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Author(s):
Möhring, Niklas; Dalhaus, Tobias; Enjolras, Geoffroy; Finger, Robert

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Crop insurance and pesticide use in European agriculture

Niklas Möhring[a], Tobias Dalhaus[b], Geoffroy Enjolras[c], Robert Finger[a,*]

[a] Agricultural Economics and Policy Group, ETH Zurich, Switzerland
[b] Wageningen University and Research, Business Economics Group, the Netherlands
[c] Université Grenoble Alpes, UMR 5820 CERAG, IAE, France

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ABSTRACT

The provision of better risk management tools for farmers and the reduction of adverse effects from pesticide use are both important goals of agricultural policy – but are potentially interrelated and might contradict each other. In this article, we analyze the relation of crop insurance and pesticide use in European agriculture using the examples of France and Switzerland. In our conceptual and empirical framework, we account for the complex structure of insurance uptake, land use and pesticide use decisions of farmers, potentially leading to insurance - pesticide use interactions both at the intensive and extensive margin. Our empirical results indicate a positive and economically significant relation between crop insurance and pesticide use in European agriculture. The findings suggest that without crop insurance, pesticide expenditures would be 6 to 11% lower. However, the importance of extensive and intensive margin relations differs between France and Switzerland and is related to country specific characteristics. We conclude that new risk management instruments should account for potential effects on input use.

1. Introduction

The current focus of agricultural policy comprises both the reduction of adverse effects from pesticide use on human health and the environment (Skevas et al., 2013; Lefebvre et al., 2015; Möhring et al., 2020), as well as the provision of better risk management instruments for farmers, such as insurances (Meuwissen et al., 2013; El Benni et al., 2016; Bardají et al., 2016). Effective and efficient policies should account for potential interrelations between the provision of such risk management tools and farmers input use decisions. Given the large-scale implementation of insurance schemes, Goodwin and Smith (2013) and Urruty et al. (2016) have highlighted the importance of the relation between crop insurance and farmers' input use for both American and European agriculture and underlined the need for more research on this topic.

In this paper, we conduct a unique analysis on the relation of crop insurance and pesticide use in European agriculture. We perform separate analyses for France and Switzerland, allowing us to highlight differences in crop insurance – pesticide use mechanisms regarding different insurance schemes, agricultural systems and agricultural policies.

In earlier studies, pesticides have been seen as risk decreasing inputs (Feder, 1979) and insurance solutions have thus often been claimed to be potential substitutes for pesticide use. However, the empirical evidence on the interrelation between insurance and pesticide use is ambiguous, and several studies also find that insurance leads to increases in pesticide use (e.g. Horowitz and Lichtenberg, 1993; Goodwin et al., 2004; Chakir and Hardelin, 2014). Most studies on the relation of crop insurance and pesticide use are conducted in the context of US agriculture (e.g. Horowitz and Lichtenberg, 1993; Smith and Goodwin, 1996; Wu, 1999; Goodwin et al., 2004; Shi et al., 2019). Studies with a focus on European agriculture are scarce, although dominant insurance types, subsidization and market penetration differ fundamentally from US agriculture (e.g. Santeramo and Ford Ramsey, 2017). Moreover, existing studies in the European context only focus on relations at the intensive margin, i.e. pesticide use per hectare (Chakir and Hardelin, 2014; Aubert and Enjolras, 2014). Yet, the consideration of changes at the extensive margin, i.e. in land use associated with changes in pesticide use levels, additionally to the intensive margin is essential for sound policy recommendations – as they might have confounding impacts (Goodwin et al., 2004).

We contribute to the literature with by analyzing the relation of crop insurance and pesticide use in European agriculture. More specifically, we consider the agricultural policy context and the dominant agricultural insurance schemes present in Europe, using the examples of France and Switzerland. We quantify the association between insurance

* Corresponding author at: Sonneggstrasse 33, 8092 Zurich, Switzerland.
E-mail address: rofinger@ethz.ch (R. Finger).

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and pesticide use at the intensive and extensive margin, accounting for simultaneity and interdependencies of insurance-, land- and pesticide use decisions. In the empirical analysis we favor a careful interpretation of the results as correlations rather than causal effects.

We find a statistically and economically significant association between crop insurance and pesticide use, both in Switzerland and France. In both countries crop insurance is related to choosing more intensive crops with a higher pesticide use. For France we further find that crop insurance is also related to a higher intensity of pesticide use per hectare. Our results indicate that risk management tools are complements for pesticide use, i.e. are associated to a more pesticide-intensive land use and an intensification of pesticide use per hectare. Findings suggest that without insurances, pesticide expenditures would be 6 to 11% lower.

The remainder of this paper is organized as follows. We first provide some background on important literature and then introduce our case studies. Following, we present the empirical framework and the used datasets. Finally, we present results of the estimations and robustness checks, discuss results and conclude.

2. Background

The provision of crop insurance and the farmers' choice of pesticide use levels are potentially interlinked. The literature distinguishes two main mechanisms through which the provision of crop insurance may be linked to pesticide use decisions. First, insurance may affect pesticide use intensity, reflecting moral hazard, i.e. that insurance protection reduces incentives to use pesticides (e.g. Mishra et al., 2005) or re-optimization of input use in the presence of insurance. Second, insurance may affect farmers land use decisions. Land use decisions are closely linked to pesticide use levels due to the great heterogeneity of pesticide use levels across crops. We will further refer to the first as "intensive margin" and to the latter as "extensive margin" relations, in line with previous literature (Wu, 1999; Graveline and Mérel, 2014). Following, we summarize the literature on the relation between crop insurance and pesticide use at the extensive and intensive margin and introduce our case studies France and Switzerland.

Insurance is potentially related to the intensity of pesticide use in the cultivated crops through moral hazard effects. The direction of this relation depends on the risk effects of pesticides, i.e. insurances may be substitutes (if pesticides are risk decreasing) or complements to pesticide use (if pesticides are risk increasing), respectively. Literature on the risk effects of pesticides shows that pesticides can either be risk decreasing or risk increasing, depending on the crop, cropping system and type of pesticide considered (Möhring et al., 2020b). Mishra et al. (2005) therefore point out that the direction of intensive margin relations due to moral hazard is a priori indeterminate, and thus remains an empirical issue. Additionally, the use of insurances may reduce background risks that can affect optimal input use for risk averse decision makers (Möhring et al., 2020b). Looking at the empirical literature on intensive margin relations of insurance and pesticide use, we find evidence for both, negative and positive relations: In the context of yield insurances, Feinerman et al. (1992), Quiggin et al. (1993) and Smith and Goodwin (1996) find negative and Horowitz and Lichtenberg (1993) positive relations of crop insurance and pesticide use at the intensive margin. Considering revenue insurance, Goodwin et al. (2004) find positive and negative intensive margin relation of insurance and chemical input use depending on the crop analyzed, while Mishra et al. (2005) and Weber et al. (2016) do not find a significant relation with pesticide use. The dominant insurance schemes in France and Switzerland, and in European agriculture in general, are hail insurance insurances and multi-peril crop insurances (see e.g. Diaz-Caneja et al., 2009; Enjolras and Sentis, 2011; Finger and Lehmann, 2012). For such insurances against specific perils, the classical moral hazard problem seems non prevalent and little direct effects on input use are expected in this context (Goodwin, 2001). More specifically, there are hardly any agronomical adjustments possible to provoke an insurance payout (Quiggin, 1994). Nevertheless, Chakir and Hardelin (2014) find (for France) a positive intensive margin relation of hail insurance and pesticide use, whereas Aubert and Enjolras (2014) find no significant relation. Even though insurance against elementary damages and pesticides does not target the same risks, decisions might be connected and influence each other – because i) pesticide use will change expected yields and may therefore also affect the insurance decision and ii) they are all assumed to be determined by farmers' risk preferences and risk perception (Waterfield and Zilberman, 2012; Chakir and Hardelin, 2014).[1] In previous studies, the magnitude of estimated intensive margin effects is often not reported, but ranges over small, negative (Smith and Goodwin, 1996; Goodwin et al., 2004) to small, positive (Chakir and Hardelin, 2014) and large positive (Horowitz and Lichtenberg, 1993) insurance – pesticide use relations, where the latter find a 7–21% higher pesticide use of insured farmers.

Insurance induces extensive margin effects on pesticide use when it creates incentives to switch from pesticide-extensive forms of land use (e.g. fallow land, temporary grasslands or extensively grown crops) to more pesticide-intensive crops. Such incentives are created if insurance solutions are particularly suited for the latter or intensive land use under insurance is more attractive than extensive land use under insurance for the decision maker (Wu, 1999; Fuchs and Wolff, 2011; Shi et al., 2019). Further, insurance might lead to the cultivation of crops on lands, where cultivation was too risky before, e.g. due to poor growing conditions, natural hazards or high pest pressure. Cultivation of crops on such lands may therefore lead to a higher input use and a positive effect of insurance on pesticide use (both at the intensive and extensive margin). Several studies empirically find a positive relation of insurance and pesticide use at the extensive margin (Wu, 1999; Claassen et al., 2011; Wu and Adams, 2001; Miao et al., 2016; Yu et al., 2018) in the context of the US crop insurance program. Young et al. (2001), Goodwin et al. (2004), Walters et al. (2012) and Shi et al. (2019) find a significant but only modest relation at the extensive margin and Weber et al. (2016) do not find a significant extensive margin relation. Estimates on the magnitude of the increase of cropland under insurance range from around 1% (Young et al., 2001; Goodwin et al., 2004) to over 20% (Wu, 1999; Wu and Adams, 2001).

Most of the above-mentioned studies in literature only focus on the estimation of relations either at the intensive or the extensive margin. For a quantification of the association between insurance and pesticide use and sound policy recommendations it is though important to consider both the extensive and intensive margin, as they might have confounding impacts. Further, separate estimations of relations at the intensive and extensive margin might not be statistically consistent, as farmers' insurance uptake, land use and pesticide use decisions are potentially interdependent and made simultaneously. As exceptions, and focusing on US agriculture, Goodwin et al. (2004) and Weber et al. (2016) consider relations of insurance and pesticide use at the extensive and intensive margin in a joint framework. Their results can though not be transferred to European agriculture as agricultural systems (e.g. crop rotations), dominant insurance types, subsidization and market penetration differ fundamentally from US agriculture (e.g. Santeramo and Ford Ramsey, 2017). Moreover, in Europe strict policies on land use change (i.e. from permanent grassland to cropland) are in place. In this article we therefore jointly assess the extensive and intensive margin relation of crop insurance and pesticide use in European agriculture - using Switzerland and France as case studies.

3. Case studies: France and Switzerland

We perform our analysis separately for the two case studies Switzerland and France, for the time period 2009–2015. The chosen case studies reflect a large diversity of agricultural systems, e.g. with respect to average farm size, level of off-farm income, agricultural policy (EU Common Agricultural Policy vs. Swiss agricultural policy) and insurance systems in Europe.

[1] See also Iyer et al. (2020) for a recent survey on risk preferences of European farmers.

Following, we discuss relevant differences for our analysis.

An important aspect of agricultural land use in France and Switzerland is that farmers generally use crop rotations, which are also a requirement of cross compliance restrictions to be fulfilled in order to receive direct payments. Apart from arable crops, also temporary grasslands and cover crops can be a part of the crop rotation. Further types of agricultural land use include permanent grassland or lands for agri-environmental schemes ("set-aside land", "greening") including fallow land (European Commission, 2008). In comparison to France, the use of temporary grasslands has a high importance in Switzerland (more than 20% of the arable land, BLW, 2018). The EU Common Agricultural Policy further incentivizes a protection of permanent grasslands, making a conversion of permanent grassland to cropland unlikely. Similarly, the Swiss system of direct payments provides no incentives to convert permanent grasslands. Whereas farms with a sole focus on arable crop production are more abundant in France, such farm types are only rarely found in Switzerland. There is a higher share of temporary grasslands in Switzerland than in France. Thus, switches from grass to crops can be obtained more easily than in mainly permanent grasslands (i.e. leading to a more pesticide-intensive land use). Therefore, we expect a stronger extensive margin relation between insurance and pesticide use in Switzerland than in France.

In both countries, insurances can be used to hedge either all cultivated crops on the farm or the entire acreage of a specific crop. Insurable cultures for the period 2009–2015 include all arable crops, temporary grasslands and cover crops, as part of the crop rotation, as well as permanent grasslands. Subsidization and market penetration of insurances in both countries is clearly lower compared to US agriculture.

In Switzerland, the most widely used crop insurance schemes include protection against hail and other elementary risks such as flooding or storm damages. Moreover, drought-related damages can be insured but these schemes have only recently been introduced and have a low market penetration.[2] Overall, the participation rate in crop insurance schemes in Switzerland was reported to be at about 60% (Finger and Lehmann, 2012). Pest related damages are explicitly excluded from coverage (see www.hagel.ch for information from the insurance provider). Deductibles are zero for hail related damages and 10% for all other perils. No insurance subsidy at the national level exists and only minor subsidies exist at the cantonal level (Finger and Lehmann, 2012). The farmer can further adjust the level of coverage (insured risks) in every period, as contracts can be initiated and terminated on an annual basis, leading to changes in the insurance premium. Premium levels per hectare vary, depending on the risk exposure of the farmer (see www.hagel.ch). Insurance premia might undergo some dynamics, e.g. due to premium increases in the year after an extreme event, reflecting a change in the underlying risk distribution. More specifically, premium increases after an extreme event indicate an increase in the risk exposure at the production location.

France has a long tradition in hedging weather-related hazards through crop insurance. Since 2005, insurance policies cover not only hail and storms but also a wide range of climatic perils.[3] According to the French Ministry of Agriculture, in 2018, more than 70,000 farms purchased crop insurance policies, representing more than 4 million hectares and 30.5% of the usable agricultural area (grassland excluded). Policies are subsidized at a 65% level maximum while a deductible of 20% to 30% generally applies (Bardají et al., 2016). Crop insurance policies hedge only yields against the consequences of weather-related events, but not directly against pest-related damages. However, if a pest or a disease is a subsequent consequence of a climatic event, then the insurance can indirectly hedge its impacts on the insured production.[4] Similarly to Switzerland, farmers can adjust their level of coverage of insured risks in every period because insurance policies are subscribed on an annual basis. Premium levels per ha may vary in France depending on the selected coverage level and guarantees, cultivated crops and farm location. Summarizing, the potential insurance coverage (in terms of risks covered) as well as the level of subsidization are higher in France than in Switzerland. We therefore expect a stronger impact of insurance on input use decisions in France.

To reduce potential adverse effects of pesticide use on human health and the environment a "National Action Plan for the Sustainable use of pesticides" has been introduced in 2008 (Directive 2009/128/EC) in France. The effectiveness of included policy measures though has been questioned (Hossard et al., 2017; Möhring et al., 2020). In both countries, pesticide regulations and directives on the protection of water bodies further restrict pesticide applications.

4. Empirical framework

Following, we describe the farmers' decision rationale regarding insurance, land use and pesticide use decisions, critically discuss challenges in estimating the relation between insurance and pesticide use at the intensive and extensive margin - and present the here used approach to tackle these challenges. See Ramaswami (1993), Innes and Ardila (1994), Chambers and Quiggin (2001) and Yu and Sumner (2018) for theoretical models on input and output effects of crop insurance.

4.1. Farmers' decision rationale

Generally, the observed sequence of decisions in both countries is similar and suggests that insurance and land use decisions are made simultaneously followed by subsequent pesticide use decisions (Fig. 1). More specifically, in France farmers need to subscribe to the insurance policies before the season begins, in order to avoid any adverse selection effect. Field crops have to be reported by end of the year, while adjustments are possible until early May. Land use decisions are made in autumn, when several important crops (such as cereals and rapeseed) are sown. This simultaneity of insurance and land use decisions is also underlined by the fact that various details on the crop choice have to be indicated for the specification of the insurance contract. In Switzerland, farmers have to quit an existing insurance contract by September, and can enter a new contract by the end of the year. Land use and insurance decisions are then made within a similar timeframe as in France. For both countries it holds that when land use and insurance decisions are made, no information on the specific pest pressure of the subsequent growing season is available yet. Consequently, the majority of pesticide use (except for some first herbicide applications, which might already take place in autumn) may occur only after the crop insurance decision is made. Cross compliance obligations[5] also include integrated pest management obligations, i.e. pesticide treatment is only allowed if

[2] In 2017, this insurance option was used by 1300 arable and 90 grassland farmers in Switzerland (Schweizer Hagel, 2018). The drought insurance for arable crops was first tested in 2008 and continuously expanded. The drought insurance for grassland was introduced in 2016 (Schweizer Hagel, 2018; Vroege et al., 2019).

[3] The list of hazards hedged through crop insurance policies is fixed by a ministerial decree (Décret n° 2016-1612). They include drought, excess of temperature, heatstroke, sunburn, low temperatures, lack of solar radiation, cold, frost, excess of water, violent rains, torrential rains, excessive moisture, hail, weight of snow or frost, storms, whirlwind and sandstorms. Insurers also are free to hedge other hazards (e.g. lightning) in addition to the ones mentioned in the official list.

[4] In 2013 a mutual fund (FMSE) was created in France to account for some specific, disease-related damages. Potential effects of this fund are though beyond our sample as only fruit, vegetable and animal production were indemnified from 2013 to 1015 (www.fmse.fr).

[5] In Switzerland this cross-compliance obligation is called "proof of ecological performance" (see e.g. Huber et al., 2017). In the EU cross compliance is defined in "Statutory Management Requirements" and "Good agricultural and environmental conditions" and for example includes requirements of Integrated Pest Management on pesticide application thresholds and crop rotations.

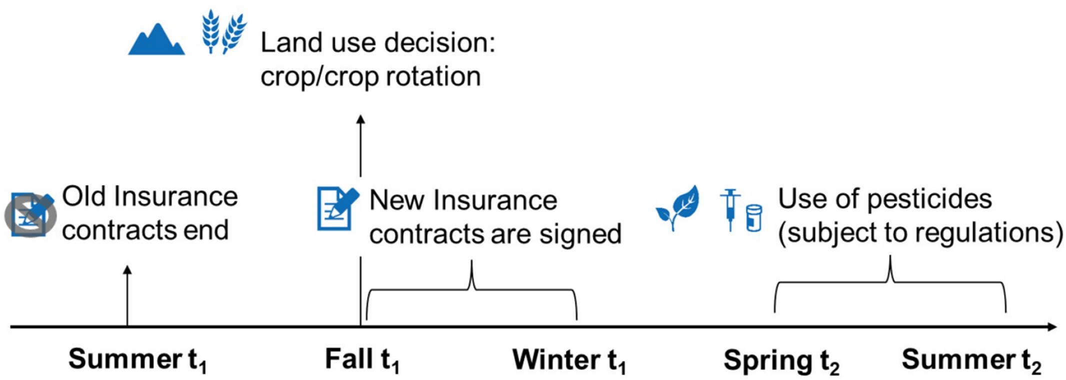

Fig. 1. Observed decision-making structure of farmers in France and Switzerland.
(Source: Own depiction, Icons: OCHA.)

certain criteria are fulfilled (e.g. certain pest thresholds are exceeded). Thus, pesticide application should be reactive to observed pest pressure and cannot be planned at the beginning of the cropping season.

4.2. Econometric framework

In estimating the association between insurance and pesticide use at the extensive and intensive margin, one has to account for two major challenges which pose a threat to consistency and identification of causal effects. They follow from the above-described decision-making structure: i) identification of the sequence of decisions, ii) accounting for simultaneity and interdependence of decisions.

Identification of the sequence of decisions should be based on observed decision making. In our case, the observed structure suggests that insurance and land use decisions are made simultaneously and are followed by pesticide use decisions. Smith and Goodwin (1996) and Goodwin et al. (2004) have argued that although decisions are made at different points in time, farmers plan land-, insurance- and input use decisions jointly at the beginning of the cropping season. In the context of our case studies, i.e. in European agriculture, such an argumentation though is not valid because pesticide use shall depend on the actual pest pressure.[6] Yet, we still test for simultaneity of all three decisions following Smith and Goodwin (1996), Wu (1999) and Goodwin et al. (2004). For this purpose, they propose to use Hausman specification tests. These tests allow to test the hypothesis, that ignoring the simultaneity of decisions yields the correct specification. Along these lines we also compute specification tests - but in order to increase robustness of the testing procedure used by Smith and Goodwin (1996), Wu (1999) and Goodwin et al. (2004) - we use two alternative specification tests. More specifically, we use the C statistic (Ruud, 2000; Hayashi, 2000) and the Davidson-MacKinnon test (Davidson and MacKinnon, 1993). Results of the test (see Appendix B) confirm our hypothesis that the decision-making rationale follows the observed structure, presented above.

Given our focus on arable crop (rotations) and the potential relations at the extensive margin in the described agricultural systems, we divide farmers land use decisions in two categories in our framework: “cropland” and “grassland”. “Cropland” comprises all arable crops and “grassland” comprises land use types which are temporarily not used for the cultivation of crops (but might be part of a crop rotation), such as temporary grasslands, fallow land or cover crops.[7] Potential substitution between the two types of land use has large implications for pesticide use, as pesticide use levels strongly differ between the categories (pesticide expenses in grasslands are close to zero on average). The econometric model and the used explanatory variables are identical for France and Switzerland but estimations for the two countries are conducted separately. Land use (Eqs. (1)–(2)), insurance (Eq. (3)) and pesticide use (Eq. (4)) equations are defined as follows:

$$LG_{i,t} = \alpha_0^{LG} + \alpha^{LG}\boldsymbol{A}_{i,t} + \beta^{LG}\boldsymbol{B}_{i,t}^{LG} + \gamma^{LG}LC_{i,t} + \delta^{LG}I_{i,t} + \theta^{LG}LG_{i,t-1} + \epsilon_{i,t}^{LG} \tag{1}$$

$$LC_{i,t} = \alpha_0^{LC} + \alpha^{LC}\boldsymbol{A}_{i,t} + \beta^{LC}\boldsymbol{B}_{i,t}^{LC} + \vartheta^{LC}LG_{i,t} + \delta^{LC}I_{i,t} + \theta^{LC}LC_{i,t-1} + \epsilon_{i,t}^{LC} \tag{2}$$

$$I_{i,t} = \alpha_0^{I} + \alpha^{I}\boldsymbol{A}_{i,t} + \beta^{I}\boldsymbol{B}_{i,t}^{I} + \vartheta^{I}LG_{i,t} + \gamma^{I}LC_{i,t} + \theta^{I}I_{i,t-1} + \epsilon_{i,t}^{I} \tag{3}$$

$$P_{i,t} = \alpha_0^{P} + \alpha^{P}\boldsymbol{A}_{i,t} + \beta^{P}\boldsymbol{B}_{i,t}^{P} + \vartheta^{I}LG_{i,t} + \gamma^{I}LC_{i,t} + \delta^{P}I_{i,t} + \epsilon_{i,t}^{P} \tag{4}$$

$LG_{i,\ t}$ and $LC_{i,\ t}$ represent land use decisions of farmer $i = 1, \ldots, n$ in year $t = 1, \ldots, T$ for the category “grassland” (LG) and “cropland” (LC) in hectares, respectively. $I_{i,\ t}$ represents the insurance decision of farmer i in year t expressed in CHF and € per hectare, respectively and $P_{i,\ t}$ represents the respective pesticide use decision expressed in logged pesticide expenses per hectare. The vectors $\boldsymbol{A_{i,t}}$, $\boldsymbol{B_{i,t}}^{LG}$, $\boldsymbol{B_{i,t}}^{LC}$, $\boldsymbol{B_{i,t}}^{I}$ and $\boldsymbol{B_{i,t}}^{P}$ contain explanatory variables, such as farm and farmers characteristics, weather and climate variables and year dummies. $\boldsymbol{A_{i,t}}$ contains explanatory variables which are common to all equations and $\boldsymbol{B_{i,t}}^{LG}$, $\boldsymbol{B_{i,t}}^{LC}$, $\boldsymbol{B_{i,t}}^{I}$ and $\boldsymbol{B_{i,t}}^{P}$ those which are specific to the respective equations. $LG_{i,\ t-1}$, $LC_{i,\ t-1}$ and $I_{i,\ t-1}$ represent lagged land use and insurance decisions and $\epsilon_{i,\ t}^{LG}$, $\epsilon_{i,\ t,}^{LC}$, $\epsilon_{i,\ t}^{I}$ and $\epsilon_{i,\ t}^{P}$ the error terms of the respective equations.

An additional challenge for our analysis is that some farmers choose zero values for insurance and “grassland”. To account for the limited nature of the dependent variables, we use Tobit estimators for both i) insurance and ii) grassland equations (e.g. Wu, 1999),

$$S_{it}^{*} = \beta \boldsymbol{X}_{i,t} + \epsilon_{i,t} \tag{5}$$

$$S_{i,t} = \begin{cases} S_{i,t}^{*} \text{ if } S_{i,t}^{*} \geq 0 \\ 0 \text{ otherwise} \end{cases} \tag{6}$$

where $S_{i,\ t}^{*}$ represents the latent and $S_{i,\ t}$ the observed decision (land use/insurance) of farmer $i = 1, \ldots, n$ in year $t = 1, \ldots, T$. $\boldsymbol{X}_{i,\ t}$ represents vectors of the independent variables that explain the respective decision (land use/insurance) and $\epsilon_{i,\ t}$ represents the respective error term.

To account for the structure of the farmers' decision-making process, we estimate Eqs. (1)–(4) as a simultaneous equation model. This allows us to model the joint determination of insurance and land use, which in turn potentially influence pesticide use decisions. The challenge to estimate this system of equations arises through the presence of the independent variables of insurance and land use as explanatory variables in the other equations, i.e. potentially endogenous variables.

[6] Additionally, joint land use and pesticide use decisions are especially relevant for agricultural systems in which herbicide resistant GM crops are used (e.g. soy and glyphosate). Note that especially in contrast to non-European countries, France and Switzerland have issued bans of GM crops.

[7] Permanent grasslands (e.g. meadows) are excluded from the category “grassland”, as substitution with cropland rarely occurs for this land use type in the context of our case studies (see explanations in background section).

Generally, two approaches are suggested to estimate such simultaneous equation models with limited dependent variables. First, Wooldridge (2010, pp. 939–941), proposes a consistent estimation strategy which accounts for censoring of dependent variables (for an application of this approach see e.g. Adams et al., 2009). Second, Angrist (2001) and Angrist Joshua and Pischke (2009) argue to ignore the censored nature of the dependent variables and use a linear 2SLS estimator, as it provides a sufficient approximation. We follow Wooldridge (2010) in the main analysis, but also apply the Angrist Joshua and Pischke (2009) approach as a robustness check.

In the first stage of our estimation, we estimate Eqs. (7)–(9), using Tobit estimators for Eqs. (7) and (9) (accounting for the limited nature of the dependent variables), and OLS regression for Eq. (8):

$$LG'_{it} = \alpha_0^{LG} + \alpha^{LG}\boldsymbol{A}_{i,t} + \beta^{LG}\boldsymbol{B}_{i,t}^{LG} + \theta^{LG}LG_{i,t-1} + \epsilon_{i,t}^{LG} \tag{7}$$

$$LC'_{it} = \alpha_0^{LC} + \alpha^{LC}\boldsymbol{A}_{i,t} + \beta^{LC}\boldsymbol{B}_{i,t}^{LC} + \theta^{LC}LC_{i,t-1} + \epsilon_{i,t}^{LC} \tag{8}$$

$$I'_{it} = \alpha_0^{I} + \alpha^{I}\boldsymbol{A}_{i,t} + \beta^{I}\boldsymbol{B}_{i,t}^{I} + \theta^{I}I_{i,t-1} + \epsilon_{i,t}^{I} \tag{9}$$

From the first stage estimations, predicted values ($\widehat{LG}_{it}$, $\widehat{LC}_{it}$, $\hat{I}_{it}$) are computed, which serve as instruments for the respective endogenous variables ($LG_{i,t}$, $LC_{i,t}$, $I_{i,t}$) in the second stage estimation (the system of Eqs. (1)–(4)). We then solve the system of Eqs. (1)–(4) "equation-by-equation", using common 2SLS estimators (Wooldridge, 2010, p.252). Results are computed using farm-level clustered standard errors and are presented in the main results. In the robustness checks, we compare the chosen approach to the "linearized" estimation strategy suggested by Angrist and Pischke (2009, see above), as well as a theoretically more robust GMM estimator and a fixed effects approach accounting for potential farm-level heterogeneity.

Identification of causal effects of insurance on land and pesticide use in the above system of equations depends critically on the choice of the equation specific variables ($\boldsymbol{B}_{i,t}^{LG}$, $\boldsymbol{B}_{i,t}^{LC}$, $\boldsymbol{B}_{i,t}^{I}$ and $\boldsymbol{B}_{i,t}^{P}$) and vice versa on the exclusion of these variables from the other equations. See the data section for a critical discussion on variable choice. We argue that conditions for a causal interpretation of estimated effects in the here described complex system of decisions in European agriculture can almost never completely be fulfilled. This is because i) variables which explain fundamental long-term decisions for farmers, such as land use, are at the same time almost always linked to other important decisions in agricultural systems and ii) long-term decisions, such as insurance uptake and land use decisions are path-dependent, i.e. depend on other decisions in previous periods. Perfect instruments for land use and insurance decisions are therefore almost never available in the context of our research question. Whereas, previous studies with a focus on North American agriculture (Goodwin et al., 2004; Weber et al., 2016) have exploited differences and changes in policy and/or insurance structure, accessibility or availability to identify effects, such variations cannot be found in most European countries due to the different focus of agricultural policy and a different insurance system (compare Section 3). We therefore cannot establish causal inference based on such variations for the case of European agriculture. Thus, we carefully interpret the empirical results as correlations rather than causal effects. It is though worthwhile to note that the plans in European agricultural policy to intensify the support of crop insurances in the future, may present opportunities to implement causal estimation strategies in a similar fashion as Goodwin et al. (2004) or Weber et al. (2016).

5. Data

In our analysis, we use unbalanced, farm-level, panel data sets for Switzerland and France from 2009 to 2015, respectively. The Swiss dataset comes from the Central Evaluation of Agri-Environmental Indicators and is combined with farm-level bookkeeping data, both provided by Agroscope, the Swiss center for excellence in agricultural research (de Baan et al., 2015; Hoop and Schmid, 2015). The dataset contains information on outputs, input use and characteristics of the farm and the farm operator. The French dataset is derived from the French Farm Accountancy Data Network (FADN). For each farm, the FADN provides precise accounting documents such as the balance sheet and the income statement as well as expenses for crop insurance and chemical inputs and characteristics of the farm operator and the farm structure. We focus on two farm types: farms with a specialization in arable crop production and mixed farms with arable crop and animal production. No organic farms are included in the Swiss sample, while farms which are partially producing organic are included in the French sample. French FADN data does generally not allow to identify and exclude partially organic farms from the dataset.[8] In both datasets, comparable explanatory variables are available (see below) but the two samples structurally differ with respect to sample size. The Swiss dataset contains 903 observations of 216 farms and the French dataset 12,502 observations of 2892 farms. See Table A1 in the appendix for a frequency count of both datasets. Before estimations, we further test the data for outliers regarding the main decision variables with the BACON algorithm (Billor et al., 2000), which is a multivariate method for outlier detection. We then remove observations which are detected as significant outliers. We find 2% (France) and 4% (Switzerland) of observations to be outliers – see Appendix C for a detailed documentation of outlier detection and removal. We combine the datasets with information on climate and weather information from MeteoSwiss (Frei et al., 2006; Frei, 2014) and Météo France weather stations (listed by the French Ministry of Environment, Ecology and Sea; www.stats.environnement.developpement-durable.gouv.fr/Eider), matched at the farm-level for Switzerland and at the regional level for France, as well as country-specific indicators for risk exposure to weather hazards. For Switzerland we choose a hail risk indicator at municipality level (Finger and Lehmann, 2012) and for France we compute a more general indicator of the number of weather hazards at the regional scale, using the Gaspar database (www.macommune.prim.net/gaspar), reflecting the wider scope of the French insurance scheme.

Farm and farmers' characteristics used in the estimations include age of the farm operator, on-farm labor force (work units/ha), education of the farm operator and topographic zone (mountain vs. valley or hilly zone) of the farm. For each of the land use-, pesticide- and insurance equations we only use those farm and farmers' characteristics, which have been identified as relevant determinants in literature. We also check robustness of our results regarding the inclusion of the same characteristics in each equation and find results to be robust. In addition, we control for yearly changes in policies,[9] insurance availability and shifts in price levels of agricultural outputs, inputs and land, using year dummies in all equations.

Equation-specific variables in the land use equations (cropland and grassland in hectares) include one-year lags of the respective land use decisions. This allows us to represent both, aspects of general suitability

[8] Note that partial conversion of the production to organic farming is allowed under EU standards, while it is not allowed under Swiss standards. We expect that the inclusion of partially organic farms in the French sample does not bias our analysis, as the share of organic farms only lies at 4.3% for field crops and 5.5% for dairy in France in 2018 (increasing trend from 2009 (2.5%)–2015 (4.8%), in line with the general European trend, see www.agencebio.org/la-bio-en-france and https://statistics.fibl.org/europe.html). Further, partially organic production is more attractive for perennial crops (not included in the analysis), as otherwise the whole crop rotation has to be switched to organic. Pesticide use is further expressed in €/ha in our analysis - a pesticide use indicator which does not down-weigh expenses for organic pesticides. Moreover, we consider this issue in the interpretation of our results for France (see Discussion section).

[9] A major policy change in agricultural insurances in France happened in 2010, when hazards considered as insurable in the official regulation could no longer be hedged by the National Agricultural Disaster Guarantee Fund. Simultaneously, maximum subsidy levels for crop insurance policies were raised from 45% to 65%.

of a farm and specialization of a farmer (see e.g. Wu, 1999; Goodwin et al., 2004). As an important determinant of grassland, we further use the share of animal production in total farm revenues. In the cropland equations, we include long-term climatic conditions (average temperature and precipitation levels over the last 51 and 45 years for Switzerland and France, respectively) in the region of the farm. Crop production is often constrained by a suitable production climate, whereas grasslands are very adaptable to climatic conditions in our case study regions. In Switzerland, temporary grasslands are for example present in all climatic regions ranging from valleys to mountain regions. In the cropland equations, we further use yearly machinery assets as an explanatory variable. Farmers who have made long-term investments in agricultural machinery (e.g. for ploughing, seeding, pesticide spraying and harvesting) are prone to utilize their machinery capacity and therefore plant crops.

To depict the farmers' insurance decision in our framework, we use the average intensity of insurance chosen by the farmers as a decision variable (crop insurance expenses in € and CHF per hectare farmed land, respectively). Earlier studies (Horowitz and Lichtenberg, 1993; Smith and Goodwin, 1996; Wu, 1999; Aubert and Enjolras, 2014) have often used binary variables (insurance uptake/no uptake) to represent the farmers' insurance decisions. In line with Goodwin et al. (2004) and Weber et al. (2016) we though argue that a binary variable does neither capture changes in the proportion of land enrolled in insurance, nor in the average level of coverage chosen (see section on case studies for a brief discussion on different coverage levels in France and Switzerland). As the chosen measure of insurance intensity captures both, adjustments in the proportion of land enrolled in insurance and the average level of coverage chosen, it is well suited to quantify the association between insurance and pesticide use at the extensive and intensive margin in our case studies. As with land use decisions, we assume insurance use to be determined by previous insurance decisions (Goodwin et al., 2004). Yet, the main risk components driving land use and insurance decisions may not be identical. More specifically, the latter may be specifically driven by the exposure to the insured risks (e.g. hail risk) rather than the overall risk exposure of the farm (e.g. Rydant, 1979; Finger and Lehmann, 2012). We therefore consider exposure to weather hazards with country-specific indicators in the insurance equations. We further include the yearly debt to equity ratio of the farm (in logs), which has been identified as an important determinant of insurance uptake (Sherrick et al., 2004; Enjolras and Sentis, 2011).

As a measure of pesticide use, we choose expenses for pesticides in € and CHF per hectare (in logs), respectively. We assume that pesticide use decisions are again driven by farm and farmers' characteristics, as well as pest pressure (Bürger et al., 2012; Aubert and Enjolras, 2014; Möhring et al., 2020b; Möhring et al., 2020c). We do not directly observe pest pressure in our datasets, which can additionally be very heterogeneous across the different crops farmers cultivate in our samples. To account for differences in pest conditions, we therefore use farm location and regional weather variables (yearly precipitation, squared precipitation and yearly average temperature, as well as their interaction) as proxies for pest conditions (Aubert and Enjolras, 2014b; Andert et al., 2015; Lechenet et al., 2016). See Table 1 for variable definitions and mean and standard deviations of all variables used in the analysis.

6. Results

6.1. Descriptive results

We first look at descriptive statistics of pesticide use and insurance for France and Switzerland to get an intuition on the insurance-pesticide use relation in France and Switzerland. More specifically, we compare the distributions of pesticide use per hectare, cropland and grassland between insured and non-insured farmers (for the two countries, respectively) i) graphically using histograms and ii) statistically using Wilcoxon rank-sum tests. Note that while the descriptive analysis may provide some basic intuition on the relation between insurance and pesticide use decisions, conclusions are limited in comparison to the regression analysis, as we i) use a binary insurance variable here, ii) do not simultaneously account for extensive and intensive margins, iii) do not control for co-variates and iv) do not account for the decision structure of farmers compared. The descriptive analysis overall indicates that insured farmers have a slightly higher pesticide use per hectare than non-insured farmers (intensive margin), although we find this relation to be stronger for France than for Switzerland. Further at the extensive margin, we see that insured farmers have more cropland than non-insured farmers. Differences for grassland are not as clear as for cropland, with a slightly higher grassland of insured farmers in Switzerland and slightly lower grassland in France. Results are both reflected in the histograms (see Appendix Figs. A1–A6) and the comparison of distributions with the Wilcoxon rank-sum test (Appendix Table A2).

6.2. Regression analysis

Following, we focus on the results of the simultaneous land use and insurance decisions of our econometric analysis (Table 2). Our results show a significant and positive relation between insurance and land use (i.e. at the extensive margin) for both countries. In Switzerland, it is significantly positive, both for “grassland” and “cropland”. In line with expectations and descriptive results, our estimations though show a considerably higher coefficient for “cropland” than for “grassland”, i.e. insurance uptake is correlated stronger with an expansion of crop- than grassland. For the Swiss sample, coefficients of “grassland” in the “cropland” equation, and vice versa, are negative, but insignificant – indicating no significant substitution of land use types. For France, we further find an indication of complementary effects in land use, where more “cropland” is associated with more land in the category “grassland” and vice versa - but no indication of a substitution of land use types. The rest of the coefficients in the land use equations are in line with our expectations and similar across the two countries. The importance of specialization and path dependency for cropland decisions is underlined by significant lagged land use coefficients and the finding that yearly shifts in price levels and policies are not significantly related to “cropland” decisions in both countries. On the other hand, year effects are related to “grassland” decisions in France, but not in Switzerland, pointing to the relevance of EU policy measures influencing use of temporary grasslands and set-aside land, which have changed over time. We would further expect that changes in insurance policies and prices are related to farmers' choices of insurance intensity, which is confirmed by significant coefficients for the year effects in the insurance equations of both countries.

Farms with a larger workforce per ha are associated with lesser land use, indicating economies of scale but also that a specialization on (work-) intensive production is associated with lower land use.[10] A higher share of animal production is further associated with more “grassland” in both samples and a higher mechanization with more “cropland”, as expected. Climate variables indicate that more crops are grown in regions with a lower average rainfall in Switzerland. In line with expectations, more “cropland” is associated with significantly higher insurance expenses in both countries - and more “grassland” with no significant changes (Switzerland) or even a decrease in insurance intensity (France). Insurance intensity in both countries is further related to the risk of weather hazards a farm faces and to its debt-to-equity ratio, as expected.

[10] As workforce might be endogenous in our model, we also estimate the model without the workforce variable, but find no changes in results, indicating that workforce decisions are made long-term in our case studies (e.g. family farms).

Table 1
Definitions, mean and standard deviations of all variables used in the analysis.

Name	Unit	Description FR	Description CH	Mean (SD) FR	Mean (SD) CH
Grassland[a]	ha	Total acreage in category grassland.	Total acreage in category grassland.	5.23 (11.82)	0.81 (1.65)
Cropland[a]	ha	Total acreage in category cropland.	Total acreage in category cropland.	123.25 (77.99)	10.13 (8.80)
Insurance	€/CHF per ha	Insurance expenses in € per ha.	Insurance expenses in CHF per ha.	22.48 (21.12)	103.31 (92.56)
Log pesticide expenditures	Log €/CHF per ha	Log of pesticide expenses in € per ha.	Log of pesticide expenses in CHF per ha.	5.00 (0.49)	5.78 (0.66)
Weather hazards indicator	Number of years	Number of weather-related hazards from 1982 to 2015 (regional level).	Years with hail damages from 1961 to 2004 (municipality level).	26.09 (13.62)	24.11 (9.23)
Log debt-equity	Ratio	Log of debt-to-equity ratio.	Log of debt-to-equity ratio.	3.47 (0.91)	−4.06 (9.27)
Farmers' age[a]	Number of years	Farmers' age in years.	Farmers' age in years.	50.10 (9.32)	46.14 (9.50)
Workforce/ha	Working units/ha	Annual working units per ha (equals 225 working days; Eurostat, 2018a, 2018b).	Working units per ha (equals 280 working days; Hoop and Schmid, 2015).	0.01 (0.01)	0.37 (0.56)
Share animal	Ratio	Animal output/Gross output.	Animal output/Gross output.	0.06 (0.16)	0.46 (0.23)
Average annual temperature	Degrees celsius	Average annual temperature 1970–2015 (regional level).	Average annual temperature 1961–2012 (municipality level).	11.31 (1.18)	8.36 (0.85)
Average annual precipitation	1000 l/m^2	Average annual precipitation 1970–2015 (regional level).	Average annual precipitation 1961–2012 (municipality level).	0.72 (0.15)	1.16 (0.16)
Machinery	1000 CHF/€	Agricultural machinery assets in 1000 €.	Agricultural machinery assets in 1000 CHF.	117. 97 (110.94)	84.54 (82.13)
Education	Binary	Higher education (1) or not (0).	Higher education (1) or not (0).	0.09 (0.29)	0.60 (0.49)
Zone	Binary	Mountain region (0) or not (1).	Mountain region (0) or not (1).	0.99 (0.12)	0.91 (0.28)
Yearly temperature	Degrees Celsius	Average yearly temperature (regional level).	Average yearly temperature (municipality level).	11.91 (1.40)	9.14 (1.08)
Yearly precipitation	1000 l/m^2	Average, yearly precipitation (regional level).	Average, yearly precipitation (municipality level).	0.70 (0.17)	1.11 (0.22)

[a] For confidentiality reasons, the age and land use variables are expressed in small classes in the French sample. Thus, midpoint values are used for these variables. As an example for farmers' age, we transform the 30 to 35-year class to 32.5 in our analysis. Note that the average yearly CHF/€ exchange rate from 2009 to 2015 was 1.25 (www.ecb.europa.eu).

Next, we turn to the results of the pesticide use equations (Table 3). For both countries we find a positive relation between insurance and pesticide use (i.e. at the intensive margin). The coefficient is highly significant for France, but not significant for Switzerland in our main analysis. In all robustness checks (see below) we though find the coefficient to be highly significant for both, France and Switzerland. The finding of a positive coefficient for the intensive margin effect points to a risk increasing effect of pesticides in our case studies, in line with e.g. Horowitz and Lichtenberg (1993), Gotsch and Regev (1996), Regev et al. (1997), Di Falco and Chavas (2006), Serra et al. (2008) and Möhring et al. (2020b). Note that coefficients reflect percent changes in pesticide expenses, as the pesticide use variable is expressed in logarithms. The control variables in the pesticide use equations show similar coefficients for both samples and their signs are in line with our expectations. As expected, an increase in "grassland" (holding "cropland" constant) relates to a decrease in pesticide expenses per hectare, while an increase in "cropland" (holding "grassland" constant) relates to higher pesticide expenses per hectare (only significant in France). Higher education is associated with less pesticide expenses in the French sample. Although this variable captures general agricultural education, and not specifically education in pesticides (i.e. their application), it can be used as an indicator for the role of training and education in pesticide application decisions. Weather variables are further significant in the French sample; a higher temperature is associated with less pesticide use, indicating that pest pressure is lower in hotter years. We also find that farmers spend more money on pesticides in wet years, indicating a positive relation between pest pressure and rainfall (compare e.g. Bürger et al., 2012; Aubert and Enjolras, 2014). The coefficient on the squared precipitation variable further indicates that rainfall and pesticide expenses are not related linearly, but in a quadratic (decreasing) way. We find this relation to be stronger in valleys and hilly zones, than in mountain zones (where rainfall levels are higher anyways). We would further expect that yearly changes in pest pressure, crop prices and pesticide prices are related to farmers' pesticide use expenses. This expectation is met, reflected in the highly significant coefficients of year dummies in both countries.

To assess the economic relevance of our results we compute elasticities of the estimated extensive and intensive margin coefficients at mean values of all variables, thus expressing the coefficients in percentage changes. Focusing on the significant results, we find that a 1% change in insurance expenses relates to changes in "cropland" of 11 and 0.3 percentage points in Switzerland and France respectively and a change of 6 percentage points in pesticide expenses per ha in France and is therefore in line with results of previous studies (see Background section). Ceteris paribus, i.e. not accounting for adaptions in land and pesticide use, this would relate to a reduction in pesticide use expenses of 6.3% (France) and 11% (Switzerland) in a scenario without any insurance.

6.3. Robustness checks

In this section, we perform robustness checks on our results regarding the used estimators and potential farm-level heterogeneity. Following Angrist Joshua and Pischke (2009), we first use a "linearized" version of the estimation approach used in the main part, which does not account for the censored nature of the dependent variables. They argue that the use of a standard 2SLS estimator might be less efficient than explicitly accounting for censoring of variables (as done in the main analysis with Tobit estimators), but also does not bear the risk of making potentially wrong assumptions about the non-linear first stage. As a first robustness check, we thus follow their argumentation and again estimate the system of equations with "equation-by-equation 2SLS estimation" (Wooldridge, 2010), as described in the econometric framework, but this time ignore the censored nature of the insurance and "grassland" variables and only use OLS estimators in the first stage. As an additional robustness check, we compare results to an "equation-

Table 2
Marginal effects of land use and insurance decisions.

	Insurance CH (CHF/ha)	Grassland CH (ha)	Cropland CH (ha)	Insurance FR (€/ha)	Grassland FR (ha)	Cropland FR (ha)
Insurance	X	0.0018* (0.001)	0.0107*** (0.003)	X	0.0013 (0.0025)	0.0189*** (0.0063)
Grassland	3.5694 (2.5870)	X	−0.0569 (0.1629)	−0.0410*** (0.0101)	X	0.0479*** (0.0145)
Cropland	0.7798*** (0.2760)	−0.0126 (0.0102)	X	0.0050*** (0.0017)	0.0005 (0.001)	X
Lag insurance	0.6637*** (0.053)	X	X	0.8139*** (0.0144)	X	X
Lag grassland	X	0.3965*** (0.0771)	X	X	0.8904*** (0.003)	X
Lag cropland	X	X	0.8883*** (0.0310)	X	X	0.9849*** (0.0031)
Weather hazards indicator	0.5753** (0.2446)	X	X	0.0305*** (0.0104)	X	X
Log debt-equity ratio	0.5335** (0.2745)	X	X	0.3794*** (0.1454)	X	X
Farmers age	0.1335 (0.2502)	−0.0007 (0.0067)	−0.0192 (0.0149)	0.0146 (0.0148)	−0.0041 (0.0050)	−0.0508*** (0.0122)
Workforce/ha	X	−0.6043*** (0.1839)	−1.0922** (0.4820)	X	−4.6724 (3.2830)	−77.1578*** (23.9192)
Share animal	X	0.8153*** (0.2719)	X	X	2.7753*** (0.4164)	X
Average annual temperature	X	X	0.3291 (0.2317)	X	X	0.0702 (0.0914)
Average annual precipitation	X	X	−1.4250* (0.8454)	X	X	−0.3002 (0.7153)
Machinery	X	X	0.0036* (0.0022)	X	X	0.0121*** (0.0019)
Constant	19.5837 (14.6181)	0.1013 (0.4589)	0.8883 (0.3010)	0.09596 (1.0840)	0.6951** (0.3340)	4.2984*** (1.4710)
H0: Year effects = 0	9.10*	3.01	7.88	211.0***	18.43*** 7.39	

Estimation of Eqs. (1)–(3) of the econometric model takes account of censoring of land use and insurance decisions and is conducted with the two-step procedure described in the econometric framework. "X" indicates that the variable is not considered in the estimation of the respective equation (see econometric model and Data section). Numbers in parentheses show farm-level cluster robust standard errors. *,**,***Indicate significance levels of 10%, 5% and 1%, respectively. For the test of joint significance of the year effects, chi-square values are reported.

Table 3
Pesticide use decisions.

	Pesticides CH (Log CHF/ha)	Pesticides FR (Log €/ha)
Insurance	0.0007 (0.0006)	0.0025*** (0.0004)
Grassland	−0.1184*** (0.0332)	−0.0122*** (0.0007)
Cropland	0.0071 (0.0045)	0.0006*** ($9*10^{-5}$)
Farmers age	−0.0006 (0.0037)	−0.0002 (0.0009)
Education	0.0145 (0.0826)	−0.0449* (0.0244)
Zone (mountain/valley)	−0.7648 (1.2050)	1.2276 (0.9310)
Yearly temperature	−0.1612 (0.2244)	−0.1091*** (0.0677)
Yearly precipitation	−2.2363 (2.0599)	1.7730*** (0.5584)
Yearly precipitation squared	0.4694 (0.3937)	−0.7784*** (0.1254)
Temperature*precipitation	0.0407 (0.1479)	0.0108 (0.0280)
Temperature*zone	0.0497 (0.0952)	0.0040 (0.0646)
Precipitation*Zone	0.2018 (0.5118)	−0.8232** (0.3650)
Constant	8.6921*** (2.5329)	4.4536*** (0.9723)
H0: year effects = 0	14.26***	386.82***

Estimation of Eq. (4) of the econometric model takes account of censoring of land use and insurance decisions and is conducted with the two-step procedure described in the econometric framework. Numbers in parentheses show farm-level cluster robust standard errors. *,**,***Indicate significance levels of 10%, 5% and 1%, respectively. For the test of joint significance of the year effects, chi-square values are reported.

by-equation GMM" estimation procedure (Greene, 2018), which again follows the "linearized" version of the estimation approach (Angrist Joshua and Pischke, 2009), but the instrumental variable GMM estimator instead of the 2SLS estimator. In equation-by-equation GMM estimation, we additionally account for potential intra-cluster correlation and heteroscedasticity and use farm-level clustered standard errors. Without further assumptions, the 2SLS estimator is the most efficient estimator among the equation-by-equation estimators. The GMM IV estimator though is more efficient when intra-cluster correlation and heteroscedasticity are present.

We also check robustness regarding individual, farm-level heterogeneity, by including farm-level fixed effects in the analysis. To account for the panel structure with fixed effects in the analysis, Wooldridge (2010) suggests demeaning of all variables before the estimation of the system of equations and correcting standard errors after estimation. We follow this approach and use the G2SLS estimator suggested by Balestra and Varadharajan-Krishnakumar (1987). As the French dataset includes over 12,000 observations, it provides us with enough intra-farm variability to perform a meaningful analysis. The Swiss dataset is considerably smaller and highly unbalanced. Indeed, the within variation in the Swiss dataset left after demeaning is very small. We therefore only consider the French sample in the robustness checks with the G2SLS estimator. We present results of all robustness checks in Table 4.

Results of all robustness checks are in line with our main results regarding the size and significance of coefficients, except for the intensive margin coefficient in the Swiss sample, where we find significant coefficients in contrast to the main results. For the fixed effect estimation, we find qualitatively and quantitatively identical results at the extensive and intensive margin, compared to all other estimators. Only the coefficient for the extensive margin on "croplands" is higher using the fixed effects estimator (around two times higher at the lower bound). We are though not concerned about this result as the economic importance of the extensive margin, compared to the intensive margin, is very low in France (see above). We further test the robustness of our results regarding the exclusion of the potentially endogenous workforce variable and the consideration of the full set of farm and farmers' characteristics in all equations and find results to be qualitatively in line in all cases.

7. Discussion

Two major goals of current agricultural policies are the provision of better (on-farm) risk management instruments, such as crop insurance, and the reduction of environmental and health risks from pesticide use. In this paper we analyze potential interdependencies of these policies and resulting implications for policy design. Our empirical analysis reveals that at the extensive margin, insurance is positively related to cropland expansion. At the intensive margin we find that insurance is related to increases in pesticide expenses per hectare in France, while we find no significant association in Switzerland. Our results are in line with a number of studies which jointly (Goodwin et al., 2004) or separately (Horowitz and Lichtenberg, 1993; Wu, 1999; Wu and Adams, 2001; Young et al., 2001; Chakir and Hardelin, 2014) analyze extensive or intensive margin effects of insurance on pesticide use – and are supported by results of the descriptive analysis, as well as several robustness checks.

We do not find signs for substitution between different types of crops (e.g. input intensive and less input intensive). An explanation for the identified extensive margin effects therefore might be that insurance makes it more attractive to i) grow riskier and thus often more intensive crops, and ii) grow crops on lands where farming was too risky or not economically attractive before and therefore influences

Table 4
Results of robustness checks for extensive and intensive margin coefficients.

	Switzerland		France		
Coefficient	2SLS	IV-GMM	2SLS	IV-GMM	G2SLS
Extensive margin grassland	0.0016* [−0.0002, 0.0035]	0.0018** [$3*10^{-6}$, 0.0035]	0.0014 [−0.0045, 0.0073]	0.0017 [−0.0029, 0.0063]	−0.0232 [−0.0797, 0.0334]
Extensive margin cropland	0.0100*** [0.0055, 0.0146]	0.0094*** [0.0039, 0.0149]	0.0189*** [0.0050, 0.0327]	0.0197*** [0.0074, 0.0320]	0.2531*** [0.1246, 0.3815]
Intensive margin	0.0008** [$2*10^{-5}$, 0.0017]	0.0010* [$-5*10^{-5}$, 0.0021]	0.0025*** [0.0019, 0.0030]	0.0026*** [0.0018, 0.0033]	0.0038*** [0.0009, 0.0068]

"Extensive Margin" refers to the coefficients of the insurance variable in the "grassland" and "cropland" equations (Eqs. (1)–(2)), respectively. "Intensive Margin" refers to the coefficient of the insurance variable in the pesticide use equation (Eq. (4)). Estimation is conducted with ("linearized") 2SLS, GMM and G2SLS (fixed effects IV) estimators as described in Robustness checks section. Numbers in parentheses show 95% confidence intervals. *,**,***Indicate significance levels of 10%, 5% and 1%, respectively. The GSLS estimator was not computed for the Swiss dataset due to the very small within variation left after demeaning of the data.

land use choices. This could be especially of importance in more remote regions in France (Renwick et al., 2013). For Switzerland, our results further indicate that the availability of crop insurance makes on-farm activities (e.g. agricultural land use) generally more attractive i.e. leads to an expansion in farmland (in line with Cai, 2016). Substitution of on- and off-farm activities might especially be of relevance in Switzerland, as Swiss farms are on average small and have a high percentage of off-farm activities (de Mey et al., 2016; BLW, 2018). The positive relation between insurance and grassland area in Switzerland might further be explained by the fact that temporary grasslands have a high importance and are integrated in the crop rotation in Switzerland (BLW, 2018). At the same time, the presence of more temporary grasslands in Switzerland than in France may present better long-term opportunities to expand cropland in reaction to future changes in insurance provision. Yet, of course, such land use change decision also depends on whole-farm constrains such as the role of grass for animal feeding. In the case of France, we do not find an association between insurance and grassland area, but the results indicate that the land use categories "grassland" and "cropland" are complements, pointing towards the influence of EU agricultural policies like "greening" or "set-aside land" on land use choices. These policies demand(ed) that a certain percentage of agricultural land is not used as cropland but temporary grassland, fallow land or similar, ecologically favorable land use types. Contrary, in Switzerland, cross-compliance regulations do not require to create ecological compensation areas on cropland, but these can also be present on permanent grasslands.

The positive association between insurance and pesticide use at the intensive margin in France (in line with Chakir and Hardelin, 2014) relates to a risk increasing effect of pesticides (Horowitz and Lichtenberg, 1993; Gotsch and Regev, 1996; Regev et al., 1997; Di Falco and Chavas, 2006; Serra et al., 2008; Möhring et al., 2020b). For crop insurances which only target specific weather hazards, such as in France, traditional explanations of moral hazard and adverse selection do not play an important role as drivers of intensive margin effects. Insurance choice and pesticide use are though both determined by farmers' risk preferences and are part of the farmers (on-farm) risk balancing, providing some explanations for interactions at the intensive margin. The French crop insurance schemes also covers a wider range of potential perils and the subsidization rate is distinctively higher in France than in Switzerland (65% compared to 0%), which may explain the greater importance and significance of intensive margin effects in the French case. Similarly, Miao et al. (2016) and Yu et al. (2018) find a stronger relation between insurance and pesticide use at the extensive margin when subsidization rates are higher. In the robustness checks, coefficients for the intensive margin further fall into the same range for the Swiss and the French sample, providing some confidence about the magnitude of estimated coefficients.

Results indicate that the association between crop insurance and pesticide use is of an economically relevant magnitude in France and Switzerland. In a simple no-insurance scenario, estimated intensive and extensive margin coefficients ceteris paribus relate to reductions in pesticide expenses of 6% (France) and 11% (Switzerland), respectively, in line with results of previous studies (see Section 2). Differences in the magnitude of estimates for France and Switzerland highlight that the relation between insurance and pesticide use is closely linked to characteristics of the agricultural system and insurance system, such as the availability of marginal lands, temporary grassland or insurance coverage and subsidization (see Discussion above). These differences are further reflected in the diverging importance of mechanisms through which insurance and pesticide use are linked: we find that results are mainly driven by the extensive margin in Switzerland and by the intensive margin in France. The latter finding is in line with Urruty et al. (2016), who find that trends in French pesticide use in the last decade were driven by changing pesticide use intensities and not by changes in land use. Our results should though be carefully interpreted, as we do not account for potential adaptions of farmers, such as substitution of farming practices, cultures or risk management tools, nor for potential changes in market conditions and assume no significant scale effects in pesticide use in this simple scenario. Changes in insurance provision could for example lead to adjustments in crop rotations, farming practices, or the mix of on-farm activities (e.g. livestock and crops) in order to provide a substitution for on-farm risk management - and consequently to changes in pesticide use intensity. Moreover, agricultural land markets in France and Switzerland are competitive in most regions and are on average facing increasing land and rent prices (Häusler, 2010; Eurostat, 2018a). In regions with a competitive land market, changes at the extensive margin would most likely not lead to changes in cropland extent, but rather to a shift in the distribution of cropland across farmers. A reduction in insurance may for example lead to a shift of croplands to farms which have better possibilities of on-farm risk management (i.e. larger and more diverse farms) or to the uptake of more diverse activities, i.e. more on- or off-farm risk-balancing (de Mey et al., 2016). Contrarily, if changes in land use mainly relate to the conversion of marginal lands or fallow land in regions which are remote (Renwick et al., 2013) or which face natural restrictions for farming (e.g. such as topography, pest pressure, climate conditions or natural hazards), markets would be less competitive and actual changes in agricultural land use were more probable.

8. Conclusion

We here analyze the relation of crop insurance and pesticide use, using the example of France and Switzerland. We account for the complex structure of insurance uptake, land use and pesticide use decisions of farmers, potentially leading to insurance - pesticide use interactions both at the intensive and extensive margin. We find a significant and economically relevant relation between the provision of crop insurance and pesticide use expenses. The chosen case studies reflect the diversity of agricultural systems, e.g. with respect to average farm size, level of off-farm income, agricultural policy (EU Common Agricultural Policy vs. Swiss agricultural policy) and insurance systems in Europe.

Our findings have important policy implications. For example, currently discussed support for the implementation of further risk management tools in European agricultural could contradict policy efforts to reduce environmental and health risks from pesticide use. Policy makers should be aware of potential effects of risk management instruments on farmers input and output decisions, and take these into account in the design of policies – not only for the type of insurance schemes established in the US, but also for the, in Europe dominant, multi-peril insurances. Our results further emphasize that studies need to consider both, potential changes in land use (extensive margin), as well as pesticide use intensity (intensive margin), to get a complete picture of the relation between crop insurance and pesticide use. While insurance and pesticide use are mainly related at the extensive margin in Switzerland, the relation at the intensive margin is stronger in France.

Our study has several important limitations. In our analysis of the extensive margin, we only consider land use in the two categories “cropland” and “grassland”. We can therefore not account for farmers switching between more extensive and more intensive management strategies in a given culture (e.g. Böcker et al., 2019). Along these lines, the uptake of organic agriculture might be linked to insurance (e.g. Serra et al., 2008) but was not considered in our analysis. Further, we measure pesticide use in monetary expenses in our analysis. Möhring et al. (2019) show that such simple quantitative measures of pesticide use do not sufficiently account for heterogeneous properties of pesticides regarding toxicity, fate and human health. Given the goal of a reduction of environmental and health risks in current pesticide policies, it would be interesting to extend our study in this direction and use an indicator of potential environmental and health risks of used pesticides. Finally, the complex interactions of farmers' decision-making regarding insurance-, land- and pesticide use require a careful interpretation of results. Additionally to the here performed robustness checks and comparison of results across countries (i.e. agricultural systems and policies), statistical techniques which make use of the increasing availability of satellite images (e.g. Wuepper et al., 2020) or potential future variations in European insurance policies and schemes (Weber et al., 2016; Goodwin et al., 2004) could help to identify causal effects of insurance on pesticide use and land use decisions of farmers in future studies.

Further research in this field should also consider other inputs, such as irrigation and fertilizers. This would allow a more holistic picture of the relation between insurance and farmers input decisions - and consequently environmental outcomes. If negative environmental effects of European crop insurances are identified (as our study indicates), the way of supporting agricultural insurances needs to be reconsidered. A more detailed analysis at the extensive margin could further show distributional effects on farms and on spatial cropland allocation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1
Frequency distribution of observations.

	Switzerland (N = 903)		France (N = 12,502)	
Number of years in the panel	Frequency	Percentage	Frequency	Percentage
1	25	11.57	483	16.70
2	36	16.67	377	13.04
3	27	12.50	344	11.89
4	29	13.43	297	10.27
5	22	10.19	229	7.92
6	40	18.52	234	8.09
7	37	17.13	928	32.09
Total	216	100.00	2892	100.00

Table A2
Comparison of log pesticide use expenditure per hectare and land use distributions between insured and non-insured farmers.

	Switzerland (N = 903)			France (N = 12,502)		
Variable	Mean insurance	Mean no insurance	P-value Wilcoxon rank-sum test	Mean insurance	Mean no insurance	P-value Wilcoxon rank-sum test
Log pesticide expenditures per hectare	5.04	4.83	0.000	5.78	5.77	0.541
Land use in category cropland	129.55	93.35	0.000	11.12	6.27	0.000
Land use in category grassland	4.82	7.17	0.000	0.93	0.38	0.000

Note that the table shows mean values of log pesticide expenditures per hectare and land use in the categories cropland and grassland for insured and non-insured farmers over all observations from 2009 to 2015 from the Swiss and French sample, respectively. P-values are indicated for the Wilcoxon-rank test on equality of the distributions, respectively.

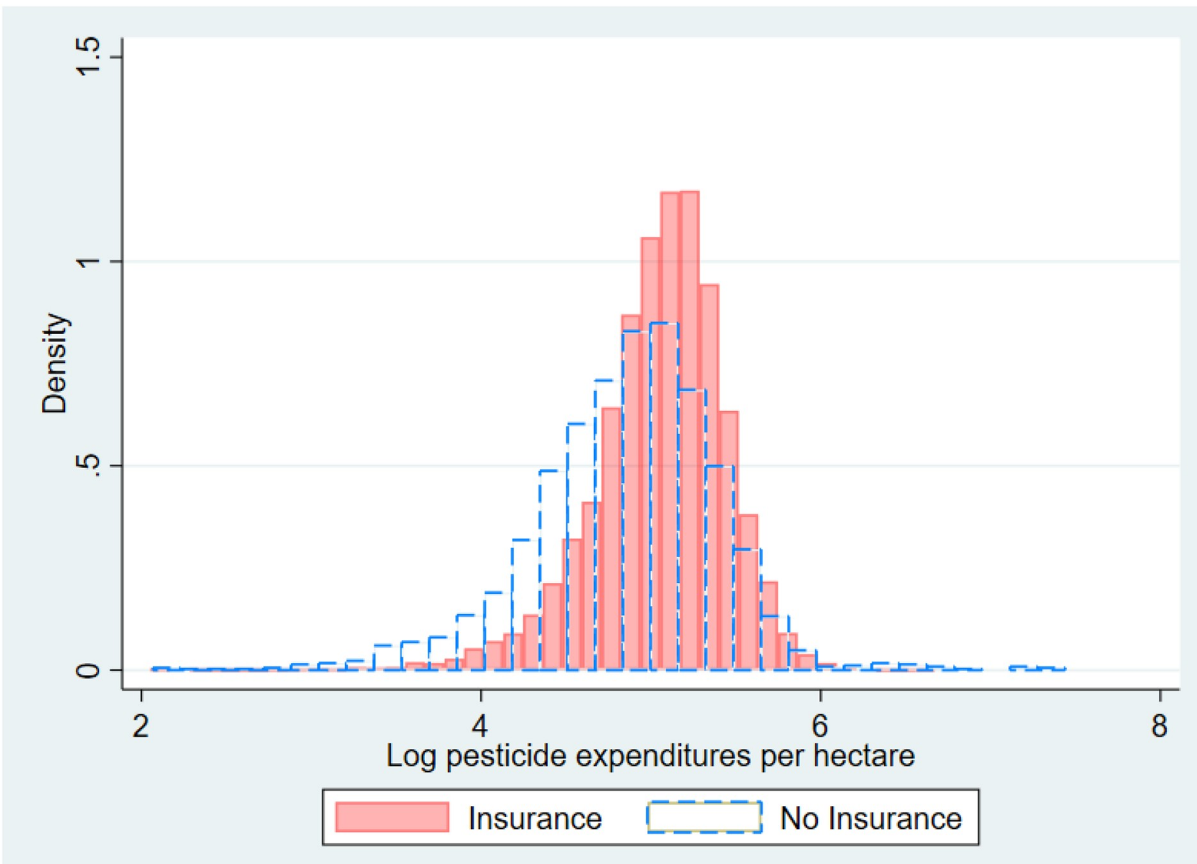

Fig. A1. Histogram of Log Pesticide Expenses per hectare for insured and non-insured farmers in France. Note that the histogram shows Log pesticide expenditures per hectare from 2009 to 2015 for all observations from the French sample with a value > 2, in order to facilitate comparison of the distributions.

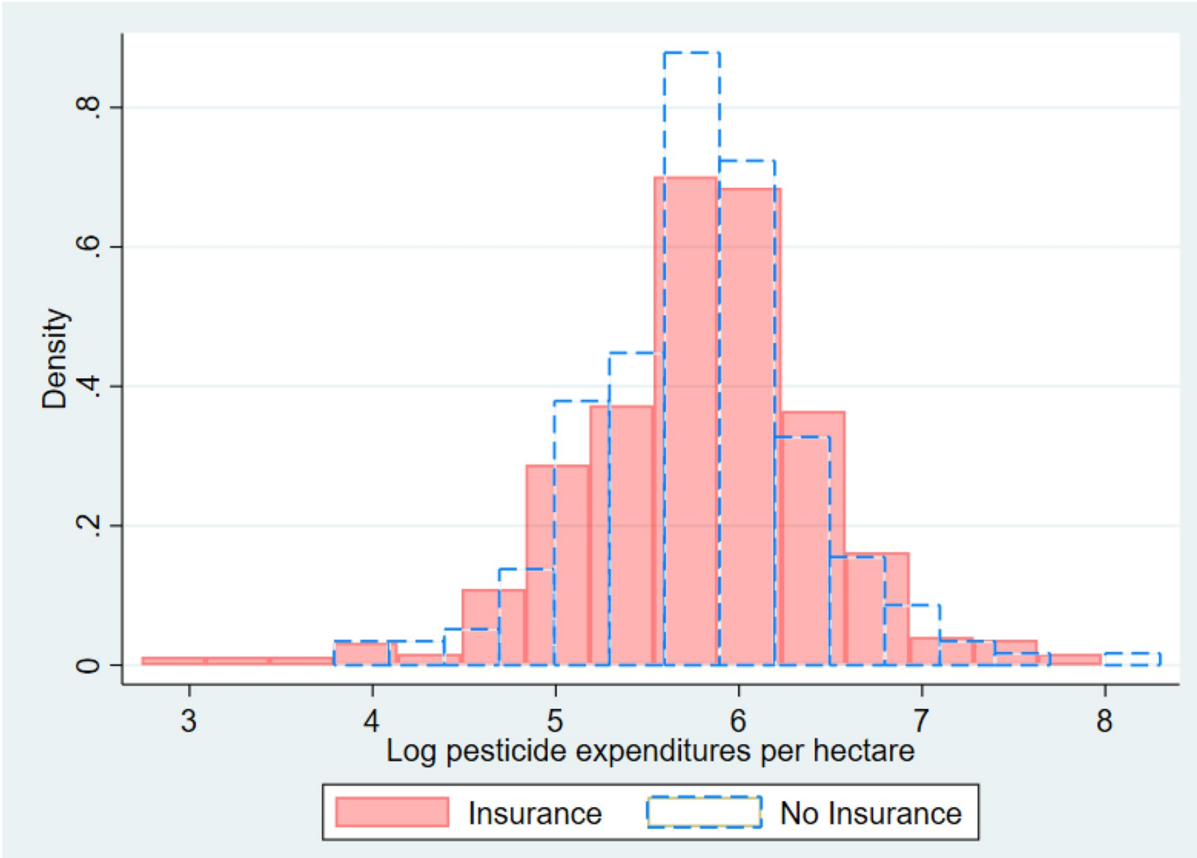

Fig. A2. Histogram of Log Pesticide Expenses per hectare for insured and non-insured farmers in Switzerland. Note that the histogram shows Log pesticide expenditures per hectare from 2009 to 2015 for all observations from the Swiss sample with a value > 2, in order to facilitate comparison of the distributions.

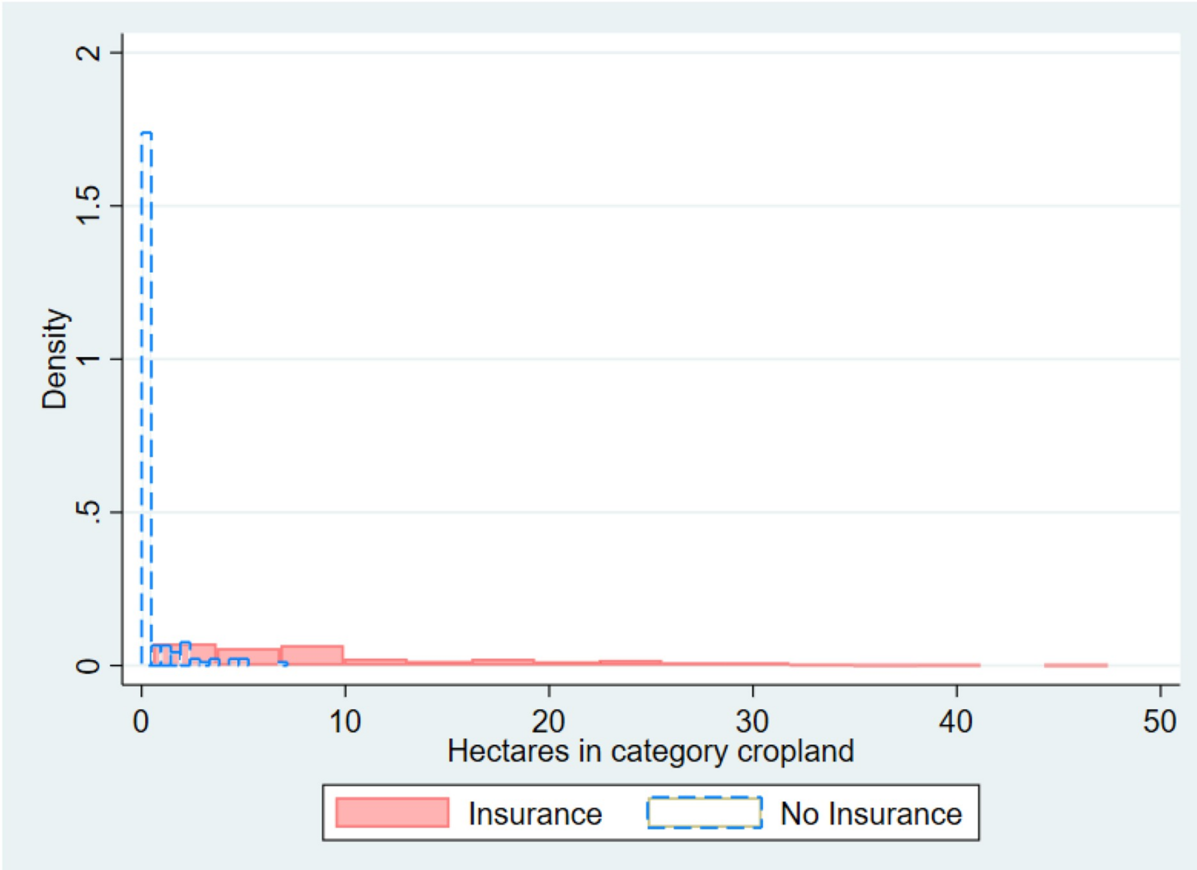

Fig. A3. Histogram of land use in the category cropland for insured and non-insured farmers in Switzerland. Note that the histogram shows land use in the category cropland (in hectares) for all observations in the Swiss sample from 2009 to 2015.

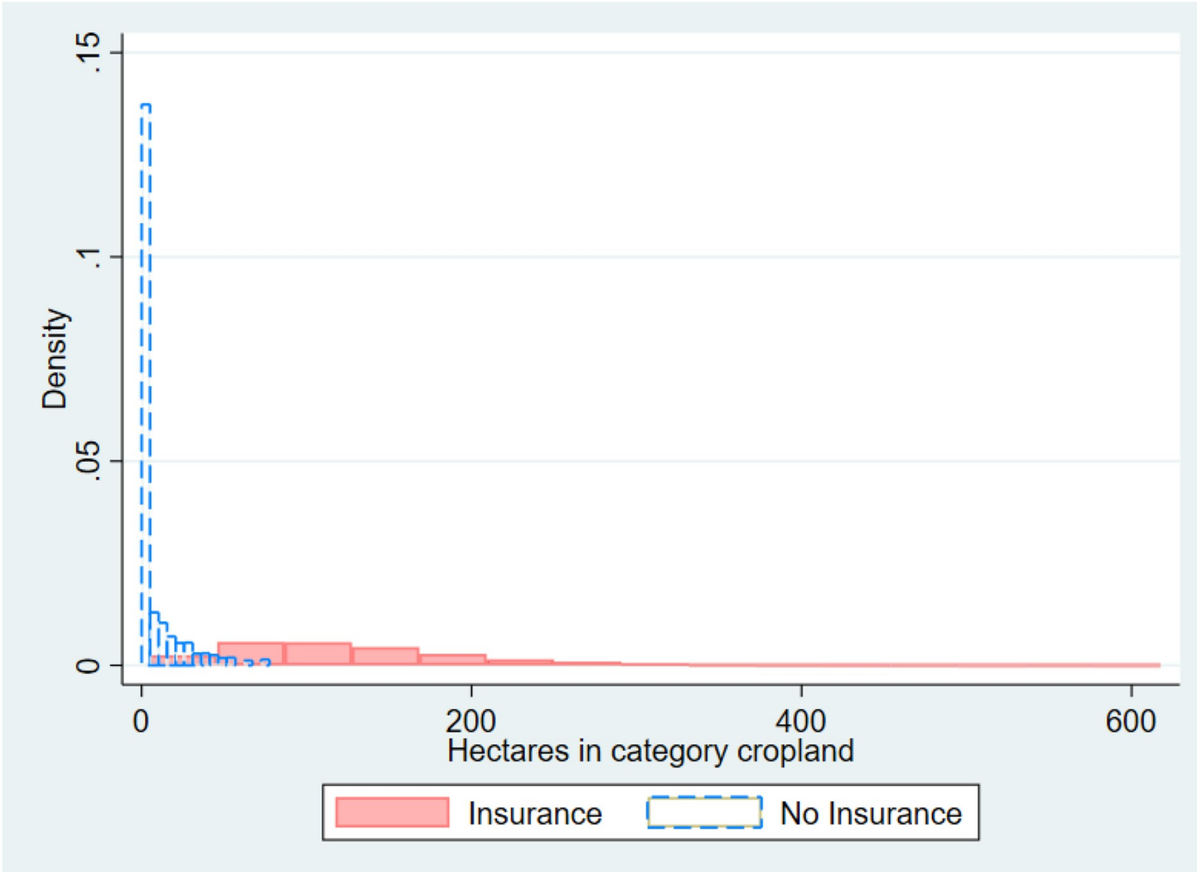

Fig. A4. Histogram of land use in the category cropland for insured and non-insured farmers in France. Note that the histogram shows land use in the category cropland (in hectares) for all observations in the French sample from 2009 to 2015.

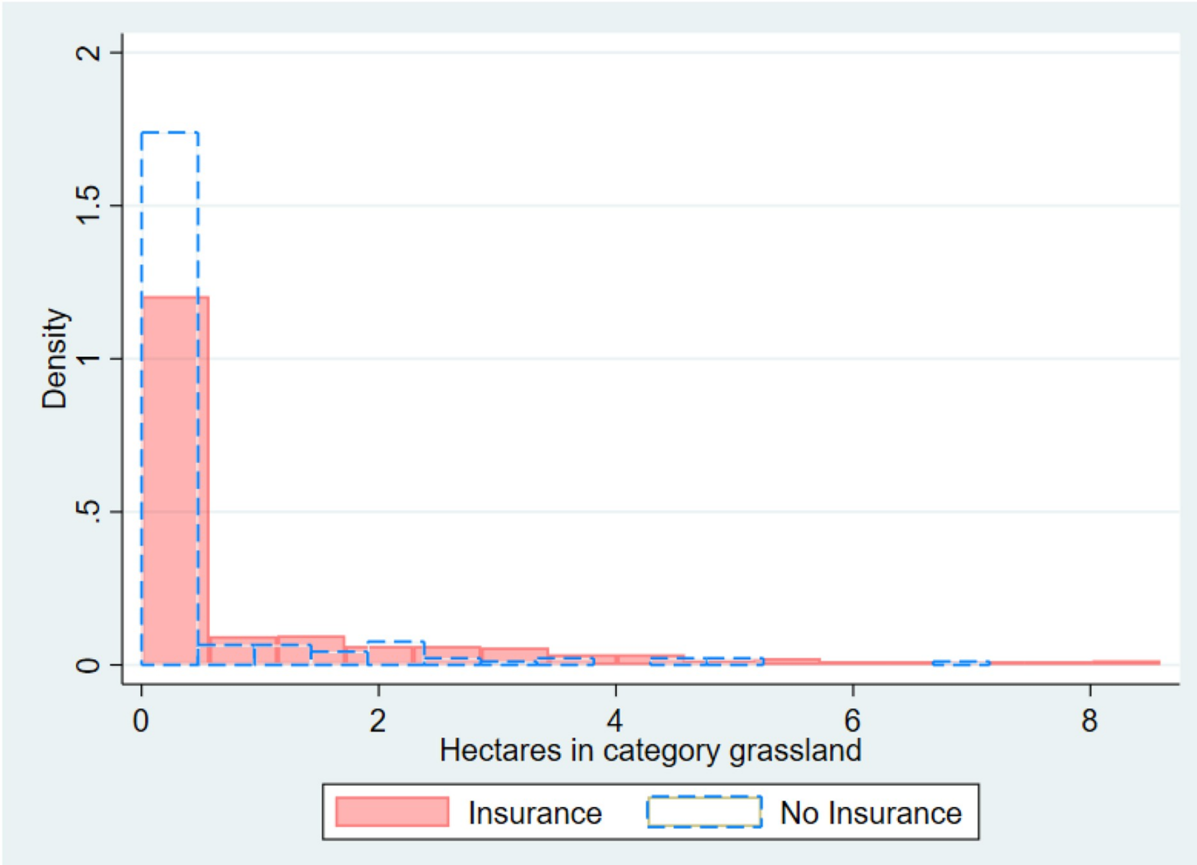

Fig. A5. Histogram of land use in the category grassland for insured and non-insured farmers in Switzerland. Note that the histogram shows land use in the category grassland (in hectares) for all observations in the Swiss sample from 2009 to 2015.

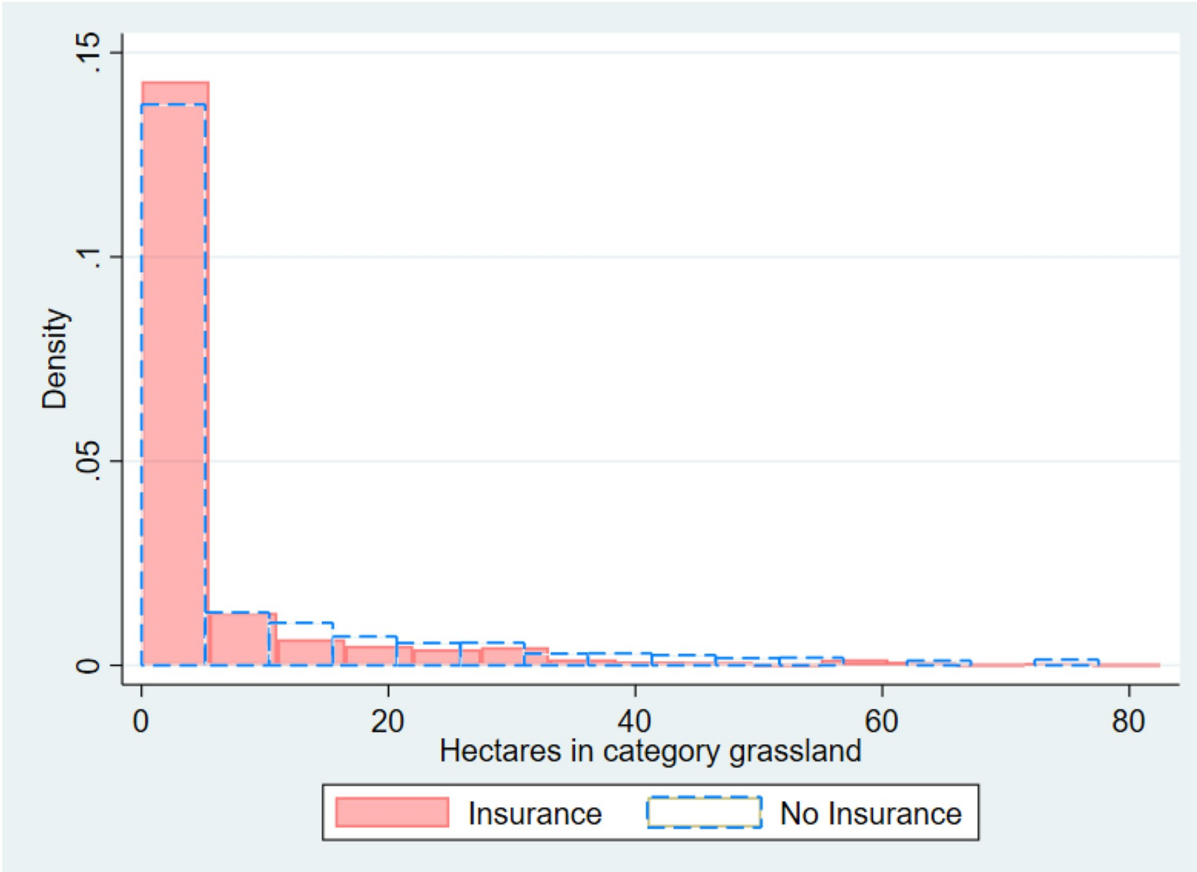

Fig. A6. Histogram of land use in the category grassland for insured and non-insured farmers in France. Note that the histogram shows land use in the category grassland (in hectares) for all observations in the French sample from 2009 to 2015.

Appendix B. Specification tests

Table B1
Results of specification tests.

	GMM (C-Statistic)	G2SLS (Davidson-McKinnon test)
	Chi-square-value	*F*-value
Switzerland		
Pesticide expenditures in Insurance equation	1.79	–
Land use in Insurance Equation	20.89***	–
Insurance and cropland in grassland equation	25.68***	–
Insurance and grassland in cropland equation	18.75***	–
France		
Pesticide expenditures in Insurance equation	0.72	0.35
Land use in Insurance Equation	1.23	4.48***
Insurance and cropland in grassland equation	11.91***	15.11***
Insurance and grassland in cropland equation	11.41***	16.41***

*,**,***Indicate significance at 10%, 5% and 1% levels, respectively.

We perform specification tests for simultaneity of land, pesticide and insurance equations separately for the French and the Swiss data. The tests for endogeneity of the respective variables are performed for the system of equations as presented in Sections 4.2 and 6.2. The C-statistic (see Ruud, 2000; Hayashi, 2000) is calculated after equation-by-equation, heteroscedasticity and intra-cluster robust GMM estimation (compare Section 6.2). The Davidson-McKinnon test (Davidson and McKinnon 1993) is computed after equation-by-equation G2SLS (fixed effects instrumental variable) estimation (compare Section 6.2). The G2SLS estimator was not computed for the Swiss dataset due to the very small within variation left after demeaning of the data (see Section 6.2). The tests show that exogeneity of land use in the insurance equations and insurance in the land use equations is strongly rejected, while exogeneity of pesticide use in the insurance equation cannot be rejected (Table B1). This means that the structure is in line with the observed decision-making structure (Fig. 1) and our hypotheses that land and insurance decisions are made simultaneously, while pesticide use decisions are exogenous in insurance decisions. Results for the two tests are in line, but stronger for the French data when we exploit the panel nature of the data with the G2SLS estimator and the Davidson-McKinnon test.

Appendix C. Removal of outliers with BACON algorithm

Before we analyze our data, we remove outliers from our datasets. To this end, we use the BACON algorithm (Billor et al., 2000), which is a multivariate method for outlier detection, to find outliers for all combinations of land use and insurance. More specifically, we use 1.5 percentiles of the chi-square distribution as the common threshold for outlier detection. Observations which are detected as outliers are then deleted from the respective sample. To document characteristics of the outliers, we show summary statistics of the decision variables for the remaining samples and the deleted outliers in Table C1.

Table C1
Summary statistics for deleted outliers and remaining samples.

	Switzerland		France	
	Sample (N = 898)	Outlier (N = 39)	Sample (N = 12,370)	Outlier (N = 255)
Grassland (ha)	0.81 (1.65)	8.33 (8.20)	5.23 (11.82)	43.53 (59.72)
Cropland (ha)	10.14 (8.80)	11.93 (15.28)	123.25 (77.99)	203.61 (129.80)
Insurance (CHF/€ per ha)	103.31 (92.56)	603.44 (1591.78)	22.48 (21.12)	33.59 (57.71)

Summary statistics for sample and outliers detected by the BACON algorithm with 1.5 percentiles. Mean values and standard deviations (in parentheses) are shown.

The summary statistics show that outliers in both countries on average have higher values of grassland, cropland and insurance then the sample observations. The difference is especially high for grassland (both samples) and insurance (Swiss sample). The outliers further show a very high variability compared to the sample observations, which confirms that the BACON algorithm has identified extreme values. Note that the BACON algorithm is a multivariate method for outlier detection, it therefore does not identify outliers based on extreme values of one of the above decision variables, but considers all of them jointly.

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