Do Farmers Internalise External Impacts of Pesticides in Production?

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Abstract

In modern agriculture, pesticides feature so prominently in growers' arsenal to reduce crop damage caused by various pests and diseases. But their indiscriminate use can harm human health and the environment and, eventually, impact agricultural productivity negatively. In an era of an increasing public awareness on the external effects of pesticides, the EU is trying to update its pesticide policy by establishing tax and levy schemes. An important question is whether the external impacts of pesticides are also affecting the farmers' production environment. A damage abatement specification is used consisting of a potential output function and a damage abatement function. The damage abatement function considers both high and low toxicity pesticides, and variables reflecting pesticide impacts on biodiversity and operator's health. The application focuses on panel data of Dutch cash crop producers. The pesticide contirbution on some biodiversity categories are found to impact farm output significantly. The outcome is important for designing tax systems that aim at socially optimal use of pesticides.

Keywords: pesticides, externalities, biodiversity, The Netherlands

1. Introduction

Pesticides constitute one of the most important inputs in arable farming as they are world-wide the most common way of controlling pests. There is a large range of positive outcomes from the use of different pesticides related to agricultural productivity. Pesticides can secure farm income by preventing crop losses to insects and other pests, improve shelf life of the produce, reduce drudgery of weeding that frees labor for other tasks and reduce fuel use for weeding.

But their use raises a number of environmental and health concerns. Indiscriminate pesticide use can lead to off-target contamination due to spray drift with devastating effects for biodiversity, bystanders, soil and water courses. Organic compounds of pesticides that are resistant to environmental degradation can contribute to soil contamination and bio-accumulate in human and animal tissue. Pesticides can be dangerous to workers, consumers and bystanders. Farm workers that lack the appropriate protective equipment can exhibit irritations, poisonings and even death. Pesticides have been shown to have devastating effects on water organisms (Fairchild & Eidt, 1993), birds (Boatman et al. 2004), non-target beetles (Lee et al., 2001) and bees (Brittain et al., 2009).

Agricultural output can be negatively impacted from the above mentioned pesticide externalities. Farm operator's health problems can decrease the efficiency of labor while a decreasing biodiversity deprives the farm from beneficial organisms' productive and damage-abating functions. Pollinators like wild bees can increase plant seed set and output quality (Roldan Serrano and Guerra-Sanz, 2006; Morandin and Winston, 2006) while beetles and birds can control pest populations.

As public awareness in Europe is growing regarding the external effects of pesticides on human health and the environment, the European Union (EU) is planning to revise its pesticide policy by introducing tax and levy schemes that will internalize pesticide externalities and lead to socially optimal pesticide use. The integration of external effects of pesticides in farmer's production technology can assist policy makers in designing appropriate pesticide tax policies. The objective of this paper is to model whether pesticide externalities are also affecting agricultural output.

The remainder of the paper is structured as follows. Section 2 presents the theoretical model of optimal pesticide use. Section 3 introduces the model specification followed by the estimation method and data description. Results are analyzed in Section 4 and conclusions presented in Section 5.

2. Model of optimal pesticide use

Let's assume the structure of production to be characterized as follows:

$$h = f(y, x_p, q_k) * m(Z, PI_{j_t}) \qquad (1)$$

where a single output is produced, y, using multiple variable inputs (x_p), fixed inputs (q_k) and damage-abatement inputs (Z, pesticides). Pesticides are separated into two categories, $Z=g(Z_l,Z_h)$, where subscripts ‘l’ and ‘h’ indicate low toxicity and high toxicity pesticides respectively. The Pesticide Impacts (PI), reflecting mainly impacts on biodiversity, are a function of pesticide use as they are yearly observations of the impacts of the used pesticide products:

$$PI_{j_t} = g(Z_{h_{t-1}}, Z_{l_{t-1}}) \qquad (2)$$

where the beginning of the year environmental impact is a product of pesticides used in the preceeding year. Therefore, the dynamics lie on the fact that pesticide use last year impacts production of the current year. The importance of PI on the farm decision environment lies on the fact that biodiversity can control pest populations (by making it difficult to spread in a non-uniform habitat) and increase production through crop pollination. The specification in (2) implies that the state variable PI_j evolves according to $PI_{j,t} - PI_{j,t-1} = g(Z_{h,t-1}, Z_{l,t-1}) - g(Z_{h,t-2}, Z_{l,t-2}) - PI_{j,t-1}$ which indicates a 100% depreciation rate. As a result, the current period choices of pesticides (Z_l, Z_h) can be fully characterized as two period optimization problem.

We can conceptualize the problem as following: Producers are trying to maximize their profit by choosing the optimal quantity of variable inputs (x_p) and pesticides (Z_l, Z_h),

$$\underset{y_t, x_{i_t}, Z_l, Z_h}{Max}\ p_t y_t - w_{p_t} x_{p_t} - w_{Z_t}(Z_{l_t} + Z_{h_t}) + \beta[p_{t+1} y_{t+1} - w_{p_t} x_{p_{tt+1}} - w_{Z_t}(Z_{l_{t+1}} + Z_{h_{t+1t}})]$$

$$(3)$$

$$\text{s.t. } y_\tau = e^{(c_0 + \sum_1^{N-1} c_i * id_i)} x_{1_t}^{\alpha_1} x_{2_t}^{\alpha_2} q_{1_t}^{\beta_1} q_{2_t}^{\beta_2} q_{3_t}^{\beta_3} e^{-(\gamma_1 Z_{l_t} + \gamma_2 Z_{h_t} + \sum_{j=1}^{4} \xi_j PI_{j_t})^2} \qquad (4)$$

and (2)

for , $\tau = t, t+1$ and β reflects the discount rate.

The solution to this optimization problem leads to the optimal x_1 and x_2:

$$x_{1_t} = \left(\frac{w_1}{pe^{(c_0+\sum_{1}^{N-1} c_i * id_i)} \alpha_1 x_{2_t}^{\alpha_2} q_{1_t}^{\beta_1} q_{2_t}^{\beta_2} q_{3_t}^{\beta_3} e^{-(\gamma_1 Z_{l_t} + \gamma_2 Z_{h_t} + \sum_{j=1}^{4} \xi_j PI_{j_t})^2}}\right)^{\frac{1}{\alpha_1 - 1}} \qquad (5.1)$$

$$x_{2_t} = \left(\frac{w_2}{pe^{(c_0+\sum_{1}^{N-1} c_i * id_i)} x_{1_t}^{\alpha_1} \alpha_2 q_{1_t}^{\beta_1} q_{2_t}^{\beta_2} q_{3_t}^{\beta_3} e^{-(\gamma_1 Z_{l_t} + \gamma_2 Z_{h_t} + \sum_{j=1}^{4} \xi_j PI_{j_t})^2}}\right)^{\frac{1}{\alpha_2 - 1}} \qquad (5.2)$$

$$\begin{aligned}
&-w_{Zt} - 2\gamma_2 p_t x_{1_t}^{\gamma_1} x_{2_t}^{\gamma_2} q_{1_t}^{\beta_1} q_{2_t}^{\beta_2} q_{3_t}^{\beta_3} [\gamma_1 Z_{l_t} + \gamma_2 Z_{h_t} + \sum_{j=1}^{4} \xi_j PI_{j_t}] \\
&e^{-(\gamma_1 R_t + \gamma_2 Z_{l_t} + \gamma_3 Z_{h_t} + \sum_{j=1}^{5} \xi_j PI_{j_t})^2} - 2\beta\gamma_2 p_{t+1} x_{1_{t+1}}^{\gamma_1} x_{2_{t+1}}^{\gamma_2} q_{1_{t+1}}^{\beta_1} q_{2_{t+1}}^{\beta_2} q_{3_{t+1}}^{\beta_3} [\gamma_1 Z_{l_{t+1}} + \gamma_2 Z_{h_{t+1}} \\
&+\sum_{j=1}^{4} \xi_j PI_{j_{t+1}}] * e^{-(\gamma_1 Z_{l_{t+1}} + \gamma_2 Z_{h_{t+1}} + \sum_{j=1}^{4} \xi_j PI_{j_{t+1}})^2} = 0
\end{aligned} \qquad (6)$$

3. Application

3.1 Model specification

3.1.1 Production function

The empirical application of model (1) requires the specification of functional forms for the production function f(·) and the damage-abatement function m(·). The Cobb-Douglas specification is used here and has a long history in the literature for ease of estimation in production studies, in general, and for pesticide impact assessment, in particular (Saha et al., 1997; Carpentier and Weaver, 1997; Carrosco-Tauber and Moffit, 1992).

3.1.2 Damage-abatement function

Following Guan et al. (2005) we use the following damage-abatement specification:

$$m = \exp(-A) = \exp[-(\gamma_1 Z_{l_t} + \gamma_2 Z_{h_t} + \sum_{j=1}^{4} \xi_j PI_j)^2] \qquad (7)$$

This specification restricts the value of abatement within a sensible region and allows for both positive and negative marginal product of pesticides. It addresses the damage abatement from the use of pesticides, and the pesticide externalities, and allows for interactions among these inputs.

3.2 Empirical estimation

After defining the production and damage-abatement function, the overall model specification in model (1) is as follows:

$$\ln y=\left[c_0+\sum_{i=1}^{N-1}c_i+\sum_{p=1}^{2}\alpha_p\ln x_p+\sum_{k=1}^{3}\beta_k\ln q_k\right]-\left(\gamma_1 Z_{l_t}+\gamma_2 Z_{h_t}+\sum_{j}\xi_j PI_j\right)^2+e \qquad (8)$$

The parameters to be estimated are α, β, γ, c and ξ. Variable inputs are denoted as x_p, with p=1 for fertilizers and 2 for other inputs. The arguments q_k are fixed inputs, with k=1 for labour, 2 for capital and 3 for land. Z_l stands for the low toxicity pesticides while Z_h for the high toxicity products. EI are the impacts of pesticides on various biodiversity categories and farm operator, with j = w for water organisms, s for soil organisms, b for bio-controllers, and o for operator's health. Finally, c_i are the farm specific dummies and e is a disturbance term that includes factors that are not accounted for in the model such as stochastic events (e.g. weather) and measurement errors.

The non-pesticide variable input choices are:

$$\ln x_1=\frac{1}{\alpha_1-1}\left[\ln w_1-\ln p-c_0+\sum_{1}^{N-1}c_i*id_i-\ln\alpha_1-\alpha_2\ln x_2-\sum_{k=1}^{3}\beta_k\ln q_k+\left(\gamma_1 Z_{l_t}+\gamma_2 Z_{h_t}+\sum_{j=1}^{5}\xi_j PI_j\right)^2\right] \qquad (9)$$

$$\ln x_2=\frac{1}{\alpha_2-1}\left[\ln w_2-\ln p-c_0-\sum_{1}^{N-1}c_i*id_i-\alpha_2\ln x_1-\ln\alpha_2-\sum_{k=1}^{3}\beta_k\ln q_k+\left(\gamma_1 Z_{l_t}+\gamma_2 Z_{h_t}+\sum_{j=1}^{5}\xi_j PI_j\right)^2\right] \qquad (10)$$

The system to be estimated must reflect the pesticide choices with the intertemporal linkages, found in (6), the profit maximizing variable input choices, reflected in (9) and (10), and the technology, in (8). With no closed form solution available for optimal pesticide use, these decision are approximated by reduced form estimation. As a result, three equations are going to be estimated simultaneously using 3SLS, where y, x_1, x_2, Z_l and Z_2 are treated as endogenous variables. The instrumental variables that were used in the estimation are the qs, the output and input price indexes and the quadratic terms of these variables.

3.3 Data

The available data are composed by the Farm Accountancy Data Network (FADN) database and detailed data on pesticide use at the farm level from the Agricultural Economics Research Institute (LEI) for arable farms in The Netherlands. Panel data are available over the period 2002-2007 from 294 farms (848 observations). The panel is unbalanced and on average farms stay in the sample for four to five years.

Variable definitions and summary statistics are provided in Table 1. One output and 8 inputs are distinguished. The output consists of root crops (potatoes, sugar beets, carrots and onions), cereals (wheat, barley, triticale, corn, oats and rye) and other crops (green beans and peas and grasseed). It is measured as total revenue from all products, deflated to 2005 values using an index of prices from Eurostat. The inputs were classified as productive inputs and damage-abating inputs. The productive inputs are separated into fixed ones which include land, capital and labour, and variable ones which consist of fertilizers and other specific crop inputs. Land was measured in hectares, capital includes the replacement value of machinery, buildings and installations, deflated to 2005 using a Tornqvist index based on the respective price indices, and labour is measured in annual work units (AWU[1]). Fertilizers were measured as expenditures deflated to 2005 using the fertilizer price index. The "other inputs" variable includes expenditures on energy, seeds and other specific crop costs, deflated to 2005 using a Torngvist index for disaggregated "other inputs" components. The damage-abating inputs include pesticides. Pesticides were measured as expenditures deflated to 2005 using pesticide price index and divided into low and high toxicity products based on their environmental impact scores.

3.3.1 Data on Pesticide Impacts (PI)

The available data were obtained from the Dutch Centre for Agriculture and Environment (CLM). For each pesticide that Dutch arable farmers use, there is an environmental (health)

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[1] One AWU is equivalent to one person working full-time on the holding (EC, 2001).

indicator which shows the impact on aquatic organisms (surface water) (PI_w), terrestrial life (PI_s), beneficial organisms [biological controllers (PI_b)], and operator's health (PI_o).

The effects of pesticides on water organisms[2] and soil organisms are known as environmental impact points. The PI_w depends on pesticide toxicity and the amount of spray drift to watercourses. The amount that reaches a watercourse depends on the application technique. For arable farming the percentage spray drift is 1%.

The PI_s is computed based on the organic matter content, pesticide characteristics (degradation rate and mobility in soil), and pesticide toxicity. The organic matter content in conjunction with the pesticide characteristics determine the amount of pesticides that in course of time stays behind in the soil. There are five classes of organic matter content with the case study farms belonging to the 3-6% category.

The environmental impact points increase when pesticides have a greater impact on the environment. For soil organisms a score of 100 impact points is in line with the acceptable level (AL) set by the Dutch board for the authorization of pesticides (CTB). The AL for aquatic organisms is 10 impact points per application (since 1995). The AL is a concentration which implicates minor risk for the environment.

The risk for biological controllers (PI_b) (e.g. ladybugs, predatory mites, hymenopteran parasitoids) is indicated in the data with a symbol. This symbol shows the usability for integrated cropping systems and is a combination of all pesticide effects (direct effects, such as mortality or non-hatching of eggs and pupae, have been taken into account as well as indirect effects, such as reduced fertility, repellency, persistence etc.) for individual beneficial organisms. There are four symbols for bio-controllers and pollinators: symbol 'A' indicates that the pesticide is useful in the effort to save beneficial organisms; symbol 'B' slightly useful; symbol 'C' not useful; and symbol '?' not well known impact.

The PI_b variable is a continuous variable that is constructed as the sum of the cost of the known effects[3]. In this way PI_b depends both on low (A,B) and high (C) toxicity pesticides as we hypothesize that low toxicity products can also increase PI_b when they are overused.

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[2] This category includes mainly aquatic insects (CLM, 2010).

[3] The known effects represent categories A,B and C.

The risk of a pesticide for the health of the operator (PI_o) is also indicated with a symbol. The symbols are deducted from the symbols (skull and crossbones) that can be found on the labels of pesticide products. The data contain the following symbols at an increasing risk order: ‘NE’ no effect on human health; ‘I’ irritating; ‘S’ harmful; ‘G’ poisonous; ‘ZG’ very poisonous; and ‘B’ biting (the effect of a very toxic pesticide).

The division of pesticides into low and high toxicity products is based on their environmental impact scores. High toxicity product is characterized by a pesticide where at least one of its PIs exceeds the acceptable levels[4] set by CTB or belongs to the most harmful[5] category. On the other hand low toxicity product is a pesticide that all its PIs are below the acceptable levels or belong to the acute categories.

The PI_o variable is also a continuous variable representing the sum of the costs of pesticides which have one of the following signs[6]: I, S, G, ZG and B. The inclusion of NE category would have resulted in PI_o being equal to the sum of low and high toxicity pesticides and created a co-linearity problem in our estimation. Another reason for excluding NE from the construction of PI_o variable is that the low toxicity category can be better represented by I and S as these symbols account for some health effects, while NE indicates that the product is acute for the health of the operator. The hypothesis is that an increased use of “NE” pesticides cannot impact PI_o, considering that the majority of Dutch farmers spray pesticides from a closed environment (tractors) and wear the appropriate protective equipment (Bremmer, 2009). As the PI_o variable does not include any unknown effect (?; like the PI_b variable), the possibility of creating a dummy[7] variable has also been examined but it was rejected due to lack of variation, as the majority[8] of farmers’ applications belong to the low toxicity categories. Excluding the PI_o variable from our estimation was also rejected as this variable,

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[4] Acceptable levels exist only for PI_w and PI_s.

[5] For PI_b the most harmful category is considered the “C” while for PI_o the most harmful categories are the last three (G, ZG and B).

[6] These signs represent both low toxicity pesticides (I, S) and high toxicity pesticides (G, ZG and B) as we hypothesize that overuse or non-precise use of low toxicity products can also increase PI_o.

[7] D=0 if the majority of pesticides used belong to NE, I or S (low toxicity categories), and D=1 if they belong to G, ZG, or B (high toxicity categories).

[8] With the dummy method around 97% of the farms per year will belong to the category D=0.

in conjunction with PI_w, PI_s and PI_b variables, enables us to model pesticide externalities both[9] from a health and environmental perspective.

4. Results

4.1 Used pesticides and Environmental Impacts.

Data analysis has shown that Dutch cash crop farmers used 357 different pesticides in total. The average pesticide applications and products used per year were 27 and 21 respectively (Figure 1). The sudden increase of pesticide applications in 2003 can be attributed to a 10.4 % increase of fungicides, in comparison to the previous year, that was caused by relatively high temperatures and humidity. The majority of pesticide applications are in potatoes followed by sugar beet, wheat, onions and barley (Figure 2). Concerning the division of pesticides into low and highly toxic products, 176 pesticides were characterized as highly toxic (49%)[10] (Table 2). From the highly toxic ones, the majority are herbicides (48%) and fungicides (24%). It is worth noting that the majority of the used herbicides and insecticides belong to the highly toxic category while in all other types of pesticides the low toxicity products have the highest share.

Moving to the PI of the used pesticides, there are a number of products whose impact on bio-controllers (PI_b) is not well know (category "?"). This category constitutes around 25% of the used plant protection products and indicates that the specific pesticide can be either harmful or harmless for beneficial organisms. The effects of pesticides on beneficial organisms are mainly monitored on indoor crops where Integrated Pest Management (IPM) can be easily applied by the use of natural enemies to reduce harmful insects’ populations. It is important to notice here that our data concern arable crops where different pesticide products are applied in comparison to indoor crops. IPM is hardly applied in arable farming, hence the 25% of chemicals used there without information on beneficial organisms’ impacts (Moerman, 2009).

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[9] Current EU pesticide policy (COM(2006), 372) highlights the importance of reducing risks to both human health and the environment. Therefore, EU policy makers can be benefited from useful implications extracted from pesticide modeling that includes both health and environmental effects.

[10] Around 90% of the highly toxic pesticides had extreme scores (or belonged to the harmful category) for more than one PI.

Furthermore, research on pesticide impacts on beneficial organisms has mostly focused on insecticides[11] while Dutch arable farmers use mostly herbicides and fungicides.

Concerning pesticide effects on human health, analysis has shown that Dutch arable farmers use a great variety of pesticides with the most commonly used ones being the 'NE' category, followed by the 'I' and 'S' categories. Table 3 shows the crops where the most dangerous pesticides applied for operator's health and bio-controllers. Concerning the health of the operator, the poisonous (G) and very poisonous (ZG) applications are mainly in potatoes, while the 'biting' (B) applications are mainly in wheat followed by barley and potatoes. For the effects of pesticides on bio-controllers the most commonly used pesticides are the "A" category followed by "C", "B" and "?" categories. Concerning the most harmful category (C), its applications are mainly in potatoes, wheat and sugar beet (Table 3). We conclude that potatoes is the crop that has the most dangerous applications followed by wheat and sugar beets, which account for 77% of pesticide applications per year (Figure 2). Many pesticides that are very risky for the health of the operator do not have the same negative effect on beneficial organisms. This can be explained by the fact that chemicals may have different effects in different organisms (e.g. humans vs. insects).

4.2 Production technology of Dutch cash crop farms.

The estimation results of the 3SLS model are presented in Table 4. Most of the variable and fixed inputs have a significant impact on production at the 5 per cent significance level. The significant parameter γ_2 confirms that highly toxic pesticides play an important damage-abating role. In contrast the highly insignificant parameter γ_1 shows that low toxicity pesticides do not affect output, implying that the more toxic products are the most effective ones in preventing pest damage. Concerning the PI variables, the only significant parameters are ξ_1 and ξ_3. Concerning water organisms, this is in line with our expectations as the Dutch farming environment constitutes of several rivers, canals and water ditches separating the fields. The significant impact of bio-controllers shows that this biodiversity category can impact crop output through the control of pest populations. On the other hand, soil organisms do not affect significantly crop output. Parameter ξ_4 is also insignificant, showing that

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[11] The idea behind this is that as this kind of chemicals target harmful for the crop insects, it is probable that they can impact negatively similar organisms like natural enemies and bumblebees.

pesticides do not affect farmers' health and as a result the efficiency of labour. This result is in line with our expectations as most pesticides are sprayed from a closed environment (tractors) and the use of protective equipment among Dutch cash crop farmers is very common. A Wald test of the joint significance of the damage-abatement parameters, γ_1 - ξ_4, rejects this null hypothesis (p=0.001) suggesting that pesticide use and their impacts have a significant contribution in damage abatement and there is indeed presence of output reductions from stochastic events (pest infestation, diseases, etc). Finally, about 91% of the farm specific dummies are significant at the 5 per cent significance level. Farm specific dummies include elements that are not modeled directly in this study. These elements can include education, farming experience, farm soil type, other damage control measures e.g. changes in tillage or use of pest resistant varieties etc.

4.3 Input elasticities and analysis of marginal products

Table 5 reports elasticities which provide further information on the output response to each input and on the economies of scale in the Dutch cash crop sector. The input elasticities sum to 0.87 indicating decreasing returns to scale which is consistent with the results reported by Oude Lansink (1997). Zhengfei et al. (2005), in their study for conventional and organic arable farms in the Netherlands, report an elasticity of 0.98 adding that these farms may operate beyond the optimal scale. The elasticity of other inputs is higher than the one reported by Zhengfei et al. (2005) implying the increasing significance of other inputs in agricultural productivity[12]. Land elasticity is higher in comparison to the rest of the productive inputs, implying that land is a scarce input that constrains the cash crop sector. Zhengfei et al. (2005) come to the same conclusion but they report a land elasticity of 0.59. The lower estimate of our study is due to an increase[13] of the mean acreage in comparison to the period studied by Zhengfei et al. (2005).

Highly toxic pesticides have higher impact on production than lower toxicity products. This is in line with our expectation that highly toxic products might be more effective in reducing pest damage. Concerning the elasticities of PI, we can identify two categories; a) a category that negatively impacts output and includes water organisms, bio-controllers and farm

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[12] e.g. improved seed varieties may increase agricultural productivity in comparison to a decade before.

[13] For the period 1990-1999 the mean acreage of arable farms in The Netherlands was 68.26 (Zhengfei et al., 2006), while for 2002-2007 it has been increased to 82.8.

operator's health and b) a category that has a beneficial effect on output and includes only soil organisms. The first category indicates that water organisms and bio-controllers can have a beneficial impact on output by reducing crop damage through the control of pest populations. Therefore, if farmers increase the pressure on the pre-mentioned biodiversity categories (by using pesticides that increase PI_w and PI_b) they will have some output loses. The same holds for the health of the operator as an increased PI_o can reduce the efficiency of labour. On the other hand, it seems that increased pressure on soil organisms impacts positively farm yields as these organisms can also cause some crop damage.

The value of the marginal product which is the shadow price of the different inputs can be used to assess whether an input is overused or not. Therefore, the value of the marginal product (VMP) can be used in the design of subsidies or taxes for individual inputs. Table 5 presents the VMP estimates which are computed at the sample means, at average output price index 1.12. The average VMP of fertilizers is 1.11, while a statistical test has shown that it is not significantly different from fertilizer price. This suggests that fertilizers are not overused which is in contrast to the conclusion of Zhengfei et al. (2005). This may be the result of the so-called MINAS[14] programme and a system of application limits for manure and fertilizers (in compliance with the Nitrates Directive) which replaced it in 2005.

Concerning pesticides, the VMP of highly toxic and low toxicity pesticides is 2.65 and 0.32 respectively. A comparison of these shadow values with pesticide price (Table 8) shows that highly toxic pesticides were underused while the lower toxicity products were overused. Oude Lansink and Carpentier (2001) report a shadow price of 3.2[15] in their study of Dutch arable farms over the period 1989-1992. Although this value is quite close to our estimate, the difference can be attributed to the failure of the latter study to take into account the heterogeneity across farms. Even higher estimates are reported by Oude Lansink and Silva (2004) in a non-parametric study of pesticides use in The Netherlands over the same period, but the authors add that this may be a result of outliers. Both Oude Lansink and Carpentier (2001) and Oude Lansink and Silva (2004) conclude that almost all pesticides are, on average, underutilized, a result that is in line with our finding. In our study the average VMP of low

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[14] MINAS is a nitrogen and phosphorus accounting system which was implemented in the Netherlands at farm level in 1998. It marked a shift in the Dutch manure policy by introducing economic incentives for lowering nutrient losses (OECD, 2005).

[15] Weighted over 3 types of pesticides (herbicides, fungicides and other pesticides) and 4 different model specifications.

and high toxicity pesticides is 1.48, which is higher than the average pesticide price. This means that farmers could increase their profitability by increasing the use of pesticides. Carrasco-Tauber and Moffit (1992) and Chambers and Lichtenberg (1994), found also that pesticides are underutilized in U.S. agriculture.

On the other hand, Zhengfei et al. (2005) report a VMP of 1.25 and conclude that pesticides were optimally used at the farm level, but they add that this might lead to an overuse if pesticide externalities are taken into account. This hypothesis is not verified by the current study where the inclusion of pesticide externalities showed that pesticides are on average underused. Overutilization of pesticides is also reported by Babcock et al.(1992) in their study on apple farms in North Carolina. The considerable amount of preventive pesticide applications that apple production requires, might be one of the reasons for the reported overutilization.

5. Conclusions

This study presents a dynamic model of optimal pesticide use on specialized cash crop farms in The Netherlands. The inclusion of two pesticide categories that differ in terms of toxicity, and pesticide externalities in the damage abatement specification is an improvement compared to earlier damage abatement specifications in terms of richness of the results. Shadow prices of pesticides and other inputs are estimated and compared with market prices in order to see whether are over- or under-utilized.

The empirical results indicate that the external impacts of pesticides on aquatic organisms and bio-controllers are affecting farmer's production environment. This result suggests that future pesticide policies should try to conserve these biodiversity categories as they seem to protect farm yields from loses through the control of pest populations. The results also show that highly toxic pesticides are underused while the lower toxic products are overused. The pre-mentioned biodiversity categories can be negatively impacted from either highly toxic applications or overuse of low toxicity products. Therefore, economic incentives like taxies and/or subsidies can be used in order not only to switch from the high to the low toxicity category, but also to reach an optimal pesticide use for the latter category.

Future research on the economics of pesticides can apply similar modeling frameworks to different EU countries where differences in climatic conditions and biodiversity statuses require the use of different pesticides. This can help EU policy makers in designing a pan-European pesticide policy that will be based on country specific economic incentives.

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Tables and Figures

Table 1. Summary statistics (in EUR 1,000, deflated to 2005 prices)

Variable	Symbol	Number of observations	Mean	S.D.
Output	y	848	212.33	190.42
Output price	p	848	1.12	0.08
Fertilizers	x_1	848	10.82	8.69
Other inputs	x_2	848	61.30	58.16
Labour	q_1	848	1.64	0.94
Capital	q_2	848	335.04	364.97
Land	q_3	848	82.80	56.15
Low toxicity pesticides	Z_l	848	11.29	10.65
High toxicity pesticides	Z_h	848	12.18	10.05
Impact* on water organisms	PI_w	848	4.72	7.03
Impact on soil organisms	PI_s	848	6.48	11.33
Impact on bio-controllers	PI_b	848	10.34	9.40
Impact on farm operator	PI_o	848	10.63	9.03

* of pesticides

Table 2. Descriptive analysis of used pesticides.

Category	**Total**	**Percent**	**Low toxicity products**	**High toxicity products**
Herbicides	154	43.14	69	85
Fungicides	116	32.49	73	43
Insecticides/Acaricides	84	9.52	5	29
Growth regulators	25	7.00	21	4
Hulpstof	8	2.24	7	1
Ground Disinfectant	6	1.68	1	5
Niet in te delen miedel	6	1.68	2	4
Sulfur (Zwavel)	4	1.12	2	2
Rodenticides	2	0.56	1	1
Detergents	2	0.56	0	2
Total	357	100	181	176

Table 3. Applications/crop (%) of the most harmful pesticides for operator's health and beneficial organisms.

	Operator's health			**Bio-controllers**
Pesticide Category	G	ZG	B	C
Year				
2002	80% P	95% P	46% W	32% P
2003	83% P	96% P	50% W	43% P
2004	69% P	95% P	55% W	32% W
2005	70% P	98% P	51% W	31% W
2006	74% P	100% P	44% W	28% W
2007	73% P	95% P	50% W	28% S

Note: P stands for potatoes, W for wheat, and S for sugar-beet.

Table 4. Estimated coefficients of 3SLS system of equations

Parameter	Estimate	p-value
α_1	0.04^{*}	0.000
α_2	0.23^{*}	0.000
β_1	0.14	0.029
β_2	0.09^{***}	0.083
β_3	0.26^{*}	0.005
γ_1	-0.004	0.727
γ_2	-0.03^{**}	0.046
ξ_1	0.01^{***}	0.065
ξ_2	-0.006	0.162
ξ_3	0.03^{***}	0.079
ξ_4	0.02	0.192

α_1 denotes fertilizers and α_2 other inputs; β_1 to β_3 denote labour, capital, and land, respectively; γ_1 denotes high toxicity pesticides and γ_2 low toxicity pesticides; ξ_1- ξ_4 denote pesticide impact on water organisms, soil organisms, bio-controllers, and farm operator respectively; (*), (**), and (***), indicate that the estimate is significantly different from zero at the 1, 5 and 10 per cent significance level, respectively.

Table 5. Production elasticities and values of marginal products (VMP in EUR 1,000)

	Elasticities	p-value	VMP	Input price (IP)
Fertilizer	0.04	0.000	1.11	0.98
Other inputs	0.23	0.000	1.12	0.99
Labour	0.14	0.029	19.58	0.42
Capital	0.09	0.083	0.06	0.09[a]
Land	0.26	0.005	1.08	0.33[b]
LT* pesticides	0.01	0.727	0.32	1.02
HT pesticides	0.08	0.046	2.65	1.02
PI_w	-0.01		-6.93	-
PIs	0.009		44.58	-
PIb	-0.07		-84.70	-
PIo	-0.05		-48.76	-

[a] Capital price is calculated as 10 per cent of average capital price index

[b] Land price is computed as the average farmland rent per ha for 2002-2007 (CBS, 2010)

Figure 1. Average pesticide applications and products used by the Dutch cash crop farms (2002-2007).

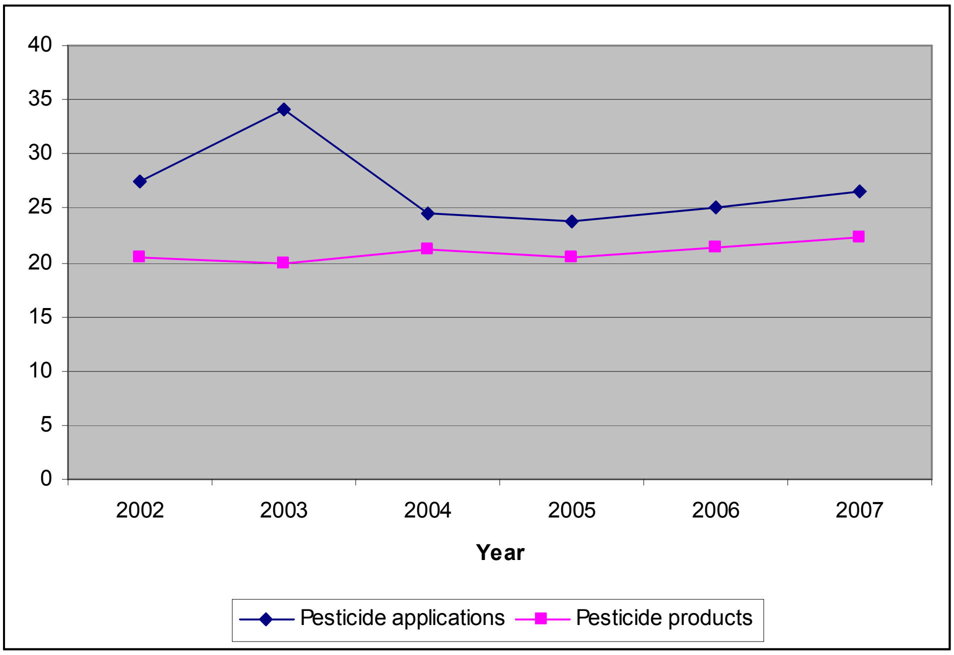

Figure 2. Average pesticide applications (%) per year for different cash crops in The Netherlands (2002-2007).