Risk perceptions, preferences and the adoption dynamics of pesticide-free production

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Abstract

We study the adoption of a new pesticide-free wheat production system in Switzerland. Using survey data from 1073 Swiss wheat producers, we empirically test whether risk preferences and risks perceptions in four domains relate to farmers' decisions to adopt and when to adopt. We observe heterogeneity in farmers' risk assessments (e.g., early vs. late adopter) and find that farmers' risk preferences, as well as their perception of production and institutional risk are related to adoption behaviour, in contrast to perceived market and investment risks. We offer recommendations for policy makers and supply chain actors to ease the transition from conventional to pesticide-free production systems.

Key words: Risk preferences, risk perceptions, Pesticides, Real Options, adoption, pesticide-free

1. Introduction

The agriculture and food sectors are facing increasing demands for food, and for actions to reduce adverse environmental and health impacts (Pretty, 2018). The conventional pest management methods such as pesticides, are at the core of this tradeoff (Savary et al., 2019). Currently, European agriculture represents a global hot spot of pesticide use and pollutions (Tang et al., 2021), and in response, ambitious action plans have been enacted (e.g., Möhring et al., 2020). For example, the "farm to fork" strategy of the EU aims for a 50% reduction of pesticide use and risks by 2030 (Schebesta & Candel, 2020, European Commission, 2020). To achieve pesticide reduction goals, rapid adjustments in farming practices and farmers' uptake of new production schemes and systems are required (Möhring et al., 2020). Recently, the emergence of (partially) pesticide-free but non-organic production systems have been highlighted as one key entry point to reach these goals. In this study we investigate farmers' decision to adopt a novel pesticide-free, yet not organic, production system in Switzerland (Möhring & Finger, 2022). More specifically, we study farmers' decision to adopt the program in relation to risk preferences and risk perceptions in four domains (i.e., institutional, market, investment and production risks). Our analysis is based on survey data from 1073 farmers matched with geographically explicit environmental data (Möhring & Finger, 2022a).

Previous literature stressed the role of risk and risk preferences for farmers' uptake of more sustainable farming practices (see e.g., Gardebroek, 2006; Kuminoff, Wossink, 2010).[1] When new farming systems and technologies become available to farmers, potential outcomes of adoption are uncertain, leaving farmers to rely upon their subjective beliefs. Production systems with low or no pesticide use, as investigated here, are often considered riskier than conventional production systems (e.g., Läpple & Van Rensburg, 2011). For example, yield outcomes, continuity of new marketing channels and stability of political support might be less predictable, and the use of new technologies can induce investment risks (McCarthy & Schurmann, 2018, Flaten et al., 2005, Bouttes et al., 2019). In this context, farmers have the possibility to delay adoption decisions until uncertainties are resolved (Coble & Lusk, 2010, Lovallo & Kahneman, 2000), eventually leading to slow conversion rates (Musshoff and Hirschauer, 2008).

Apart from the literature mentioned above, there is little evidence on how different domains of risk exposure affect farmers' adoption and delayed adoption of low-input farming practices. More specifically, beyond production and market risks, the question of whether farmers perceive institutional and investment risks as relevant for their adoption decisions, remains yet unexplored.[2] Finally, although both risk perceptions and risk preferences have been shown to matter for adoption, the conception that risk perceptions mediate the relation between risk preferences and adoption of sustainable practices has not yet been empirically tested. We contribute to this literature and quantify the role of risk perception and risk preferences on the adoption of pesticide-free farming practices, using the example of a novel pesticide-free wheat production system in Switzerland. We further the analysis of adoption as a binary decision by analyzing the prospective timing of adoption. Thereby, we enrich the debate on the adoption of sustainable practices by considering the incentives to delay adoption.

We use survey data that captures risk perceptions in different domains, namely, production, market, investment and institutional risks. Additionally, the data allow us to differentiate

[1] See Piñeiro et al., (2020), Streletskaya et al., (2020) for reviews.

[2] There is extensive literature exploring the ranking of risk perceptions among farmers of different production systems. For example, (Koesling et al., 2004) and (Bouttes et al., 2019) discuss the ranking of risk perceptions of organic and conventional farmers in different domains including institutional and market risks. Nevertheless, no previous study empirically tests whether these perceptions ultimately relate to adoption decisions.

between farmers that postpone and not adopters. We estimate a linear model to empirically test how risk preferences and perceptions relate to adoption decisions and a sequential g-estimation to differentiate between direct and mediated relations. Our analysis shows that early adopters, postponers and never adopters differ significantly in their risk assessments regarding the pesticide-free system. Moreover, production and institutional risks are relevant for adoption and the prospective timing of adoption as they relate to an increase in the waiting behavior. Finally, we find that risk loving farmers are more likely to adopt and less likely to postpone, and this role does not seem to be mediated by risk perceptions. We offer recommendations for policymakers and supply chain actors to ease the transition from conventional to less-pesticide-intensive agriculture.

The rest of this paper is divided into six sections. Next, we present a background of the pesticide-free wheat production system in Switzerland. Section 3 presents the conceptual framework, the hypotheses, and the model we estimate. Section 4 presents the data and Section 5 the results. Finally, Section 6 concludes.

2. Pesticide-free production systems in Switzerland

Switzerland, similarly to other European countries, aims to reduce pesticide risks by 50% by 2027 (Federal Council, 2021, Finger, 2021). To reach this goal, coordinated actions between different value chain actors towards the reduction of pesticide risks and use are needed (Möhring et al., 2020). The pesticide-free wheat production system that we analyse in this paper, offers a unique oppportunity to see the dynamics behind a new production system that integrates the actions of farmers, the food industry (e.g., retailers) and the government. In 2018, the Swiss farmer association IP-SUISSE introduced the pesticide-free wheat production system that consists of a set of guidelines for farmers to produce wheat without any synthetic pesticides. In contrast to organic farming, no restrictions to fertilizer use, or the use of pesticides in other parts of the crop rotation apply in this production system. The system has paired with efforts from a major retailer (i.e., Migros) to increase the offer of pesticide-free wheat, thereby increasing the demand for such products and their economic viability (See Möhring & Finger (2022b) for a detailed description of the program). The system operates in a context where industry actions (e.g. setting price markups) are expected to generate major changes in incentivizing large-scale adoption of low-pesticide agricultural practices in Switzerland.

The pesticide-free wheat system builds on an existing agri-environmental, low pesticide use program called Extenso in which farmers renounce the use of insecticides, fungicides, chemical-synthetic stimulators and growth regulators. Farmers receive both governmental direct payments and private price markups for participation (see Table 1). Farmers can since the growing season 2019/2020 also transition into the new pesticide-free wheat system. Participating farmers must, in addition, avoid the use of herbicides and chemical seed treatments.[3] Like the adoption of organic production, pesticide-free production can entail higher production risks compared to the initial Extenso and conventional farming due to the complexities in pest and weed management.[4] For this reason, farmers must transform their entire wheat production after adoption. Pesticides are reduced by a combination of adjusted crop rotations, use of resistant varieties and uptake of mechanical instead of chemical weed control. If farmers acquire machinery for weeding this implies additional investment risks.

As a result of these adjustments, for pesticide-free production practices, yields are expected to be lower (see also Table 1). Considering these challenges, the adoption of pesticide-free system is incentivized with additional federal direct payments and additional price markups (see Table 1 for an overview). Considering the expected yields under pesticide-free production (See Table 1 and Böcker et al. (2019)), the price markup accounts for 19.4% of the potential revenue. Additionally, the federal government offers farmers a total payment of 650 CHF/ha under pesticide-free wheat production compared to 400 CHF/ha under Extenso production. From Möhring & Finger (2022b), it follows that direct payments constitute the 16% of expected pesticide-free wheat production revenues. The magnitude of these shares poses a risk for participant farmers if direct payments change, or mark-ups and marketing channels are not secured.

In summary, the expected revenues in pesticide-free production are higher, while costs may or may not be higher compared to conventional production[5] (see Böcker et al., 2019, Möhring and Finger, 2022). However, after adoption, farmers may face higher risks stemming from production (e.g., yield risk), markets (e.g., because of uncertainty on the durability of price markups), investment risks (e.g., because new machinery is needed) and institutional risk (e.g., because of uncertainty on durability of direct payments). Risks, risk perceptions and attitudes of farmers might thus be an important barrier for adoption and need further investigation. The next section presents, conceptually, how risks and risk preferences relate to the adoption decision of farmers.

[3] Appendix 8.1 presents a summary of the requirements for participation.

[4] In comparable settings from organic agriculture, farmers during the first years after conversion focus their efforts on weed control and yield stabilization (Chongtham et al., 2017).

[5] More specifically, costs may be reduced as pesticide use decreases. However, production costs likely increase if pesticides are substituted with mechanical tools requiring investment and/or adjustment in production systems take place (e.g., adjusted crop rotations), inducing opportunity costs.

Table 1. Participation of economic incentives on expected revenues

	Initial production system (Extenso, low pesticide use)	**Pesticide-free production system**
a. Expected average yield (dt/ha)[a]	55	52
b. Expected market price (incl. price markup) (CHF/dt)[a]	55	65
c. Direct payment per hectare(CHF/ha)[a]	400 (for Extenso program)	650 (Extenso plus non-use of herbicides)
Expected average revenue:		
d. Including markup and payment (CHF/ha)	3,425	4,030
e. Including only markup (CHF/ha)	3,025	3,380
f. Excluding markup and payment (CHF/ha)	2,750	2,600
Participation of economic incentives		
(Compared to scenario d)		
i) Percentage of direct payments (=c/d)	11.7%	16.1%
ii) Percentage of price markups (=a*markup/d)	8%	19.4%

[a]Adapted from Möhring & Finger (2022b). Expected average yield is based on an average farmer.

3. Conceptual and econometric framework

We follow the approach of Hugonnier & Morellec (2013) to represent, under the Real Options approach, the decision-making process of farmers that decide to adopt the pesticide-free wheat production system. The model incorporates decision- makers' risk preferences under an optimal stopping time approach. Risk aversion in this setting is relevant first, because we expect that similar levels of risk generate a different optimal response among farmers with heterogeneous risk preferences, and second, because European farmers are mostly found to be risk averse (Iyer et al., 2020). The main mechanism at play is that investments in the technology turn a safe asset into a risky return flow, which reduces farmers' utility.

We assume that farmers maximize their expected utility over a time span and decide whether to produce under current practices or produce under a pesticide-free system. This feature captures the irreversibility of the investment (i.e., farmers give up one production system for another). In the representation, farmers decide only on the timing of adoption. This feature suits our analysis as in the pesticide-free production system, partial compliance (or partial investment) is not possible, and farmers accept the conditions for the whole plot where wheat is planted.

Farmers receive a risk-free return $r > 0$ on their investment from their current agricultural system.[6] An infinitely lived project of production of wheat under no pesticide generates a cash flow X_t governed by a geometric Brownian motion as shown in Equation (1). The constant parameters μ and σ represent the expected growth rate of the project value and the standard deviation of the expected cash flows. The term Z_t represents a random component that follows a standard Wiener process with $E[dZ] = 0$ and $E[dZ]^2 = dt$. In addition to this, changes in Z are assumed to be serially uncorrelated.[7]

$$dX_t = \mu X_t\, dt + \sigma X_t\, dZ_t \qquad (1)$$

We assume that farmers maximize their expected utility over production returns over time as shown in Equation (2). Where $U(.)$ is farmers' utility function, assumed to be increasing, concave and first order differentiable. Preferences are temporally separable which implies that the curvature of the utility function reflects both risk aversion and intertemporal elasticity of substitution (i.e., preference over fluctuations). Let ρ be farmers' time preference. Farmer's consumption level is given by the return to their investment, that is either conventional or pesticide-free production systems. Farmers select the adoption timing τ that maximizes their utility according to Equation (3).[8] For simplicity, farmers' discount rate is assumed to be the same as the markets' discount rate.

$$E\int_0^{\infty} e^{-\rho t} U(\pi_t) dt \qquad (2)$$

$$Sup_{\tau \in S} E_x \left\{ \int_0^{\tau} e^{-\rho s} U(rI) ds \; + \; \int_{\tau}^{\infty} e^{-\rho s} U(X_s) ds \right\} \qquad (3)$$

Hugonnier & Morellec (2013) show that the optimal τ is given by Equation (4), where the optimal adoption time is a function of the trigger threshold X^*. When preferences are defined

[6] The assumption here is that the default production system for farmers (e.g., conventional farming) can be seen as the safe asset farmers have, and pesticide-free system as the risky asset.
[7] This assumption holds when the risk entailed under the new production system does not decrease over time and the cash flow is always uncertain.
[8] Equation defined over the supremum of the expected utility.

over a constant relative risk aversion utility function $U(x) = \frac{x^{1-R}}{1-R}$, the optimal adoption threshold is defined as Equation (5), with R the parameter that captures risk and fluctuations aversion.[9] In this equation, the cost of investment rI is scaled by a factor $g(.)$ that depends on the growth of the cash streams from pesticide-free system μ, its volatility σ, the discount rate of the market r and risk and fluctuations aversion R (See Hugonnier & Morellec (2013), pp 57). This factor represents the minimum return of the pesticide-free system relative to the initial production, to induce adoption.

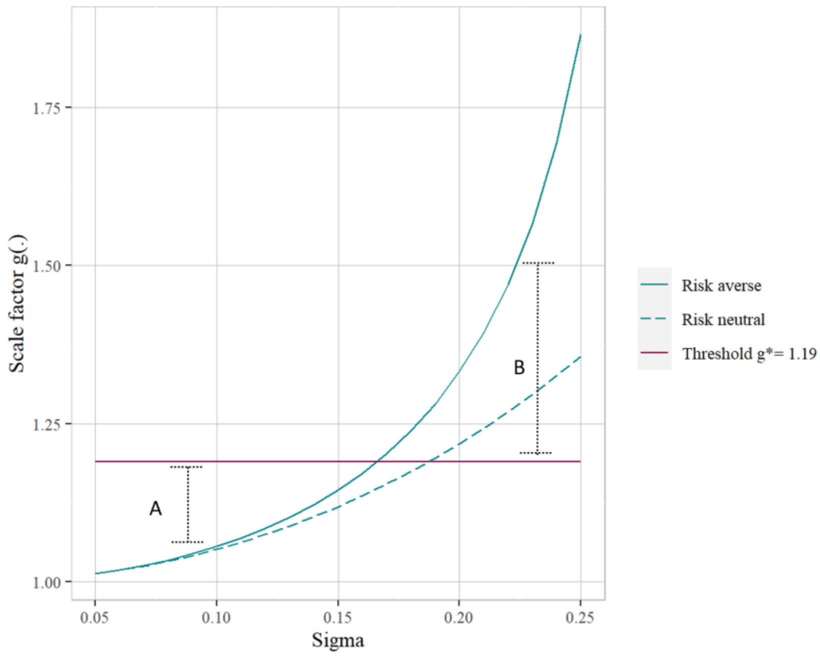
$$\tau^* = \inf\{t \geq 0 : X_t \geq X^*\} \tag{4}$$

$$X^*(R) = rIg(R, r, \mu, \sigma) \tag{5}$$

For illustrative purposes, Figure 1 shows the relationship between the scale factor $g(.)$ and the level of risk for risk neutral and risk averse farmers. Transition to pesticide-free production is characterized by at least partial irreversibility, e.g., if new machinery is bought and/or long-term adjustments in production systems are made. With investment irreversibility and as soon as the new system introduces risks, farmers will require a larger expected return to switch. Moreover, for a given risk level, risk averse farmers will require a larger expected return compared to risk neutral farmers to adopt. The horizontal line shows a threshold g^* that represents the relative return of the pesticide-free wheat including economic incentives (i.e., price-mark ups and direct payments) compared to the initial production system, i.e., Extenso production. The crossing point between the threshold and the curves define the highest level of risk that farmers can withstand according to their specific risk preferences, at the given incentives level. In the illustration, only farmers exposed to risk levels below 20% have the incentive to adopt. Two major implications follow the constant compensation g^* across risk. First, that farmers that experience low levels of risk have the incentive to adopt, and second, that the setting entails both, depending on risk levels and risk preferences, excess of incentives (distance A in the figure) and insufficient incentives (distance B) to induce adoption.

[9] Farmers with a positive R dislike both fluctuations and risk. The present model cannot disentangle between the two motives. However, they are closely related. A risk averse farmer will tend smooth the returns from farming to increase his/her utility. A discussion on the implication of intertemporal separable preferences is found in Attanasio, and Weber (2010).

Figure 1. Scale factor and risk preferences



[a] The scale factor $g(.)$, represents the relative return of the pesticide-free wheat including economic incentives. A scale factor of 1 refers to the scenario in which the initial production system is as profitable as the new system. Note that $g(.)$ and g^* differ as the first varies across risk levels, while the incentive scheme, captured by g* does not. Appendix 8.5 describes the values of the parameters.

From the conceptual model we derive several insights regarding farmers' decisions to adopt the pesticide-free production system. At the program level, the pesticide-free production system induces higher risks in production, which increases the value of waiting. Direct payments and price mark-ups increase the amount of risk farmers can tolerate by generating higher expected returns, and therefore decrease the value of waiting. At the individual level, however, adoption decisions further depend on farmers' perceived risk and risk aversion. Specifically, we test the following two hypotheses:

I. The higher farmers' risk aversion, the higher the threshold $X^*(R)$ and the lower the adoption of pesticide-free production system

II. The higher farmers' perceived levels of risk, the higher the threshold $X^*(R)$ and the lower the adoption of pesticide-free production system.

Econometric framework

In the following, we propose an econometric framework to capture the role of risk on adoption and the timing of adoption of the pesticide-free wheat production. We model the timing of adoption as a latent index model, where latent variables X_t and X^* presented in the model above, define the minimum project value that induces adoption. T_i is the adoption and adoption timing of farmer i observed in our sample.

$$T_i = \inf\{t \geq 0 : X_t \geq X_i^*\} \tag{6}$$

and,

$$X_i^* = \omega + \theta_1 \boldsymbol{RP_i} + \theta_2 \boldsymbol{R_i} + \theta_3 \boldsymbol{C_i} + \gamma_c + \varepsilon_i \tag{5}$$

Risk perceptions are represented by RP_i and include four domains of risk, namely production, market, investment and institutional. Moreover, it includes uncertainty on the expected return of the production system and probability of yield losses and crop failure. As all the different risk sources might be positively correlated (Figure 5 in Appendix), we analyse them at first independently.[10] We consider risk preferences through farmers' willingness to take risks R_i. According to the hypothesis, we expect θ_1 to be positive for all measures of risk perceptions and θ_2 is expected to be negative. By estimating an OLS model, we treat the limited dependent variables (adoption and adoption timing) linearly given our interest in the marginal effects more than the estimation of the conditional expectation function. In the robustness checks we provide an alternative to the linear probability model.

Given that risk perceptions are a cognitive construct, they might depend on the context and characteristics of farmers, raising concerns of omitted variable bias. To reduce this risk, we include a vector C_i with farmers' characteristics (i.e., age, education, share of income from agriculture, succession of farm, workforce, machinery availability, farmers' main language, i.e. German or French), farm geographic characteristics (i.e., temperature, precipitation, mountainous geography) and local conditions through weed presence and herbicide resistance. To limit geographic-specific sources of endogeneity, we include canton dummies γ_c (i.e., Swiss regions). The error term ε_i is assumed to have zero mean and is clustered at the canton level.

In this analysis, the role of risk perceptions and risk preferences is assumed to relate to adoption decisions independently. This aspect would not hold if risk preferences and risk perceptions are closely linked. For example, farmers that are less willing to take risks might perceive risks differently by overweighting the probability of bad scenarios (e.g., Menapace et al., 2013). Furthermore, risk perceptions could be less important for more risk willing farmers (Trujillo-Barrera et al., 2016, Pennings and Wansink, 2004). To explore this aspect we use

[10] We can expect that risks over the continuation of the program (i.e., market risk) are correlated with risks over changes in the direct payments for the reduction of herbicides. In the Appendix we provide the results of the estimation with all sources jointly.

sequential g-estimation following the approach of Acharya et al. (2016) to identify whether there is a direct relation between risk preferences and adoption decisions that is not mediated by risk perceptions.

3.1 Robustness checks

We test for robustness of the main model presented in (5) in different ways. First, to acknowledge the nature of the dependent variable, we estimate a Probit model for the adoption outcome and a Generalized Ordered Logit for the adoption timing specification.[11] The second aspect is the concern of omitted variable bias. To address this possibility, we test whether our results are robust to the inclusion and exclusion of control variables to account for selection on observables and test for robustness to non-observables with Oster bounds (Oster, 2019). Third, we split the sample of farmers according to the share of wheat in their production system at the median and estimate Equation 7 for each of the two samples. This reflects that specialized and less specialized farms may perceive risks differently. Fourth, we limit the sample of farmers to those who did not participate in a pilot of the program in the 2018/19 season to reduce the concerns of reverse causality due to previous experience with the system.

4. Data

The data used in this analysis is publicly available and described in Möhring & Finger (2022a). It consists of a stand-alone survey of 1,073 Swiss wheat farmers in Switzerland that answered an online questionnaire on the determinants and challenges for adopting a pesticide-free production standard. The survey consists of two sections. The first section comprises questions regarding the participation in the pesticide-free wheat production program, and the second asks about the personal characteristics of the farmers and farms.

Given the cross-sectional nature of the data, we infer the timing of adoption by looking at the participation in the program in previous periods and the intention to join the program at a later point (See Table 2). The variable is constructed as a categorical variable that takes the value of 1 if farmer is an early adopter, the value of 2 if the farmer indicated that he/she participates in the next or future growing seasons, and the value of 3 if the farmer reports that will certainly

[11] In our case, the Generalized Ordered Logit is preferred to the Ordered Probit/Logit given the rejection of the parallel regression assumption. This is the case due to the dissimilarity of the ordered categories and the fact that the estimated coefficients are not equal across them. See (Williams, 2006) for a description of the method.

not participate. The variable can be interpreted as a propensity to postpone. Under this definition, the largest share of farmers is non-adopter located between taking the program at some point (45.4%) and not willing to take the program at any point (36.8%). On average in our sample, the measure for postponement takes the value of 2.2 (Table 3).

Table 2. Categorization of adoption timing

Value	Categories	%
1	Early Adopter	17.8
2	Adopt at some point	45.4
3	Never adopt	36.8
	N=1073	

Risk preferences

Risk attitudes are retrieved from willingness to take risks in four domains: plant protection, production, marketing and general agriculture.[12] This domain specific self-assessment follows, for example, Weber et al. (2002), and Meuwissen et al. (2001). We use a 11-point Likert scale assessment question following (Dohmen et al., 2005). In responses, higher numbers correspond to more risk loving decision makers (see Iyer et al. 2020, for an overview of further applications). The variable takes values from zero to ten. We consider the production risk preferences as our unique measure of risk willingness given that this domain shows the largest correlation with the other domains (See Figure 4 in Appendix). The average farmer in our sample is nearly risk neutral although there is important heterogeneity around neutrality (standard deviation is 2.4 in a scale from 0 to 10).

Table 3. Descriptive statistics

	(1)	(2)	(3)
Variables	Mean	Std.	Description
Adoption	0.63	-	Adopter (1/0)
Adoption timing	2.19	0.71	Range 1-3 (See Table 2)
Willingness to take risks	5.13	2.40	Range 0-10, Production Domain
Risk asssessments			
Perceived magnitude of yield decrease	3.06	1.34	Categorical, Range 1-5 (See Table 4)
Perceived probability of an increase in yield losses	2.93	1.29	Categorical, Range 1-4 (See Table 4)

[12] Appendix 8.2 reports the exact wording of the question.

Table 3. Descriptive statistics (continue)

Variables	(1) Mean	(2) Std.	(3) Description
Risk of yield decrease	3.18	1.22	Range 1 (not important)-5(very important)
Risk of more weeds in crop Rotation	3.97	1.13	
Risk of decreased wheat quality	3.39	1.25	
Risk of reduced price markups	3.28	1.22	
Risk of reduced direct payments	3.72	1.20	
Risk of investment	3.20	1.31	
Perceived magnitude of yield decrease	3.06	1.34	Categorical, Range 1-5 (See Table 4)
Perceived probability of an increase in yield losses	2.93	1.29	Categorical, Range 1-4 (See Table 4)
Farm characteristics			
Work force in farm	1.68	1.19	Units of labour force
Age of farmer	47.08	9.35	Age of farmer in years
Agricultural land	34.63	21.65	Hectares of agricultural land
Presence of weed species	0.48	0.29	Percentage of weed species in land (out of 21 types)
Share of wheat	0.16	0.11	Percentage of wheat in agricultural land
Arranged succession	0.67	-	Dummy variable (1/0)
Education of farmer	0.64	-	Has higher degree, i.e. “Meister” degree (1/0)
Language	0.22	-	Survey in French (1/0)
Machinery[b]	1.83	0.66	Categorical, Range 1(available) -3(not available at all)
Geograp. Information			
Share of mountainous area	0.05	0.20	Share of land
Yearly average of temperature	9	0.63	Mean 1971-2018, in °C
Historical mean of precipitation	703.54	73.77	Mean 2008-2018, in mm
Land suitable for grain cultivation	0.63	-	Dummy variable (1/0)
Herbicide resistance	0.11	0.33	Number of herbicide resistant variety in municipality of farmer
N=1,073			

[a]Geographic coverage of 17 Cantons. [b]Variable included as a categorical variable. Takes the value of 1 if machinery is available to farmer, 2 if it is not available but could potentially be, and 3 if it is not available and there are no means of acquisition. [c] Description of all control variables in Appendix 8.2.

Risk perceptions

Farmers were asked to assess how risky is the investment in machinery and to provide a reason for their assessment.[13] From this assessment, we can capture four domains of risk, namely, production, market, investment and institutional risks.[14] Production risks are measured with fears over high yield loss in wheat production without pesticides, high weed pressure in other cultures of the crop rotation, and quality risk. Market risks are measured through fears over the continuation of IP-SUISSE program, investment risks through fears over the profitability of investment and institutional risks through fears over changes in direct payments. The phrasing of the question includes the word *fear*, which sets these sources of risk in the domain of losses. Farmers report their views on these aspects on a scale that ranges from one (not important) to five (very important).[15] Values below 3 would suggest that the risk source is not important for the farmer, while values above that threshold suggest relevant risks (See Table 3 in Appendix for a description of these variables). The distribution of the risk assessments is shown in Figure 5 in Appendix.

In addition to domain-specific risk perceptions, farmers were asked to express their expectations over the magnitude of the yield decrease and the probability of crop failure or low yield when adopting. [16] The specific phrasing is presented in Table 4.

Table 4. Risk perceptions phrasing: magnitude and probability

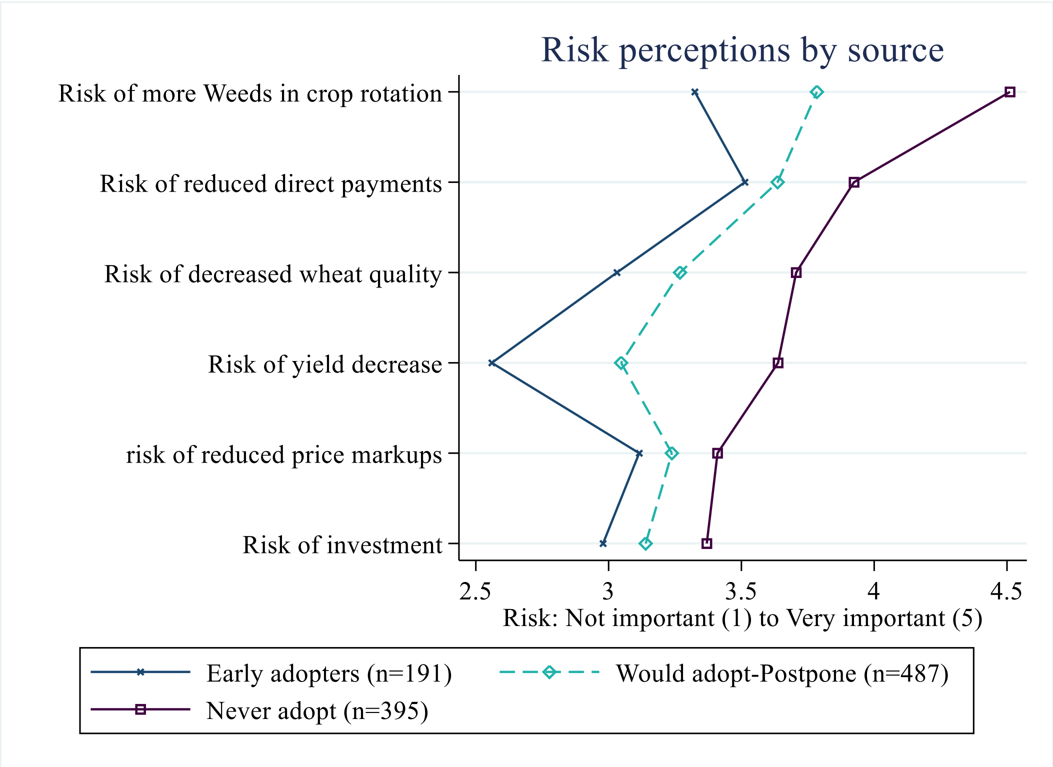
Perceived magnitude of yield decrease	**Perceived probability of an increase in yield losses**
I would expect with the conversion (...) that in the long term my average wheat yield (dt/ha) will…	*Due to the conversion, I expect…*
1)…not change.	1)…No increase in bad years
2)…decrease by 0-5%.	*An additional "bad year" (with complete crop failure/ very low yield) every…*
3)…decrease by 5-10%	2)…20 years.
4)…decrease by 10-15%	3)…10 years
5)…decrease by more than 15%.	4)…5 years.

[13] Appendix 8.2 reports the exact wording of the question.
[14] See OECD (2009) for the categorization of risks.
[15] Similar risk assessments have been used previously in the literature (e.g., Flaten et al., 2005; Menapace et al., 2013; Meuwissen et al., 2001).
[16] The perceived frequency (or probability) and perceived magnitude of the loss is a common simplification of risk perceptions. For example, Pennings et al. (2002) describes these components as "perception of the uncertainty" and "seriousness of adverse consequences", respectively. A fully specified characterization of risk would require the complete (subjective) probability distribution of the returns of the new production system. Attanasio (2009) offers a discussion on the elicitation of expectations and perceptions.

5. Results

Figure 2 shows the average perceived risk level for each domain across three groups of farmers, namely, early adopters, farmers that delay adoption and farmers that would never adopt. For all groups of farmers, risks over weed in crop rotation and changes in direct payments are the most important. As expected, risk perceptions are lowest for early adopters and highest for never adopters. For this last group, institutional risks seem to be the most important source of risk after risks over weeds in crop rotation.

Figure 2. Risk sources by farmer's adoption status



All differences are significant with only three exceptions: Direct payments, IP-SUISSE program and investment risk between early adopters and farmers that postpone (See Table 8 in appendix)

Next, we show how risk perceptions and risk preferences relate to the adoption and adoption timing of the pesticide-free system. Table 5 shows the results of the estimation of Equation (5) for adoption and Table 6 for adoption timing. Results include the complete set of control variables (See Table 3).

The main results are as follows. First, farmers tend to postpone less and adopt more likely, the more risk willing they are. An increase in one unit in the risk willingness scale from 0 to 10, is related to an increase in adoption by 2 to 3 percentage points (Table 5). Second, production risks are associated with the decision to adopt and to delay adoption (column 1). In terms of magnitude, an increase in one unit in the risk assessment of weeds in crop rotation is associated with a decrease of 11 percentage points in adoption. Third, risks of changes in federal direct payments are related with less adoption and more postponement, while market risks and investment risks do not seem to play a role in farmers' adoption decisions (column 2-4). Finally, while the expected yield decrease is not of relevance for farmer's decision, the expected probability of yield losses and crop failure is highly significant. The higher the perceived probability of yield losses, the higher the postponement is (column 5).

Table 5. Estimation results per domain of risk: outcome adoption

DependentVariable: Adopt No/Yes (0/1)	(1)	(2)	(3)	(4)	(5)
Willingness to take risks (0-10)	0.02***	0.03***	0.03***	0.03***	0.02***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
Perceived risks					
Risk of yield decrease	-0.03**				
	(0.02)				
Risk of more weeds in crop	-0.11***				
	(0.01)				
Risk of decreased wheat quality	-0.01*				
	(0.01)				
Risk of reduced price markups		-0.01			
		(0.01)			
Risk of reduced direct payments			-0.03**		
			(0.01)		
Risk of investment				0.00	
				(0.01)	
Perceived magnitude of yield decrease					-0.00
					(0.01)
Perceived probability of an increase in yield losses					-0.07***
					(0.01)
Constant	1.52**	1.20	1.26*	1.11	1.22*
	(0.67)	(0.70)	(0.72)	(0.72)	(0.66)
Set of controls					
Canton Dummies	✓	✓	✓	✓	✓
Farm/farmer level	✓	✓	✓	✓	✓
Geographic	✓	✓	✓	✓	✓
Observations	1,073	1,073	1,073	1,073	1,073
R-Squared (Adjusted)	0.20	0.11	0.12	0.11	0.14

[a] Clustered- robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

We explore whether the relation between risk preferences and adoption is mediated by risk perceptions. Results from the g-estimation (i.e, Acharya et al. (2016) approach), suggest that risk preferences have a direct relation with adoption and adoption timing that is not mediated by risk perceptions, regardless of what domain and measure is considered as mediator (See Figure 3). This means that risk perceptions alone cannot explain the lower adoption and higher postponement of those farmers who have a low willingness to take risks. The result instead points towards the existence of other mediators.

Table 6. Estimation results per domain of risk: outcome Postpone

Dependent Variable: Postpone (1-3)					
Early adopter/Postponer/never adopter	(1)	(2)	(3)	(4)	(5)
Willingness to take risks (0-10)	-0.02***	-0.04***	-0.03***	-0.04***	-0.03***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Perceived risks					
Risk of yield decrease	0.07***				
	(0.02)				
Risk of more weeds in crop	0.16***				
	(0.02)				
Risk of decreased wheat quality	0.01				
	(0.02)				
Risk of reduced price markups		0.03			
		(0.02)			
Risk of reduced direct payments			0.05**		
			(0.02)		
Risk of investment				-0.01	
				(0.02)	
Perceived magnitude of yield decrease					0.02
					(0.02)
Perceived probability of an increase in yield losses					0.10***
					(0.02)
Constant	0.97	1.43	1.35	1.61	1.44
	(0.95)	(1.03)	(1.07)	(1.06)	(0.96)
Set of controls					
Canton Dummies	✓	✓	✓	✓	✓
Farm/farmer level	✓	✓	✓	✓	✓
Geographic	✓	✓	✓	✓	✓
Observations	1,073	1,073	1,073	1,073	1,073
R-Squared (Adjusted)	0.24	0.15	0.15	0.14	0.17

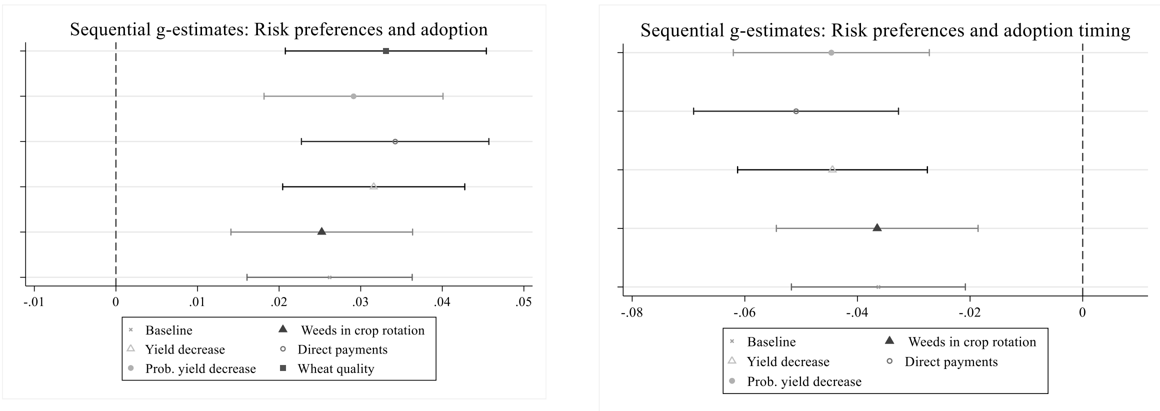
Clustered robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Robustness Checks

First, we estimate a Probit model for the outcome adoption (Table 10) and an ordered Probit model for the adoption timing outcome (Table 11) and find that the estimators for production and institutional risks are robust. Second, we test for selection on observables and find that the coefficients for production risks are more robust than the institutional risks (See Table 13 and

Table 14). In particular, the coefficient of risks of yield decrease does not change after the inclusion of farmer and farms' characteristics while the coefficients of weeds in crop rotation, and institutional risk change up to 29% in the different specifications. To further explore the stability of our coefficients, we follow the approach of Oster (2019) who proposes a test to assess whether unobserved controls have the potential of shifting the estimated coefficients towards (or away from) zero.[17] We find that non-observables would need to be more than twice as important as the rich set of used observables to bring the coefficient of risk preferences to zero (Table 6, Table 5). Similarly, the estimates of production and institutional risks are stable. For example, for risk of weeds in crop rotation, potential omitted variables would need to be at least 1.6 times as important as the observables to move the coefficient to zero (Table 6).

Figure 3. Sequential g-estimates for risk preferences



[a] Baseline estimation refers to the model that includes all risk perceptions at once. For testing the mediation of each of the risk perception variables, we set to intermediate confounders the other risk perceptions. Only significant risk perceptions are tested as mediators.

Third, we estimate the model for two samples of farmers according to the share of wheat in their production system (See Table 16 and Table 17). [18] Production risks remain to be important determinants of farmers adoption decisions. For farmers more specialized in wheat, the risk of weeds in crop rotation is twice as large as the estimator for farmers below the median. Given that the system is wheat and season specific, this result implies that farmers with more diversity in their production systems (i.e., producing wheat alongside other crops), have too lower fears over weed pressure. Institutional and market risks seem to be only relevant for farmers with less than 15% of wheat in their land, which could suggest a level of reliance of these farmers

[17] The test consists of the estimation of a parameter delta that measures the degree of selection on unobservable that would move the coefficients towards zero. For a true coefficient of zero (beta=0), a delta of one suggests that non-observables need to be as important (in terms of explanatory power) as the observables to move the coefficient to zero.
[18] In our sample the mean share of wheat is equal to 15%.

on the economic incentives provided by the government and the farmer's association, i.e., low economies of scale. Regardless of the wheat specialization level of farmers, the expected probability of yield losses and crop failures remain to be an important aspect for their adoption decisions (i.e., the coefficient has the same magnitude and significance across samples).

Finally, we find that results are robust when we restrict the sample to farmers who report risk perceptions about the program only prior to adoption. In our sample, 132 farmers adopted during the piloting of the system, which means that their risk perceptions might be influenced by their experience during these trials. After excluding these farmers from the analysis, the results remain robust in magnitude and significance. All in all, our results are robust to the model specification, selection on both observables and un-observables and different samples of farmers considered.

Discussion

We study the risk-related barriers for adoption of a pesticide-free production system in Switzerland. We find that risks over weed in crop rotation and changes in direct payments are the most important in farmers' risk assessments. Moreover, we observe that perceived risk levels in the production, market (i.e., price markups), institutional (i.e., federal direct payments) and investment domains are lowest for early adopters and highest for never adopters. This finding is in line with previous literature where risk perceptions differ for farmers under different production systems (e.g., Flaten et al., 2005; Koesling et al., 2004).

The pesticide-free wheat production system is based on a comprehensive set of incentives including marketing channels and related price mark-ups, and direct payments. There is an ongoing discussion in the literature of whether such tools and others such as cost sharing of conversion and marketing contracts should be used to encourage adoption of sustainable practices (e.g., Lohr & Salomonsson, 2000; Offermann et al., 2009; Ricome et al., 2016; Lefebvre et al., 2015). Läpple & Kelley (2013), for example, study the decision of Irish farmers to transition to organic farming and find that prospects of increasing farm income through support payments are more important than prospects of receiving higher prices. We find differences in the perceptions of risk coming from the durability of direct payments and price-markups and how they relate with adoption decisions. In particular, our main result is that despite the prevalence of several risks, only production and institutional risks are related with lower adoption and more waiting behavior.

Regarding production risks we focus on three measures, namely, risks over yields, weed pressure in crop rotation and quality risks. Only the first two are significant for the timing decision to adopt the pesticide-free wheat system. The result indicates farmers' expectation that renunciation of herbicides results in an increased competition of weeds with crops and thus, lower yields and higher production risks. Risks over wheat quality, relevant for revenues in Switzerland, ranked third and above the risks over wheat yields, but the estimate is small. This result can be explained because the main aspects of wheat quality relevant for the Swiss market (e.g., protein content, baking quality) are not affected mainly by pesticide use.

The risk literature usually distinguishes between the magnitude and the probability of a risk scenario. There is evidence, for example, that people have a preference for risk coming from the probability of winning over the risk coming from the magnitude of the reward (See, e.g., Bruner, 2009)[19]. Our result conforms to this idea and suggests that the expected probability of yield losses and crop failures is a strong predictor of farmers' adoption decisions while the magnitude of the expected yield loss is not.

We argue that the participation of different actors in the incentive schemes (i.e., federal government and farmers' associations), while desirable to foster pesticide-free agriculture, can also introduce collateral dimensions of risk, such as institutional risk (e.g., Kuminoff & Wossink, 2010). We find that the perceived risk over direct payments is significant- an increase in one unit in the risk perception scale is associated with a 3% increase in the probability that farmers never adopt. Although small in magnitude, this finding is in line with the literature that finds a key role of payments in the participation of agri-environmental schemes (e.g., Jaime et al., 2016).

In addition to receiving direct payments, farmers can sell their wheat with a price markup for pesticide-free production. Risks over the continuation of this marketing program translate to risks over the price markups and the marketing channels. Our results suggest that this risk is relatively important in farmers' risk assessment (with average importance of 3.28 out of 5) but is not significantly related to adoption and timing of adoption of this system. This finding is surprising, as price markups and direct payments are economically almost equally relevant (See Table 1). The farmers' organization IP-SUISSE has a long tradition in Swiss agriculture (i.e., more than 30 years). This tradition could increase the level of farmers' confidence in the viability of the production system led by this association. Moreover, the agricultural sector has experienced in the last few years, pressure to reduce the reliance on chemicals, specifically from the civil society through popular initiatives for pesticide policies (See Finger, 2021). This highlights the important role of trusted supply chain partners in the transition to pesticide-free production.

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[19] Bruner, (2009) study the preferences of risk averse individuals to changes in the probability of gains and the magnitude of the reward in a set of gambles. The set of preferences are elicited through an experiment with two settings in which the probability varies, and the reward is kept constant, and the contrary case.

Contrary to our hypothesis, we find that the perceived investment risk is not correlated with adoption and waiting behaviour, and specifically, once machinery availability is controlled for, perceived investment risk ceases to be significant. In our sample, we observe that investment risk perceptions adhere to the availability of weeding machinery, an important determinant for adoption. Finally, farmers tend to postpone more the more risk averse they are. This aspect is consistent with the empirical literature that finds a negative correlation between adoption and timing of adoption of organic agriculture and risk aversion (e.g., Läpple & Kelley, 2015; Hermann et al., 2016). Previous literature suggests that risk preferences play a role in decision making mainly through risk perceptions (e.g., Menapace et al., 2013). In contrast, we find that farmers' risk preferences have a direct relation with adoption and adoption timing that is not mediated by risk perceptions (i.e. their expected yield losses and risks).

There are important limitations in our analysis. For example, while we focus on risk, farmers might as well have uncertainty regarding the probability of different scenarios, leading to considerations of ambiguity and ambiguity aversion (Cerroni, 2020). These issues are beyond the scope of this paper but define an important research avenue in the adoption of agricultural innovations. Moreover, we identify system-specific risk assessments of a low-input agricultural scheme, but farmers are exposed to a wide range of risks, some not associated with adoption (i.e., background risk). Recent findings suggest that the presence of background risk reduces adoption of sustainable practices in the presence of foreground risk (i.e., risk associated with adoption) (Lefebvre et al., 2020). Future efforts could elicit risk perceptions for both types of risk to better characterize farmers' risk context.

6 Conclusion

Our analysis offers insights into the different dimensions of farmers' risk perceptions and preferences and explores how they are related to the adoption of a pesticide-free wheat production system. We conceptually and empirically illustrate the importance of risk preferences and attitudes for the uptake of pesticide-free production schemes using a large-scale survey on farmers' observed and intended adoption decisions. Our main result is that production and institutional risks and risk preferences are associated with lower adoption and waiting behavior, whereas market and investment risks do not seem to be relevant for farmers' decision-making. Additionally, we find evidence that the expected probability of yield losses and crop failures is related to less adoption while the magnitude of the expected yield loss is not.

Our findings have industry and policy implications. Reducing farmers' perceived risks in various domains associated with new production systems could encourage and accelerate their adoption. Industry and policy makers could address (perceived) production risks and institutional risks in different ways. First, communication channels to provide farmers with information and technical advice could reduce differences between perceptions of production risk and risk exposure. Moreover, our analysis implies that information about the system should focus on the potential frequency of yield losses, more than the potential magnitude of yield losses. Policy efforts can also reduce the production risk of farmers that adopt pesticide-free systems. This includes additional extension service on pest management, the design of production systems (e.g., specific crop rotations) and in general, the support of innovations that effectively reduce farmers reliance on pesticides in wheat and other crops in their production system (e.g., Jacquet et al., 2022 ; Walter et al., 2017). System-specific insurance solutions, for example, could increase the amount of risk farmers are able to tolerate and thus encourage adoption.

Moreover, in the presence of high perceived institutional risk and unexpected policy changes (Gardner, 2002), a stable regulatory framework for the use of pesticides and marketing channels could decrease the risks of conversion to pesticide-free agriculture (Schneeberger et al., 2002; Bouttes, et al, 2019; and Poortvliet & Lokhorst, 2016). Market acceptance by consumers could further reduce uncertainties about the system.

The current incentive scheme for pesticide-free wheat is constant across farmers' actual production risk levels under adoption. The implication of this setting is that farmers facing lower risks, adopt, while those exposed to higher risks, remain under their current practices. An important question that arises is whether incentive schemes can introduce risk considerations, for example, by categorizing farmers into adoption risk levels, e.g., though indices by objectively assessing different levels of pest pressure. This approach, moreover, could increase the efficiency of resources by allocating payments only where needed to encourage adoption (e.g., Fezzi et al., 2021). Answering this question deserves further attention in the empirical literature on the adoption and diffusion of low input agriculture.

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Appendix

8.1 Pesticide-free wheat production system

Requirements: i) have a proof of ecological performance (ÖLN), ii) use of untreated seeds, iii) avoid the use of pesticides (i.e., growth regulators, fungicides, herbicides, insecticides and chemical-synthetic stimulators of the natural immune system), and iv) ensure that at least one year passes between wheat and wheat on the same plot.

Wheat production:	**Conventional**	**Extenso**	**Pesticide-free (IP-Suisse)**	**Organic (Bio-Suisse)**
Growth regulators	✓	×	×	×
Fungicides	✓	×	×	×
Insecticides	✓	×	×	×
Chemical-synthetic stimulators	✓	×	×	×
Treated seeds with chemical-synthetic additives	✓	✓	×	×
Chemical-synthetic herbicides	✓	✓	×	×
Synthetic fertilizers (e.g., mineral nitrogen)	✓	✓	✓	×

Agricultural production without pesticides in Switzerland

A partnership between IP-SUISSE and Denner (a Swiss retailer), launched in early 2021 a program for winemakers to reduce the use of pesticides by 50%.[20] A collaboration between Migros- one of the largest retailer in Switzlerand- and an agricultural research institute (FiBL),

[20] Retrieved from: https://www.migros.ch/de/unternehmen/medien/mitteilungen/show/news/medienmitteilungen/2021/nachhaltigkeit-kernobst.html

has led to a program to support farmers in the production of pears and apples without pesticides.[21] These actions, sum to guidelines that farmers asssociations such as IP-SUISSE have for the abandonment of insecticides, fungicides and growth regulators in the production of rapeseed, potatoes, quinoa and sugarbeet add efforts for the production of different crops without pesticides.

8.2 Variables of interest

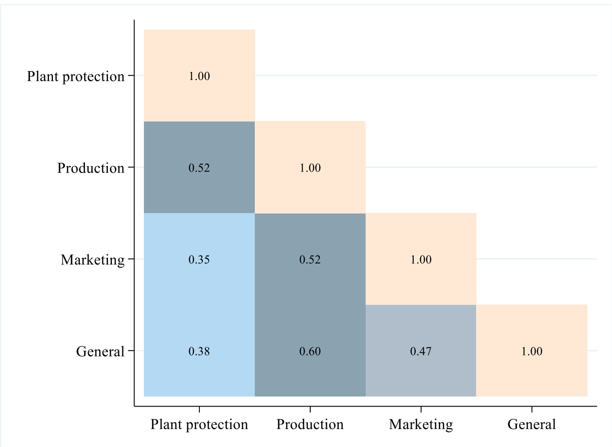
Risk preferences

Likert scale-type risk assessments have been extensively used in the literature. The advantage of these type of assessments is that they reduce the cognitive burden for individuals while retrieves meaningful patterns across risks (See Patrick, et al, 1985). We use such assessments for eliciting risk preferences and risk perceptions. In a Likert scale from 0 to 10 farmers answer to the question: "Do you avoid taking risks or are you willing to take risks in the following areas?"

- Plant protection
- Agricultural production
- Marketing
- Decisions on my farm (in general)

In Figure 4 it is shown that the domain with the highest correlation with other domains is agricultural production. Hence, we use this domain as our reference risk preference.

Figure 4. Risk preferences



[21] Retrieved from: https://www.lid.ch/medien/agronews/alle-agronews/lid-news/ip-suisse-auch-im-weinbau/

Risk perceptions

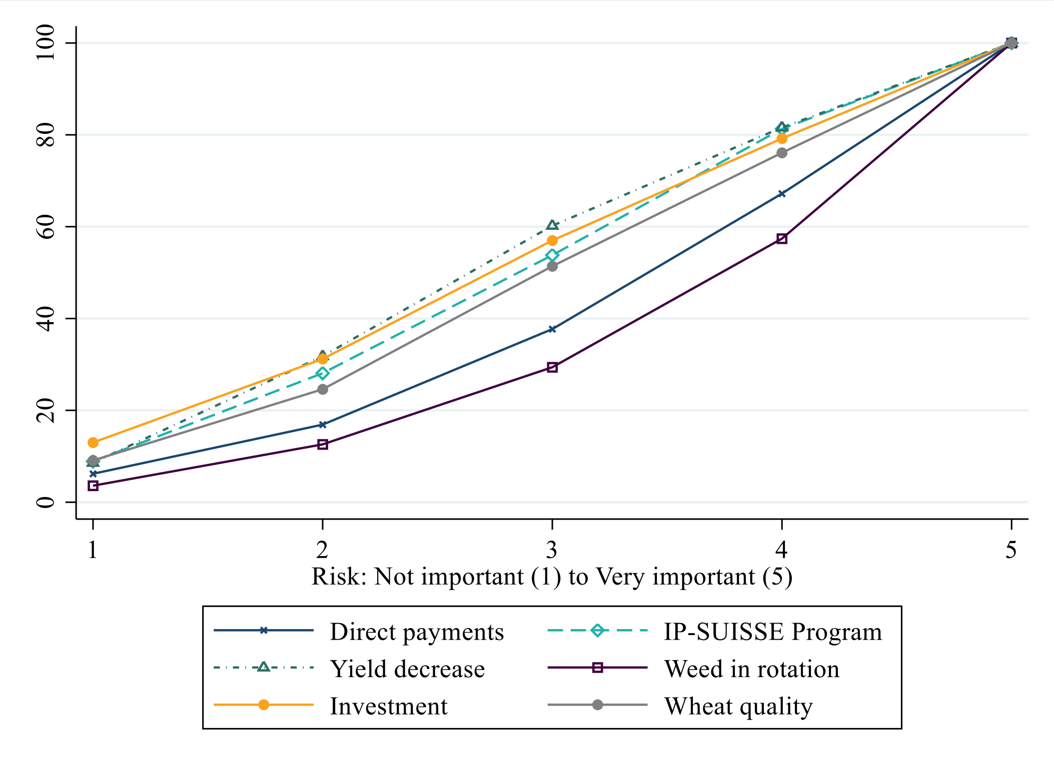
Risk perceptions were captured for four domains of risk as indicated in the following table.

Table 7. Risk perceptions phrasing

Domain	Question- Risk perception domain	Scale
Institutional	I fear that direct payment programs will change again (soon)	1= Not important 5= Important
Market	I fear that the IPSUISSE program will not be continued	1= Not important 5= Important
Production	I fear high yield loss in wheat production without PPP	1= Not important 5= Important
Production	I fear a high weed pressure in the other cultures of the crop rotation	1= Not important 5= Important
Investment	I fear that the machinery will not be used sufficiently (investment is not profitable)	1= Not important 5= Important
Production	Higher quality risk	1= Not important 5= Important

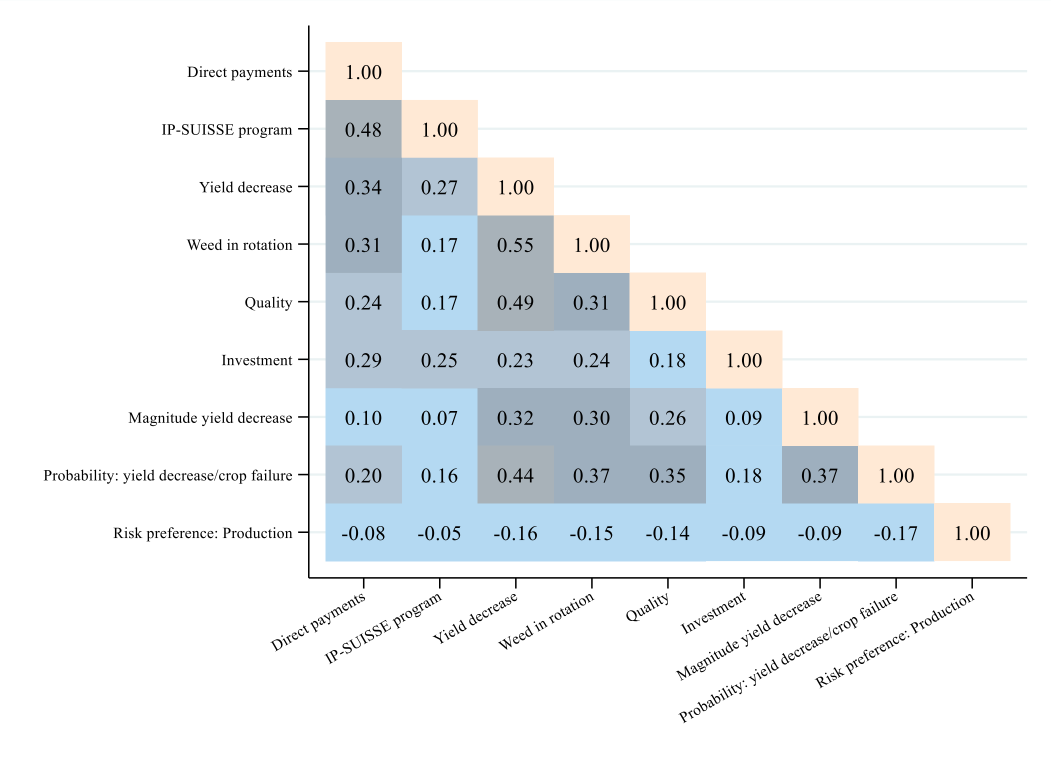
Figure shows the cumulative percentage of risk perceptions across levels. It is observed that risks over weeds in crop rotation and changes in the direct payments are the risks with the highest incidence of high-risk assessments (i.e., values four and five). The other sources of risk are similar to each other with a more uniform incidence across risk levels.

Figure 5. Cumulative percentage of risk perceptions



Observing the correlation between risk sources and risk preferences serves several purposes. First, to evaluate the validity of our risk perceptions variables, we observe the correlation between the risk perceptions elicited through Likert scales in the production domain with those elicited through categories of magnitude and probability of yield losses. We find that the correlation between the two types of measure is positive and mostly above 0.30.

Figure 6. Correlation between risk perceptions domains and risk preferences



Control variables

In our sample, the average farmer is 47 years old, has 35 hectares of agricultural land, and produces wheat in 16% of her agricultural land. A large percentage of farmers produce in lands suitable for grain cultivation (63%), approximately 67% have arranged succession, 64% have at least a "Meister" degree and 22% chose the survey in French. On average, farmers report 1.68 units of labour force in their farms. Availability of machinery is a categorical variable that takes the value of 1 if machinery is available to farmer, 2 if it is not available but could potentially be, and 3 if it is not available and there are no means of acquisition. On average, farmers tend to not have machinery available although consider possible to acquire.[22] Regarding weed control, farmers experience 48% of the 21 weed species present in wheat in their lands (See Böcker, et al 2019). Herbicide resistance is measured through the number of herbicide resistant varieties in the municipality of the farmer (See Möhring and Finger, 2021). On average farmers are exposed to 0.11 herbicide resistant kind of weeds.

Mostly, farms in our sample are located outside the mountainous area. On average, the share of land in mountainous area is 5%. Temperature is considered through two variables: the historical mean of yearly averages of temperature between 1971 and 2018 that on average is 9 °C for our sample of farmers, and the historical mean of precipitation between 2008 to 2018 that has a mean of 704 mm.

Table 8. Difference of means for two groups (paired t-test)

Test of differences:	**Early adopters vs would adopt**			**Would adopt vs Never adopter**		
Variable/ Group	Early adopter	Would adopt	Difference	Would adopt	Never adopter	Difference
feardirect	3,51	3,64	-0,12	3,64	3,92	-0,29***
	(1,29)	(1,15)		(1,15)	(1,20)	
fearipprogram	3,12	3,24	-0,12	3,24	3,41	-0,17**
	(1,29)	(1,16)		(1,16)	(1,26)	
fearyield	2,56	3,05	-0,49***	3,05	3,64	-0,59***
	(1,15)	(1,14)		(1,14)	(1,18)	
fearweedrotation	3,32	3,78	-0,46***	3,78	4,51	-0,73***
	(1,20)	(1,10)		(1,10)	(0,86)	
fearinvprofit	2,98	3,14	-0,16	3,14	3,37	-0,23***
	(1,33)	(1,26)		(1,26)	(1,34)	
partimport_qualityrisk	3,03	3,27	-0,24**	3,27	3,71	-0,44***
	(1,17)	(1,21)		(1,21)	(1,28)	

Standard errors in parenthesis *** p<0.01, ** p<0.05, * p<0.1.

8.3 Estimations

Table 9. All risk sources estimated jointly

	(1)	(2)
Dep. Var:	Adopt (0/1)	Postpone(1-3)
Willingness to take risks (0-10)	0.01***	-0.02***
	(0.00)	(0.01)
Perceived risks		
Yield decrease	-0.03*	0.07***
	(0.02)	(0.02)
Weeds in crop rotation	-0.11***	0.16***
	(0.01)	(0.02)
Wheat quality	-0.01	0.01
	(0.01)	(0.02)
IP-SUISSE program	0.00	-0.00
	(0.01)	(0.02)
Direct payments	0.01	-0.01
	(0.01)	(0.01)
Investment	0.03**	-0.05**
	(0.01)	(0.02)
Magnitude: Yield decrease	0.02	-0.01
	(0.01)	(0.02)
Probability: yield losses	-0.04**	0.04*
	(0.01)	(0.02)
Constant	1.44**	1.10
	(0.68)	(0.96)
Observations	1,073	1,073
R-squared	0.23	0.28
R adjusted	0.20	0.25

Clustered- robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. All set of control variables are included: canton dummies, farm and farmer characteristics and geographic controls.

8.4 Robustness

Estimation of Probit and Generalized Ordered Logit models

Table 10. Probit estimation (marginal effects only)

Dep. Var: Adopt (0/1)	(2)	(4)	(6)	(8)	(10)
Willingness to take risks (0-10)	0.02***	0.03***	0.02***	0.03***	0.02***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Perceived risks					
Risk of yield decrease	-0.03**				
	(0.01)				
Risk of more weeds in crop	-0.11***				
	(0.02)				
Risk of decreased wheat quality	-0.01**				
	(0.01)				
Risk of reduced price markups		-0.02			
		(0.01)			
Risk of reduced direct payments			-0.03***		
			(0.01)		
Risk of investment				0.00	
				(0.01)	
Perceived magnitude of yield decrease					-0.00
					(0.01)
Perceived probability of an increase in yield losses					-0.08***
					(0.01)
Set of controls					
Canton Dummies	✓	✓	✓	✓	✓
Farm/farmer level	✓	✓	✓	✓	✓
Geographic	✓	✓	✓	✓	✓
Observations[a]	1,072	1,072	1,072	1,072	1,072

[a] One observation excluded from the analysis refers to one cluster with only one observation, for which adoption is fully explained by the dummy variable. Clustered- robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 11 reports the marginal effects of the Generalized Ordered Logit model in relation to the category of “Never adopt”.

Table 11. Ordered Probit estimation (marginal effects reported with respect to never adopters)

Dep. Var: Postpone(1-3)	(1)	(2)	(3)	(4)	(5)
Willingness to take risks (0-10)	-0.02***	-0.03***	-0.03***	-0.03***	-0.02***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
Perceived risks					
Risk of yield decrease	0.04***				
	(0.02)				
Risk of more weeds in crop	0.14***				
	(0.02)				
Risk of decreased wheat quality	0.01				
	(0.01)				
Risk of reduced price markups		0.02			
		(0.01)			
Risk of reduced direct payments			0.04***		
			(0.01)		
Risk of investment				-0.00	
				(0.01)	
Perceived magnitude of yield decrease					0.00
					(0.02)
Perceived probability of an increase in yield losses					0.09***
					(0.01)
Set of controls					
Region Dummies	✓	✓	✓	✓	✓
Farm/farmer level	✓	✓	✓	✓	✓
Geographic	✓	✓	✓	✓	✓
Observations	1,073	1,073	1,073	1,073	1,073

Clustered- robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Canton Dummies are replaced with region dummies due to convergence.

Table 12. Generalized Ordered logit estimation (estimates)

Binary logistic regression Dep. Var: Postpone(1-3)	(1) > 1	(2) > 2	(3) > 1	(4) > 2	(5) > 1	(6) > 2	(7) > 1	(8) > 2	(9) > 1	(10) > 2
Willingness to take risks (0-10)	-0.04	-0.09***	-0.08*	-0.13***	-0.08*	-0.13***	-0.08*	-0.13***	-0.07	-0.11***
	(0.04)	(0.02)	(0.04)	(0.02)	(0.04)	(0.02)	(0.04)	(0.02)	(0.04)	(0.02)
Perceived risks										
Risk of yield decrease	0.40***	0.19***								
	(0.09)	(0.07)								
Risk of more weeds in crop rotation	0.33***	0.66***								
	(0.09)	(0.08)								
Risk of decreased wheat quality	-0.02	0.06								
	(0.11)	(0.04)								
Risk of reduced price markups			0.11*	0.07						
			(0.06)	(0.06)						
Risk of reduced direct payments					0.13	0.16***				
					(0.08)	(0.05)				
Risk of investment							-0.07	-0.00		
							(0.07)	(0.06)		
Perceived magnitude of yield decrease									0.11	0.02
									(0.09)	(0.07)
Perceived probability of an increase in yield losses									0.18***	0.40***
									(0.06)	(0.07)
Constant	3.42	-2.91	5.48*	0.93	5.30*	0.32	6.18*	1.30	5.06	-0.27
	(3.07)	(3.03)	(3.12)	(3.24)	(3.19)	(3.35)	(3.27)	(3.40)	(3.17)	(3.14)
Observations	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073

Clustered- robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Odd columns represent the binary logistic regression that contrasts category 1 versus 2 and 3 (> 1), and even columns the binary regression that contrasts category 1 and 2 versus 3 (> 2). Positive coefficients mean that higher values of the explanatory variable are associated with a higher probability that farmer will be a postponer or never adopter (i.e., category > 1) or never adopter (category > 2).

Table 13. Robustness: Inclusion of control variables for adoption timing outcome

Dep. Var: Postpone(1-3)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Willingness to take risks (0-10)	-0.03***	-0.03***	-0.02***	-0.05***	-0.05***	-0.04***	-0.05***	-0.05***	-0.03***	-0.05***	-0.05***	-0.04***	-0.04***	-0.04***	-0.03***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Perceived risks															
Risk of yield decrease	0.07**	0.08***	0.07***												
	(0.02)	(0.03)	(0.02)												
Risk of more weeds in crop	0.19***	0.19***	0.16***												
	(0.02)	(0.02)	(0.02)												
Risk of decreased wheat quality	0.02	0.02	0.01												
	(0.02)	(0.02)	(0.02)												
Risk of reduced price markups				0.05**	0.04**	0.03									
				(0.02)	(0.02)	(0.02)									
Risk of reduced direct payments							0.07***	0.07***	0.05**						
							(0.02)	(0.02)	(0.02)						
Risk of investment										0.05***	0.05***	-0.01			
										(0.01)	(0.01)	(0.02)			
Perceived magnitude of yield decrease													0.04	0.04	0.02
													(0.02)	(0.03)	(0.02)
Perceived probability of an increase in yield losses													0.13***	0.13***	0.10***
													(0.02)	(0.02)	(0.02)
Constant	1.29***	1.30***	0.97	2.28***	2.33***	1.43	2.17***	2.23***	1.35	2.26***	2.29***	1.61	1.86***	1.89***	1.44
	(0.07)	(0.08)	(0.95)	(0.06)	(0.07)	(1.03)	(0.07)	(0.08)	(1.07)	(0.04)	(0.05)	(1.06)	(0.08)	(0.08)	(0.96)
Set of controls															
Canton Dummies		✓	✓		✓	✓		✓	✓		✓	✓		✓	✓
Farm/farmer level			✓			✓			✓			✓			✓
Geographic			✓			✓			✓			✓			✓
Observations	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
R-squared	0.18	0.19	0.27	0.03	0.05	0.17	0.04	0.06	0.17	0.04	0.05	0.17	0.10	0.11	0.20
R adjusted	0.18	0.18	0.24	0.03	0.03	0.15	0.04	0.04	0.15	0.03	0.04	0.14	0.10	0.09	0.17

Clustered- robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 14. Robustness: Inclusion of control variables for Adoption outcome

Dep. Var: Adopt (0/1)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Willingness to take risks (0-10)	0.02***	0.02***	0.02***	0.03***	0.03***	0.03***	0.03***	0.03***	0.03***	0.03***	0.03***	0.03***	0.02***	0.02***	0.02***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
Perceived risks															
Risk of yield decrease	-0.04**	-0.04**	-0.03**												
	(0.02)	(0.02)	(0.02)												
Risk of more weeds in crop	-0.12***	-0.12***	-0.11***												
	(0.01)	(0.02)	(0.01)												
Risk of decreased wheat quality	-0.02*	-0.02*	-0.01*												
	(0.01)	(0.01)	(0.01)												
Risk of reduced price markups				-0.03**	-0.03*	-0.01									
				(0.01)	(0.01)	(0.01)									
Risk of reduced direct payments							-0.05***	-0.04***	-0.03**						
							(0.01)	(0.01)	(0.01)						
Risk of investment										-0.03***	-0.03***	0.00			
										(0.01)	(0.01)	(0.01)			
Perceived magnitude of yield decrease													-0.02	-0.01	-0.00
													(0.02)	(0.02)	(0.02)
Perceived probability of an increase in yield losses													-0.09***	-0.09***	-0.07***
													(0.01)	(0.01)	(0.01)
Constant	1.18***	1.19***	1.52**	0.56***	0.56***	1.20	0.64***	0.62***	1.26	0.57***	0.58***	1.11	0.82***	0.83***	1.22*
	(0.04)	(0.04)	(0.67)	(0.04)	(0.04)	(0.70)	(0.03)	(0.04)	(0.72)	(0.03)	(0.04)	(0.72)	(0.04)	(0.05)	(0.66)
Set of controls															
Canton Dummies		✓	✓		✓	✓		✓	✓		✓	✓		✓	✓
Farm/farmer level			✓			✓			✓			✓			✓
Geographic			✓			✓			✓			✓			✓
Observations	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
R-squared	0.16	0.17	0.22	0.03	0.06	0.14	0.04	0.06	0.14	0.04	0.06	0.14	0.10	0.11	0.17
R adjusted	0.15	0.16	0.19	0.03	0.04	0.11	0.04	0.05	0.12	0.03	0.04	0.11	0.09	0.10	0.14

Clustered- robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 15. Oster bounds: delta parameter

Outcome variables	**Adoption (0/1)**	**Postpone (1-3)**
Willingness to take risks (0-10)	2.96	2.66
Risk of yield decrease	0.8	1.17
Risk of more weeds in crop rotation	1.57	1.68
Risk of decreased wheat quality	0.72	0.43
Risk of reduced price markups	0.81	1.17
Risk of reduced direct payments	1.11	1.49
Risk of investment	-0.06	-0.13
Perceived magnitude of yield decrease	0.07	0.24
Perceived probability of an increase in yield losses	1.3	1.12

The maximum R squared in our model is 0.20 for the outcome adoption and 0.24 for outcome adoption timing. We add 1/3 of this to set the maximum R squared. This leads to an R-max of 0.27 for the first and 0.32 for the second, respectively.

Table 16. Robustness: Sample according to wheat share- Outcome adopt

Dep. Var: Adopt (0/1)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above
Share of wheat	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Willingness to take risks (0-10)	0.02**	0.01	0.03***	0.02**	0.02***	0.02**	0.03***	0.02**	0.02**	0.02
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Perceived risks										
Risk of yield decrease	-0.05*	-0.00								
	(0.02)	(0.02)								
Risk of more weeds in crop	-0.08***	-0.14***								
	(0.02)	(0.02)								
Risk of decreased wheat	-0.01	-0.02								
	(0.02)	(0.02)								
Risk of reduced price markups			-0.03*	-0.00						
			(0.01)	(0.02)						
Risk of reduced direct					-0.03**	-0.02				
					(0.01)	(0.02)				
Risk of investment							0.00	0.01		
							(0.03)	(0.02)		
Perceived magnitude of yield decrease									-0.00	-0.01
									(0.02)	(0.02)
Perceived probability of an increase in yield losses									-0.07***	-0.07***
									(0.02)	(0.02)
Constant	0.72	2.56***	0.52	2.12**	0.56	2.20**	0.36	2.10**	0.63	2.00**
	(0.92)	(0.84)	(0.91)	(0.90)	(0.97)	(0.89)	(0.90)	(0.92)	(0.85)	(0.86)
Observations	537	536	537	536	537	536	537	536	537	536
R-squared	0.23	0.26	0.15	0.17	0.15	0.17	0.15	0.17	0.18	0.20
R adjusted	0,18	0,21	0,10	0,12	0,10	0,12	0,09	0,12	0,12	0,15

Clustered- robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. All set of control variables are included: canton dummies, farm and farmer characteristics and geographic controls.

Table 17. Robustness: Sample according to wheat share- Outcome adoption timing

Dep. Var: Postpone(1-3)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above
Share of wheat	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Willingness to take risks (0-10)	-0.02*	-0.02	-0.04**	-0.03**	-0.03**	-0.03**	-0.04**	-0.04**	-0.03**	-0.03*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Perceived risks										
Risk of yield decrease	0.12**	0.01								
	(0.05)	(0.03)								
Risk of more weeds in crop	0.11***	0.22***								
	(0.03)	(0.03)								
Risk of decreased wheat	0.02	0.00								
	(0.03)	(0.03)								
Risk of reduced price markups			0.05*	0.01						
			(0.02)	(0.03)						
Risk of reduced direct					0.06**	0.03				
					(0.02)	(0.03)				
Risk of investment							0.01	-0.02		
							(0.04)	(0.03)		
Perceived magnitude of yield decrease									0.03	-0.00
									(0.03)	(0.02)
Perceived probability of an increase in yield losses									0.10***	0.08***
									(0.03)	(0.02)
Constant	2.22**	-0.37	2.52**	0.19	2.41*	0.11	2.76**	0.28	2.35**	0.38
	(0.92)	(1.17)	(1.04)	(1.28)	(1.14)	(1.27)	(1.00)	(1.32)	(0.90)	(1.27)
Observations	537	536	537	536	537	536	537	536	537	536
R-squared	0.28	0.31	0.16	0.22	0.17	0.22	0.16	0.22	0.20	0.24
R adjusted	0.22	0.26	0.11	0.17	0.11	0.18	0.10	0.17	0.14	0.19

Clustered- robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1 All set of control variables are included: canton dummies, farm and farmer characteristics and geographic controls.

Table 18. Robustness: Sample with ex-ante assessments only

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dep. Var:	Adopt (0/1)	Adopt (0/1)	Adopt (0/1)	Adopt (0/1)	Adopt (0/1)	Postpone(1-3)	Postpone(1-3)	Postpone(1-3)	Postpone(1-3)	Postpone(1-3)
Willingness to take risks (0-10)	0.02***	0.03***	0.03***	0.03***	0.02***	-0.02***	-0.03***	-0.03***	-0.03***	-0.02***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Perceived risks										
Risk of yield decrease	-0.03*					0.05***				
	(0.01)					(0.02)				
Risk of more weeds in crop	-0.11***					0.13***				
	(0.01)					(0.02)				
Risk of decreased wheat	-0.01					0.02				
	(0.01)					(0.01)				
Risk of reduced price markups		-0.02					0.03			
		(0.02)					(0.02)			
Risk of reduced direct			-0.03**					0.04*		
			(0.01)					(0.02)		
Risk of investment				-0.00					0.00	
				(0.01)					(0.02)	
Perceived magnitude of yield decrease					-0.00					0.02
					(0.02)					(0.02)
Perceived probability of an increase in yield losses					-0.08***					0.09***
					(0.01)					(0.02)
Constant	1.62**	1.24*	1.29*	1.17	1.29*	1.59*	1.49*	1.45*	1.61**	1.46**
	(0.72)	(0.71)	(0.73)	(0.73)	(0.68)	(0.87)	(0.73)	(0.77)	(0.74)	(0.65)
Observations	941	941	941	941	941	941	941	941	941	941
R-squared	0.20	0.13	0.13	0.13	0.16	0.20	0.13	0.13	0.12	0.16
R adjusted	0.17	0.09	0.10	0.09	0.13	0.17	0.09	0.09	0.09	0.13

Clustered- robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

All set of control variables are included: canton dummies, farm and farmer characteristics and geographic controls.

8.5. Parameters

We assumed a risk-free return of 5.3%. The rest of the parameters are assumed to be $X_0 = 0.85, \mu = 0.1$ after normalizing the investment to 1. From Böcker et al., (2019), Extenso yields are found to be in the range 32-69dt/ha. There, average yields under Pesticide-free system are estimated up to 6% lower than Extenso, with a maximum potential loss of CHF 192/ha. Considering the adjustment in the mark-up and the direct payment, the net profit ratio of pesticide-free and Extenso production is 1.19 (g^* in the figure).