Does pesticide use have short-term spillover effects? The case of Swiss winter wheat producers

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Abstract

In this study, we empirically estimate the extent of pesticide spillovers on agricultural productivity on a farm-level. As a basis for our empirical analysis, we develop a dynamic damage control specification model of pesticides, where spillovers are associated with the previous period's consumption. We then analytically derive potential spillovers of pesticides on agricultural productivity through effects on the production area, nitrogen fertilizer, and work-machinery productivities and estimate the extent of these effects empirically. To this end, we use a rich farm panel data set on Swiss wheat producers over the period 2009-2015. To account for both pesticide volume and toxicity, a load index is used. Our preliminary results indicate positive short-term spillover effects of the fate toxicity index while the ecotoxicity has a negative spillovers.

JEL CODES: Q12, Q15, Q50

1. Introduction

Apart from their primary role of protecting crops from pests and diseases (Oerke, 2006), the extent to which pesticides negatively affect the environment and human health (Blair, et al., 2015, Jones, 2020, Spycher, et al., 2018, Stehle and Schulz, 2015) has been very challenging for policy regulation towards sustainable agriculture. Not only pesticide use has external effects on others, but it may also affect long-term on-farm productivity. For instance, several studies have discussed the negative health impacts of pesticide exposure (Aerts, et al., 2018, Lai, 2017, Larsen, et al., 2017, Mascarelli, 2013). Other studies have focused on the related environmental impacts, namely on the destruction of biodiversity, soil and water organisms (Geiger, et al., 2010, Mahmood, et al., 2016, Stehle and Schulz, 2015, van der Werf, 1996). Finally, Skevas, et al. (2013) have shown that pesticides have an indirect negative impact on agricultural output in Dutch cash crop producers. Many attempts have been undertaken to approximate these spillovers' external costs (Fantke, et al., 2012). In the US, the estimated health costs of pesticides are about $1.5 billion in 2005, while the environmental costs reached $8 billion in 1992 (Bourguet and Guillemaud, 2016, Pimentel, et al., 1992).[1]

In this article, we focus on pesticide spillover on-farm and address how the use of toxic pesticides affects farms' production abilities over time. To this aim, we use a rich multiple years, multiple farm data set from Swiss wheat production. More explicitly, we consider the harmful effects of pesticides on farmworkers' health (Suratman, et al., 2015, Zhang, et al., 2016) but also on natural ecosystems with the destruction of non-targeted species (pollinators, soil organisms…) that can disrupt ecosystem services relevant to agriculture. Those services include, for instance, nutrient cycle regulation, pollination, natural predators, seed dispersal (Power, 2010, Tilman, et al., 2014). A consequence of this disruption is soil microflora changes, which negatively affect soil fertility and, hence, crop productivity (Prashar and Shah, 2016). Moreover, excessive use of pesticides also translates into the appearance of resistance and the emergence of secondary pests, which decreases the efficacy of the control (Pimentel and Burgess, 2014).[2] Failure to consider all those spillovers may result in an overestimation of the direct effects of pesticides effect in controlling crop enemies.

The economic literature on pesticides has focused mainly on the direct effect of pesticides regarding the prevention of crop damages from harmful pests and the assessment of their marginal productivity (Babcock, et al., 1992, Chambers and Tzouvelekas, 2013, Fox and Weersink, 1995, Karagiannis and Tzouvelekas, 2012, Lichtenberg and Zilberman, 1986, Saha, et al., 1997). Only a few papers have

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[1] See also Tegtmeier and Duffy (2004) for the estimation of overall agricultural external costs still in the case of U.S.

[2] Example of resistance has been documented in the case of herbicide (Busi, et al., 2013)).

considered the potential spillovers associated with pesticides. For instance, in a series of articles, Antle and Pingali (1994) and Antle, et al. (1998) have shown the adverse effects of pesticides on famers' health and, consequently, agricultural productivity. Their applications were in developing countries where lack of protective gear and proper training on pesticides manipulation mainly explain the health issues and the deterioration of labor input productivity.[3] Skevas, et al. (2012) and Skevas, et al. (2013) have considered pesticides environmental spillovers using a damage control specification. In the former, the spillovers appear only in the damage control specification, thereby affecting pesticide efficacy, and in the latter, pesticide spillovers affect pesticides and fertilizers efficacy.

Our article adds to the empirical literature on pesticide spillover on agricultural output, and our contribution is threefold. First, we provide a single framework where pesticide spillover on labor and the environment are examined simultaneously. Second, the pesticides' spillovers are analyzed through the lens of pesticides toxicity. To this aim, we have used a set of new indicators known as the load index, which account for the volume of pesticides and their potential effects. Three load indices are used to describe the spillovers: the human health load (HLI) and two environmental indices, namely the ecotoxicology (TLI) and environmental fate (FLI), with the latter capturing the persistence of substances in the environment. Finally, we employ a general specification of the production technology under the framework proposed by Zhengfei, et al. (2006). Following agronomic principles, a distinction is made between growth and facilitating inputs. Altogether, our article provides another view on pesticide's direct and indirect impacts by enriching the framework using new indicators and a clear separation between the different types of input.

The rest of the article is structured as followed. Section 2 introduces a background on pesticides load indices. Section 3 presents the theoretical framework. Section 4 describes the data while section 5 discusses the results. Finally, section 6 concludes.

2. Background on pesticides indicators

As underlined in Möhring, et al. (2019) quantity based indicators like QA (quantity of active ingredients[4]) or TFI (treatment frequency index[5]) largely used as risk indicators for implementing

[3] See also Maumbe and Swinton (2003), Ngowi, et al. (2007).

[4] QA is simply of an indication of pesticides volume used.

[5] TFI is a simple indicator to assess pesticides use intensity. According to the Danish Environmental Protection Agency, “treatment Frequency Index is an expression of the average number of times the arable area can be treated,

pesticides regulation (Barzman and Dachbrodt-Saaydeh, 2011) failed to account for the inherent properties of pesticides (Möhring, et al., 2020). Indeed, pesticides differ in terms of active ingredients[6] that may have different adverse effects. To account for the potential environmental and health impact of pesticides, the Danish government has pioneered a new set of indicators. Those new indicators, known as the load index (LI) have been introduced in the regulation since 2009 (Pedersen and Nielsen, 2017). The benefits of these new indicators are to account for pesticide effects on all types of lands (including water). For instance, TFI only focuses on the cultivated area and does not account for product toxicity.[7] The LI consists of three sets of sub-indicators: human health (HLI), ecotoxicology (TLI), and environmental fate (FLI) (Kudsk, et al., 2018). HLI primarily focuses on the operator's degree of exposure to pesticides using scores that weigh the potential health impact (from skin irritation – 10pts- to genetic risks or cancer – 100pts). On the other hand, TLI measures aquatic and terrestrial ecosystems' exposition in fields and in the adjacent nature. Finally, the FLI is more a long-run indicator as it accounts for the degradation time in soils of active ingredients and the accumulation in food chains, and contamination of water bodies through run-off and leaching.

3. Theoretical framework

Let's consider that the production technology is described as follows:

$$\Psi_{\mathrm{t}} = \left\{ \begin{matrix} (y_t, x_t, LI_t, TLI_{t-1}, FLI_{t-1}, HLI_{t-1}) \; |x_t \text{ can produce } y_t \text{ given} \\ LI_t, TLI_{t-1}, FLI_{t-1}, HLI_{t-1} \end{matrix} \right\} \tag{1}$$

Where y_t is the wheat production, x_t the vector of production inputs (land, fertilizers, labor, and machinery costs), and LI is the total load index which, as earlier discussed, better-captured pesticides use in terms of volume but also toxicity. $TLI_{t-1}, FLI_{t-1}, HLI_{t-1}$ are respectively the ecotoxicity, fate, and human health indices from the previous period.

The functional form specification of the production technology in (1) has been subject to vivid discussion between the classical production function where all inputs are symmetrically treated and the

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based on the total amount of plant protection products sold in the year and assuming use of standard doses" (https://eng.mst.dk/chemicals/pesticides/pesticides-statistics/agriculture-etc/ accessed October 2020).

[6] In the European Union (EU), about 500 active ingredients are authorized (https://ec.europa.eu/food/sites/food/files/plant/docs/pesticides_approval-factsheet.pdf).

[7] Because TFI does not account for the adverse effects of different pesticides, it cannot be used to discriminate them.

damage control specification where damage control agents like pesticides are asymmetrically treated (Fernandez-Cornejo, et al., 1998). Under the symmetric specification, the production function can be written as

$$y_{it} = F(x_{it}, LI_t, TLI_{t-1}, FLI_{t-1}, HLI_{t-1}) \quad (2)$$

Where $F()$ can, for instance, be a Cobb-Douglas or a Translog functional form. On the other hand, the asymmetric treatment of pesticides has been subject to several specifications (Frisvold, 2019, Sexton, et al., 2007). We have considered the general specification that allows pesticides to negatively affect agricultural output and presented in Zhengfei, et al. (2005). Moreover, as mentioned in the introduction, we have adopted the framework discussed in Zhengfei, et al. (2006) where a distinction is made between growth inputs and facilitating inputs. Indeed, following agronomic principles, some inputs like capital and labor, which as pesticides, do not have a direct impact on production.[8] Nevertheless, to keep the discussion more empirical (and testable) we consider a very general production technology which can be described as follows:

$$y_{it} = F(x_{1,it}, x_{2,it}, x_{3,it}, TLI_{t-1}, FLI_{t-1}, HLI_{t-1})G(x_{3,it}, LI_{it}, LI_{it-1}) \quad (3)$$

Where $x_{1,it}, x_{2,it}$ are two growth inputs, namely land, and fertilizers, $x_{3,it}$ is the facilitating input labor and machinery work costs. $G()$ is the damage control specification which is defined following Zhengfei, et al. (2005):

$$G(x_{3,it}, z_{it}, LI_{it}) = \exp\left[-(\beta_0 + \beta_1 x_{3,it} + \beta_2 LI_{it} + \beta_3 LI_{it-1})^2\right] \quad (4)$$

4. Data

For the analysis, we consider a sample of 146 Swiss wheat producers surveyed between 2009 and 2015. The descriptive statistics of the data can be found in **Table 1**.

[8] Following van Ittersum and Rabbinge (1997), the conceptual framework presented by Zhengfei, et al. (2006) distinguish three levels of production depending on the type of production factors. Growth-defining factors determine the potential output, which is the maximum output given plant characteristics and weather conditions (not under the control of the farmers). Growth-limiting factors such as water and nutrients result in the attainable output that is lower than the potential output. Finally, growth-reducing factors encompass all crop damage agents like weed, pests, diseases and pollutants, which further reduce the level of the production to the actual output.

Table 1: Descriptive statistics of the data during 2009-2015

Variables	Mean	Standard deviation	Median	Minimum	Maximum
Wheat production (tons): y	37.2	30.2	27.0	1.7	222.6
Agricultural area (hectares): x_1	5.1	3.9	3.8	0.3	21.8
Nitrogen (kilogram): x_2	753.4	642.7	519.1	31.7	4385.7
Machinery and labor costs (constant Swiss francs): x_3	7766.4	6082.3	5598.1	599.8	33536.5
LI	8.3	12.8	2.8	0.0	73.0
TLI	2.4	5.4	0.5	0.0	39.1
FLI	2.4	3.6	0.8	0.0	22.2
HLI	3.4	5.6	0.9	0.0	32.3
Number of observations	**670**				

5. Results and discussion

For the estimation, we have considered a Cobb-Douglas production function. To account for potential weather effects, we have also included year dummies. The main estimation results are summarized in **Table 2**. The results show that in both symmetric and asymmetric treatment of pesticides, spillover effects exist. TLI has a negative spillover effect through the agricultural area and a positive effect through labor and machinery costs. On the contrary FLI has a positive impact through the agricultural area and a negative through nitrogen consumption. HLI has no impact in both models. Under the symmetric treatment of pesticides, pesticides' current period consumption does not affect wheat production. Moreover, the overall effect of TLI is negative while it is positive for FLI.

In the case of the damage control specification, the current period of pesticides positively affects the abatement while the previous pesticide use and labor and machinery cost negatively affect the abatement. (The latter effect is very small). Overall and as in the case of the symmetric treatment, the effect of TLI is negative while it is positive for FLI.

Table 2: Estimated coefficients of the production function in the presence of pesticides spillover

Variables	Symmetric treatment of pesticides	Asymmetric treatment of pesticides
Production function		
Intercept	2.281***	2.606***
log(x_{1t}: surface)	0.988***	0.974***
log(x_{2t}: nitrogen)	0.101***	0.093***
log(x_{3t}: labor and machinery cost)	-0.102**	-0.124**
LI_t (total load index in t)	-0.001	-
TLI_{t-1} (ecotoxicity load index)	-0.238***	-0.236***
FLI_{t-1} (fate load index)	0.321***	0.296**
HLI_{t-1} (human health load index)	-0.086	-0.077
log(x_{1t})× TLI_{t-1}	-0.031***	-0.03***
log(x_{1t})× FLI_{t-1}	0.04**	0.04**
log(x_{1t})× HLI_{t-1}	-0.019	-0.016
log(x_{2t})× TLI_{t-1}	0.009	0.009
log(x_{2t})× FLI_{t-1}	-0.028**	-0.029**
log(x_{2t})× HLI_{t-1}	0.013	0.013
log(x_{3t})× TLI_{t-1}	0.026**	0.025**
log(x_{3t})× FLI_{t-1}	-0.022	-0.018
log(x_{3t})× HLI_{t-1}	0.004	0.002
Farm in mountain area dummy	-0.065***	-0.066***
D_{2010} (dummy for year 2010)	-0.014	-0.018
D_{2011} (dummy for year 2011)	0.003	-0.003
D_{2012} (dummy for year 2012)	-0.109***	-0.119***
D_{2013} (dummy for year 2013)	-0.106***	-0.109***
D_{2014} (dummy for year 2014)	-0.047	-0.057
D_{2015} (dummy for year 2015)	-0.038	-0.047
Damage control specification		
Intercept	-	-0.352**
x_{3t}: labor and machinery cost	-	0.00002***
LI_t (total load index in t)	-	-0.009***

LI_{t-1} (total load index in $t-1$)	-	0.006**

Note: *, **, *** indicate significance at the 10, 5, 1% level, respectively.

6. Conclusion

Our analysis indicates that spillover effects are present when pesticides are used. To assess the spillover effects, we consider new indicators of pesticide consumption that account for the volume of pesticides and their toxicity. Our results reveal that ecotoxicity (TLI) has an overall negative effect while fate toxicity (FLI) positively affects. More robustness in terms of the damage control specification is still required.

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