effect (FE) specification depends  
 170 on the model and data (Baltagi, 1995). According to Greene (2008) (chapter 11, page 347):  
 171 "*... the crucial distinction between fixed and random effects is whether the unobserved individual*  
 172 *effect embodies elements that are correlated with the regressors in the model, not whether these*  
 173 *effects are stochastic or not". A RE model requires that the individual effects are independent*  
 174 *of regressors. We choose to model individual effects through FE specification<sup>3</sup>, as this choice*  
 175 *allows the individual effects to be correlated with exogenous regressors. To estimate the FE*  
 176 *model, we apply the within transformation to all variables and estimate a Seemingly Unrelated*  
 177 *Regression Equations (SURE) model. The within transformation, which causes the variables to*  
 178 *deviate from their individual means, cancels out time-invariant unobserved individual effects.*

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<sup>3</sup>As suggested by a reviewer, this fixed effect estimator is consistent only if these effects are additive. Adding interaction effects is a very good idea, but because our model is structural their addition would involve changing the whole set of constraints.

## 179 4 Data description and estimation results

### 180 4.1 Data description

181 The study is conducted on a sample of French farmers from the *Département de la Meuse*.<sup>4</sup>  
182 Our data are provided by the Meuse Management Centre (*Centre de Gestion de la Meuse*),  
183 and they were used in previous studies (Boussemart et al., 2011; Chakir and Hardelin, 2014).  
184 Agricultural land in Meuse represents 54% of the department's overall area: 36% is arable land  
185 and the remaining 18% is grassland. Cereals and oil crops are the main agricultural products  
186 and account for 81% of the arable area. Our sample is an unbalanced panel observed between  
187 2006 and 2009. An interesting feature of our database is that it contains detailed information  
188 on the main inputs for each crop: fertilizers (nitrogen, phosphorous, potassium - NPK) and  
189 pesticides (herbicides, fungicides, insecticides, growth regulators). The sampled farms mainly  
190 produce cereal and oil crops. The most frequent crop rotation observed in our sample involves  
191 wheat, barley, and rapeseed. More than 97%, 92% and 81% of farmers in our sample produce  
192 wheat, barley and rapeseed respectively every year. The percentage of farmers having set aside  
193 land varies between 86% in 2006 and 59% in 2009.<sup>5</sup>

194 This data set is representative from two standpoints. First, Delame (2014) notes that the  
195 acreage of this sample is very representative for all years of the acreage of the *Département de la*  
196 *Meuse* described by Annual Agricultural Statistics.<sup>6</sup> Permanent pastures occupy less than one  
197 third of the total area. Wheat is the most important crop in terms of area (25%) followed by  
198 rapeseed (15%) and barley. Peas, corn and sunflower are rather marginal crops.

199 Second, we note that pesticide and fertilizer expenditure per hectare of our sample in 2006,  
200 wheat pesticide: €/ha 132, barley pesticide: €/ha 110, rapeseed pesticide: €/ha 150; wheat  
201 fertilizer: €/ha 141, barley fertilizer: €/ha 113, rapeseed fertilizer: €/ha 133 (see Table 1), are  
202 comparable to those from FADN data.<sup>7</sup> On average for all crops, we note that the statistics  
203 of our sample are comparable to the expenditure of other agricultural regions such as Ile-de-  
204 France (Fertilizer: €/ha 106; Pesticide: €/ha 92), Champagne-Ardenne (Fertilizer: €/ha 147;

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<sup>4</sup>The *Département de la Meuse* is located in a relatively small French territorial division (6,211 kilometers<sup>2</sup>). It is one of four *départements* in the *Lorraine Région*. Information about *Département de la Meuse* and a map can be found at <http://en.wikipedia.org/wiki/Meuse>.

<sup>5</sup>The presence of censored observations in land areas is important to be acknowledged. Econometrically dealing with multiple censoring with panel data and SURE is a challenge that is beyond the scope of this paper. For examples of studies that addressed this issue, see Fezzi and Bateman (2011), Lacroix and Thomas (2011), and Platoni et al. (2012).

<sup>6</sup>Source: <http://agreste.agriculture.gouv.fr/enquetes/statistique-agricole-annuelle-saa/>

<sup>7</sup>The FADN data is representative at the regional level, covering a larger spatial area than that of *départements*. The FADN data does not distinguish the levels of inputs used for each crop.

205 Pesticide: €/ha 133) and Lorraine (Fertilizer: €/ha 132; Pesticide: €/ha 151).

206 We now describe how the data is constructed. Output crop prices are computed using a unit  
207 value approach, by dividing annual crop sales by the quantity produced. In doing so, we are aware  
208 that crop prices depend on the quantity sold but the calculated prices are annual average prices.  
209 Given that crop prices depend on the crop quality (protein content) and that they are subject  
210 to seasonal variations as well, the relationship between the average annual price and quantity  
211 sold is rather complex. We also constructed unit subsidy rates for each crop area and land set-  
212 aside by dividing the total subsidy by the associated area. Physical quantities of pesticides and  
213 fertilizers need to be observed to augment the system of estimated equations. In our data we  
214 observe only expenditure on pesticides, which we divided by a national pesticide price index to  
215 calculate pesticide demand. With regard to fertilizers, we observe physical quantities as well as  
216 expenditure, enabling us to calculate the individual average price of fertilizers.

217 The summary statistics presented in Table 1 show that, in our sample, rapeseed prices in-  
218 creased by 19% between 2006 and 2009. This is fairly large compared to the observed increase at  
219 the national level (7%). Table 1 shows also that expenditure on fertilizers for rapeseed increased  
220 by 88% whereas rapeseed area increased by about 50%. Fertilizer expenditure is fairly similar  
221 in 2006 and 2007, but then increases significantly in 2008 and 2009. This increase in expendi-  
222 ture could be explained by the sharp increase in fertilizer prices internationally in the period  
223 2008-2009.

## 224 4.2 Estimation results

225 We estimate the system of equations presented above 3-4-5. We have then nine equations esti-  
226 mated simultaneously: wheat output, rapeseed output, barley output; wheat area, rapeseed area,  
227 barley area, set-aside area; pesticide demand and fertilizer demand. We estimate this system  
228 by Within-SURE<sup>8</sup> (using SAS software). Raw estimation results, which are used to calculate  
229 elasticities, are not reported here but are available from the authors upon request.

230 We estimate the elasticity of crop output, input demand, and land allocation decisions with  
231 respect to crop and input prices, as well as with respect to subsidy rates as shown in equations  
232 6-7-8. In our view, the most interesting results are those related to elasticities involving demand  
233 for chemical inputs with respect to crop prices and area-subsidy rates. We present these results  
234 first.

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<sup>8</sup>In order to check the robustness of our results we have also estimated the system by OLS. The two methods give very similar results.

Table 1: Descriptive statistics

Variable	2006		2007		2008		2009	
	mean	std	mean	std	mean	std	mean	std
Wheat output (t)	291	207	297	204	333	216	370	237
Barley output (t)	208	165	183	145	228	181	247	184
Rapeseed output (t)	83	76	100	85	101	84	121	98
Wheat area (ha)	42	28	43	28	48	29	48	29
Barley area (ha)	34	27	35	27	37	29	37	28
Rapeseed area (ha)	27	24	30	25	30	24	32	26
Set-aside area (ha)	7	9	6	8	3	5	2	4
Wheat price (€/t)	111	32	182	36	143	22	107	13
Barley price (€/t)	85	55	120	91	111	85	69	50
Rapeseed price (€/t)	186	103	242	116	273	132	222	93
Wheat subsidy (€/ha)	81	11	79	15	75	15	74	13
Barley subsidy (€/ha)	81	12	79	15	75	14	74	12
Rapeseed subsidy (€/ha)	78	43	74	38	74	41	76	37
Set-aside subsidy (€/ha)	9	20	8	20	5	19	37	38
Wheat pesticide (€/ha)	132	45	133	44	156	46	163	48
Barley pesticide (€/ha)	110	62	111	61	130	71	131	68
Rapeseed pesticide (€/ha)	150	88	151	83	167	91	187	91
Set-aside pesticide (€/ha)	6	129	0	3	0	3	0	3
Wheat fertilizer (€/ha)	141	42	145	40	189	56	237	76
Barley fertilizer (€/ha)	113	61	119	59	152	81	195	109
Rapeseed fertilizer (€/ha)	133	79	139	75	180	102	250	133
Set-aside fertilizer (€/ha)	9	199	0	3	0	2	0	0
Observations	N=527		N=526		N=526		N=483	

Table 2: Elasticities of agro-chemical inputs demand calculated at the sample mean

with respect to	Fertilizer demand	Pesticide demand
Wheat price	-0.0701*** (0.0212)	-0.0541** (0.0252)
Barley price	0.1193*** (0.0142)	-0.1029*** (0.0172)
Rapeseed price	0.1789*** (0.0123)	0.0370*** (0.0143)
Wheat subsidy	-0.0023*** (0.0004)	0.0017** (0.0008)
Barley subsidy	0.0015*** (0.0004)	-0.0011 (0.0008)
Rapeseed subsidy	0.0003 (0.0004)	0.0002 (0.0009)
Set-aside subsidy	0.0006 (0.0005)	-0.0011 (0.0013)
Fertilizer price	-0.2784*** (0.0142)	-0.1097*** (0.0133)
Pesticide price	-0.1028*** (0.0125)	-0.0259 (0.0354)

\*p<0.1; \*\*p<0.05; \*\*\*p<0.01

Standard errors in parentheses

Table 3: Elasticities of output calculated at the sample mean

with respect to	Wheat Output	Barley output	Rapeseed output
Wheat price	0.0148 (0.0272)	-0.3837*** (0.0272)	-0.0236 (0.0223)
Barley price	-0.1965*** (0.0139)	0.1812*** (0.0228)	-0.1178*** (0.0144)
Rapeseed price	-0.0122 (0.0116)	-0.1189*** (0.0145)	0.1624*** (0.0190)
Wheat subsidy	0.0016*** (0.0005)	-0.0057*** (0.0005)	-0.0004 (0.0004)
Barley subsidy	-0.0035*** (0.0004)	0.0080*** (0.0006)	-0.0039*** (0.0004)
Rapeseed subsidy	0.0006** (0.0003)	-0.0016*** (0.0004)	0.0047*** (0.0004)
Set-aside subsidy	0.0020*** (0.0004)	-0.0008* (0.0005)	-0.0010* (0.0004)
Fertilizer price	0.0282*** (0.0086)	-0.0938*** (0.0112)	-0.1393*** (0.0096)
Pesticide price	0.0204** (0.0095)	0.0758*** (0.0127)	-0.0270*** (0.0104)

\*p<0.1; \*\*p<0.05; \*\*\*p<0.01

Standard errors in parentheses

Table 4: Elasticities of land allocation calculated at the sample mean

with respect to	Wheat area	Barley area	Rapeseed area	Set-aside area
Wheat price	0.0196*** (0.0060)	-0.0564*** (0.0071)	0.0119** (0.0059)	0.1655*** (0.0313)
Barley price	-0.0369*** (0.0035)	0.0653*** (0.0052)	-0.0168*** (0.0041)	-0.0358* (0.0211)
Rapeseed price	-0.0027 (0.0027)	-0.0319*** (0.0036)	0.0488*** (0.0037)	-0.0423** (0.0172)
Wheat subsidy	0.0022 (0.0018)	-0.0166** (0.0068)	0.0407*** (0.0077)	-0.1551*** (0.0410)
Barley subsidy	-0.0130** (0.0053)	0.0735*** (0.0125)	-0.0516*** (0.0091)	-0.1436*** (0.0450)
Rapeseed subsidy	0.0252*** (0.0048)	-0.0409*** (0.0072)	0.0119 (0.0105)	0.0146 (0.0458)
Set-aside subsidy	-0.0231*** (0.0061)	-0.0273*** (0.0086)	0.0035 (0.0110)	0.4361*** (0.0818)
Fertilizer price	0.0116*** (0.0022)	-0.0097*** (0.0029)	-0.0028 (0.0030)	-0.0200 (0.0168)
Pesticide price	-0.0081** (0.0039)	0.0068 (0.0049)	-0.0013 (0.0069)	0.0342 (0.0418)

\*p<0.1; \*\*p<0.05; \*\*\*p<0.01

Standard errors in parentheses

### 235 4.2.1 Elasticity estimates

236 The results presented in Table 2 show that farmers tend to demand more fertilizers and pesticides  
237 in a context of high rapeseed prices. Our empirical estimates of the elasticities of demand  
238 for fertilizers and pesticides with respect to rapeseed price are both positive and statistically  
239 significant at the 1% level: 0.1789 for fertilizer demand and 0.0370 for pesticide demand. For  
240 other crops, we obtain the following results. The barley price has a positive and significant  
241 effect on fertilizer demand but a negative and significant effect on pesticide demand. In the  
242 case of wheat, the crop price negatively and significantly affects demand for both fertilizers and  
243 pesticides.

244 Our estimates of chemical input demand with respect to rapeseed price are positive for both  
245 fertilizer and pesticide. Moreover, it appears that demand for fertilizers is more responsive  
246 than demand for pesticides to the rapeseed price. Moro and Sckokai (1999) find that elasticity  
247 estimates with respect to crop prices are negative for maize, other cereals, and oilseeds, but  
248 positive for other field crops (0.063). Williams and Shumway (2000) estimate that for the US  
249 elasticity of pesticides with respect to food grain prices is negative ( $-0.427$ ), but positive for  
250 other field crops (0.461). For fertilizers, U.S. elasticity estimates with respect to crop prices are  
251 negative for both food grains and other field crops ( $-0.090$  and  $-0.023$  respectively).

252 Let us look now at the link between demand for chemicals and area-subsidy rates. In the case  
253 of fertilizers, subsidies for barley area, rapeseed area and set-aside land positively affect fertilizer  
254 demand, but only the effect of the barley-area subsidy is significant. The wheat area subsidy has  
255 a negative and significant effect on fertilizer demand. In the case of pesticides, area-payments for  
256 rapeseed and wheat have a positive effect on pesticide demand, but the effect is not significant for  
257 rapeseed subsidy. Barley area and set-aside land subsidies negatively affect pesticide demand but  
258 their effect is not significant. Laukkanen and Nauges (2014) estimate that area-based subsidies  
259 for grains increase total fertilizer and pesticide use, while set-aside subsidies decrease it.

260 Our estimation results show first that the effects of area-payments on the demand for chemi-  
261 cals differ significantly among crops – in our case rapeseed, barley, and wheat. More importantly,  
262 our results show that in all cases where the coefficients are significant, the demand for chemicals  
263 is more responsive to crop prices than to subsidy rates. For example, in the case of fertilizers,  
264 demand is more elastic (in absolute value) with respect to the wheat price than to the wheat  
265 area subsidy. This finding also holds for the barley price and barley area subsidy. In the case of  
266 pesticides, demand is more elastic with respect to wheat price than to wheat area subsidy.

267 We now present, in Table 4, the results related to elasticities involving land allocation de-  
268 cisions with respect to crop prices and subsidy rates. First, they are responsive to the price of



269 their respective crops. Second, they are positively influenced by their respective subsidies.

270 Let us now summarize our findings. We note that higher rapeseed prices increase demand  
271 for both fertilizers and pesticides. Furthermore, increased rapeseed prices induce farmers to  
272 expand their land area allocated to rapeseed at the expense of barley and set-aside land. These  
273 findings confirm the argument in Nelson and Robertson (2008) that higher prices for biofuel  
274 crops encourage farmers to intensify cultivation of these crops and also to convert some land  
275 area to biofuel crops.

#### 276 4.2.2 Own-price and cross-price effects

277 As shown in Tables 3-4, with the exception of wheat output and rapeseed area, all own-price  
278 elasticities of output and own-subsidy elasticities of land are significantly different from 0. Supply  
279 of barley and rapeseed is inelastic with respect to their own-prices. Note also that the supply  
280 of wheat, barley, and rapeseed is inelastic with respect to their area-subsidies. Nonetheless, the  
281 positive but inelastic elasticities with respect to subsidies confirm that CAP aid in the period  
282 2006-2009 is not fully decoupled.

283 All cross-price elasticities of output are negative. Also most of the significant cross-subsidy  
284 elasticities of land are negative (with the exception of that between wheat and rapeseed, which  
285 is significantly positive).

286 Table 2 shows that the own-price elasticity of fertilizer demand is significantly different from 0;  
287 this is not the case for pesticide demand. Fertilizer demand has a significant own-price elasticity  
288 of  $-0.28$ . Estimates of own-price elasticity of fertilizers and pesticides are infrequent in the  
289 literature; these two inputs are usually aggregated due to data limitations. Our estimate of the  
290 own-price elasticity of fertilizers is slightly lower than those estimated by Lacroix and Thomas  
291 (2011):  $-0.371$  (t-statistic:  $-1.97$ ) for France, and Williams and Shumway (2000) for the US  
292  $-0.44$  (standard error:  $0.095$ ) and Mexico  $-0.46$  (standard error:  $0.0874$ ).

293 There are a few estimates of the own-price elasticity of pesticides for the US or the Nether-  
294 lands.<sup>9</sup> Our results indicate an estimated own-price elasticity of pesticides of  $-0.026$  but it is  
295 not significant. In our estimations, the non-significance of pesticide elasticity with respect to  
296 its own-price could be explained by lower time-series variation in pesticide expenditure than in  
297 fertilizer expenditure. Our estimate is lower in absolute value than the estimates in the literature,  
298 which range from  $-1.2$  to  $-0.1$ . For instance, Williams and Shumway (2000) provide a larger  
299 absolute value of the own-price elasticity of pesticides, namely  $-0.25$  (standard error:  $0.053$ ) for  
300 the US and  $-0.28$  (standard error:  $0.1755$ ) for Mexico. For pesticides, it is well known that

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<sup>9</sup>See, for instance, INRA-CEMAGREF (2005) (chapter 5, p.75) for a list of estimates found in the literature.

301 the technical dependence of conventional production systems vis-à-vis the use of pesticides is  
302 reflected economically by a low elasticity of demand for pesticides relative to their price (INRA-  
303 CEMAGREF (2005), p.25). Carpentier (2010) also notes that these elasticities are usually small  
304 in absolute value in the long run and very small in the short run.

305 In our study, the cross-price elasticity of fertilizer demand with respect to pesticide price is  
306 negative and significantly different from zero. This finding indicates that these two inputs are  
307 complements in agricultural production.

### 308 4.3 Simulations and discussion

309 Given the extent of nitrogen and pesticide pollution in French water bodies, it is interesting  
310 to simulate the impact on demand for agro-chemicals of high rapeseed prices driven by biofuel  
311 policies. To conduct this simulation exercise, we use three different assessments from the litera-  
312 ture on the evolution of oilseed prices, partly driven by EU biofuel policies. Louhichi and Valin  
313 (2012) estimate an increase of 43% in the price for rapeseed in the EU by 2020 under the scenario  
314 of the current EU biofuel mandate as defined by the 2009 Renewable Energy Directive. This  
315 scenario assumes an incorporation rate of 7.7% for first generation biofuels in the total fuel used  
316 in the transport sector. We also use two other assessments of the increase in oilseed prices at  
317 the international level related to EU biofuel policies: 32% (Britz and Leip, 2008), and 9% AGRI  
318 (2007).

319 We use these assessments to simulate the impacts of such price variations on demand for  
320 agro-chemicals in France. To do this, we take into account our elasticity estimates of chemicals  
321 demand with respect to the rapeseed price. We are aware that our estimates are based on a  
322 specific sample from one *département* out of a total of 96 in Metropolitan France over a specific  
323 time period (2006-2009). However, as subsection 4.1 shows, our data set is representative of the  
324 whole *département* in terms of acreage, and of a large number of regions in France in terms of  
325 chemicals usage levels. The outcomes of this simulation exercise are summarized in Table 5.

326 It emerges that demand for fertilizers will increase by +1.6% to +7.69% by 2020 due to the  
327 rise in rapeseed prices driven by EU biofuel policies. The increase will be lower for pesticide  
328 demand: from +0.33% to +1.6%.

329 In the last column of Table 5, we report the simulated tax on fertilizers needed to overcome  
330 the implied increase in fertilizer demand due to higher rapeseed prices partly driven by EU biofuel  
331 policies.<sup>10</sup> Using our estimate of the own-price elasticity of fertilizers ( $-0.28$ ), and depending on  
332 the various price scenarios, the corresponding fertilizer price variation ranges between +5.71%

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<sup>10</sup>Note that there is no room here for a tax to reduce pesticide demand because its own-price elasticity is not significant.

Table 5: Variation in agro-chemicals demand and the fertilizer taxes required according to different oilseed prices

	Oilseed price (%)	Fertilizer demand (%)	Pesticide demand (%)	Tax on fertilizers (€/kg)
Louichi and Vallin (2012)	43%	7.69%	1.6%	0.27
Britz and Leip (2008)	32%	5.72%	1.19%	0.20
DG Agri (2007)	9%	1.60%	0.33%	0.05

333 and +27.46%. Since the average price of fertilizers during the period under study (2006–2009) is  
 334 €0.98 per kg (Eurostat), this corresponds to a fertilizer tax ranging between €0.05 per kg and  
 335 €0.27 per kg. These tax rates are of the same magnitude as those applied in some European  
 336 countries. For instance, Sweden applies a tax on nitrogen fertilizers of €0.19 per kg (Mattheiss  
 337 et al., 2013).

## 338 5 Conclusion

339 World crop prices increased dramatically during the period 2006–2009. In a context of high  
 340 crop prices, farmers may tend to increase the amount of agro-chemical inputs they use both to  
 341 increase yield and to manage risks related to crop production. These practices could, however,  
 342 have potentially adverse environmental effects in terms of loss of biodiversity and increased  
 343 water and air pollution. We estimated a structural econometric model to measure the effects  
 344 of crop prices on demand for agro-chemical inputs and land allocation. The model tested the  
 345 hypothesis that a rise in the rapeseed price increases demand for chemical inputs (fertilizers and  
 346 pesticides), rapeseed being the principal feedstock for production of biodiesel in France. We  
 347 studied individual farms observed in the period 2006 to 2009 in the French *Département de la*  
 348 *Meuse*.

349 Our estimations of a multi-output profit function with farm-level panel data reveal that  
 350 higher rapeseed prices increase demand for both fertilizers and pesticides. Furthermore, higher  
 351 rapeseed prices encourage farmers to expand the area allocated to rapeseed at the expense of  
 352 barley and set-aside. These results suggest that biofuel policies, through an increase in rapeseed  
 353 prices, induce changes in chemicals demand and land allocation. These changes, in turn, may  
 354 have potentially adverse effects on the environment, such as nitrogen runoff and water pollution.

355 In the context of a link between chemicals demand and area-subsidy rates, our estimation

356 results show, first, that the effects of subsidy rates on chemicals demand differ significantly from  
357 one crop to another – in our case rapeseed, barley, and wheat. Second, and more importantly,  
358 we find that in all cases where the coefficients are significant, demand for chemicals is more  
359 responsive to crop prices than to subsidy rates.

360 We discussed a policy option to limit the use of fertilizers. A fertilizer tax could be considered,  
361 given the significant negative own-price elasticity of fertilizer demand. Our simulation exercise  
362 suggests that a fertilizer tax ranging from €0.05 per kg to €0.27 per kg would be appropriate in  
363 response to the increase in fertilizer demand due to a higher rapeseed price, driven by EU biofuel  
364 policies. In France, a new fertilizer measure was announced by the French President during  
365 the 2nd French Environmental Conference in October 2013, to the effect that value-added tax  
366 on fertilizers would be increased; however, no details were supplied. This announcement has  
367 disappointed a number of environmental non-governmental organizations which were hoping for  
368 an environmental tax on fertilizers.

369 It is important to note that our modelling approach does not consider either uncertainty or  
370 production risk. Indeed, part of the variation in demand for agro-chemicals might be driven by  
371 uncertainty and production risk if farmers are not risk neutral. If this is the case, then the impact  
372 of crop prices on fertilizer and pesticide use as measured in the paper may be overestimated.  
373 The inclusion of uncertainty in the model could be the subject of a future study.

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