Title: Short supply chains and the adoption of fungi-resistant grapevine varieties

Robert Finger, Lucca Zachmann, Chloe McCallum

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Abstract

The reduction of environmental and human health risks from pesticide use is on top of the policy agenda worldwide. Grapevine is one of the most intensive crops in terms of pesticide use in many parts of the world. The use of varieties that have increased resistance to fungal pressure could allow substantial reductions in pesticide use, but the adoption and diffusion of these varieties globally is still very limited. We here provide the first paper investigating the adoption of these varieties. More specifically, we investigate the farm-level adoption decision of resistant grapevine varieties in Switzerland and provide insights into the determinants and barriers for their wide-spread use. Using survey data from 775 producers, we especially investigate the relevance of marketing channels and especially short supply chains for the uptake of resistant varieties. More specifically, we test and quantify the relevance of specific channels by which grapes and wines reach consumers, such as direct marketing to consumers. We focus on both the uptake of resistant varieties and the extent of adoption. We find that 20.1% of the respondents use fungi-resistant varieties. However, the acreage under fungi-resistant varieties is only about 1.2%. Our results show positive associations of adoption and the use of marketing wine, not grapes. Moreover, we especially find that a specialized focus on direct marketing is associated with a higher uptake of fungi-resistant varieties. Our results narrow down to a simple conclusion: the more distant the producer is from the final consumer of wine, the less likely the producer will use fungi-resistant varieties. We draw policy conclusions how the uptake of resistant varieties could be stimulated, embedded in a bigger set of agricultural and food policies.

Introduction

The reduction of pesticide use is at the top of agendas in policy and industry (e.g. Möhring et al., 2020). Intensive use of pesticides harms both human health and the environment (Jones, 2020; Larsen and Noack, 2021; Stehle and Schulz, 2015). Grapevine is among the most intensive crops in terms of pesticide use in many parts of the world. In Switzerland, for example, the average number of treatments (10-16 per season) and the applied quantities of active substances (more than 20 kg per hectare) are among the highest of all crops (de Baan et al., 2015; Linder et al., 2006). The use of fungicides to cope with fungal diseases constitute the major pesticide use in vineyards.[1] Embedded in a set of integrated pest management practices (e.g. Barzman et al., 2015; Fernandez-Cornejo et al., 1998; Möhring et al., 2020), the use of varieties that are resistant to fungal pressure could allow substantial reductions in pesticide use and thus reduce risks for human health and the environment (e.g. Mailly et al., 2017; Pedneault and Provost, 2016). The adoption and diffusion of these varieties,

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[1] In Swiss vineyards, for example, the use of fungicides represents on average more than 80-90% of all pesticides treatments (de Baan et al., 2015).

however, globally is still very limited (Mailly et al., 2017; Montaigne et al., 2016; Pedneault and Provost, 2016).

In this paper, we provide the first study to reveal insights in determinants and barriers of the farm-level adoption of resistant grapevine varieties. Using survey data from 775 Swiss producers, we especially investigate the relevance of marketing channels and short supply chains for the uptake of resistant varieties. More specifically, we test and quantify the relevance of specific channels by which grapes and wines reach consumers, such as direct marketing.

Previous studies identified the large possible effectiveness of resistant cultivars to reduce fungicide use in vineyards (Montaigne et al., 2016; Pedneault and Provost, 2016; Viret et al., 2019). This affects conventional and organic wine production. The application of both synthetic and non-synthetic fungicides, including the widely used organic fungicide copper, have to be reduced drastically to meet policy goals (e.g. Mackie et al., 2012; Pedneault and Provost, 2016; Reiff et al., 2021). There has been a large progress in breeding new resistant varieties (e.g. Pedneault and Provost, 2016, Montaigne et al., 2016). Yet, the current adoption of resistant varieties is low, covering only some thousand hectares worldwide (see Pedneault and Provost, 2016, Montaigne et al., 2016 for an overview). The uptake differs, however, strongly across regions and production systems.[2] For example, the uptake of resistant varieties was found to be higher in organic vineyards, but is also limited (Pedneault and Provost, 2016). Overall, adoption rates of fungi resistant varieties are below socially optimal levels. A larger share of resistant varieties used would reduce environmental and human health impacts of grapevine production and would imply lower production costs for producers.

There is no empirical literature on the farm-level adoption of resistant grapevine varieties and determinants and barriers of adoption. However, previous studies identified that wine produced with resistant varieties may face marketing challenges (Fuller et al., 2014). For example, resistant cultivars have been reported to result in lower wine quality, at least as perceived by consumers (e.g. Ferreira et al., 2004). Thus, perceived low market opportunities are a limiting factor. Here, tradition also plays a role, particularly in prestigious wine regions where the adoption of resistant varieties is still low (Pertot et al., 2017). Moreover, fungi-resistant wines are cross breeds of popular/common varieties which consumers usually favour but fungi-resistant wine can only be sold with allusions to varieties (e.g. Chardonnay-like). Thus, this wine may be faced with additional market pressure and market risks. However, an increased societal demand for more environmentally friendly wine production has been reported recently (Cullen et al., 2013; Pomarici and Sardone, 2020; Pomarici and Vecchio, 2019). As market demand and breeding success are increasing rapidly, producers limited uptake of fungi-resistant varieties is increasingly the bottleneck towards more sustainable wine production. Thus, understanding farm-level adoption decisions is crucial for facilitating policy and industry measures to foster adoption and diffusion of resistant varieties and the resulting reductions in pesticide use in wine production.

We here contribute to filling this gap and provide the first study investigating the farm-level determinants of the adoption of resistant grapevine varieties. We conducted a survey that covers 775 Swiss wine producers (representing ca. 28% of all acreage under grapes in Switzerland). Our survey covers all language and winemaking regions of Switzerland, allowing us to distinguish different farm structures, climatic and cultural regions, and marketing methods. The latter allows us to test whether

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[2] In Switzerland, resistant varieties currently cover less than 2% of all area under grapevine, but the trend is increasing (Bundesamt für Landwirtschaft, n.d.).

short supply chains, e.g. direct marketing, enable more sustainable production practices. Farmers indicated which varieties they use and on which acreage, allowing us to identify the use of resistant varieties. We also use a rich set of farm and farmers' characteristics. Survey data is matched with data on environmental conditions, e.g. local information on weather conditions and pest pressure. We also match survey data with further socio-economic information that matters to explain uptake of specific marketing channels such as income per capita and the number of supermarkets per drinking-age population. We investigate how marketing channels affect the uptake of resistant varieties, controlling for a wide range of other factors.

We find that 20.1% of the respondents use fungi-resistant varieties. However, the acreage under fungi-resistant varieties is only about 1.2%. Our results show positive associations of adoption and the use of marketing wine, not grapes. Moreover, we especially find that a specialized focus on direct marketing is associated with higher uptake of fungi-resistant varieties. For example, if a producer has more than 50% of wine sales via direct marketing to consumers this increases the probability that they have fungi-resistant varieties by ca. 8%-38%. In contrast, producers who are specialized in marketing wines to retail are less likely to use fungi-resistant varieties. Our results narrow down to a simple conclusion: the shorter the supply chain and the closer the distance the producer is to the final consumer of wine, the more likely the producer will use fungi-resistant varieties. The identified associations are robust to the inclusion of various controls as well as controlling for omitted variable biases (e.g. using Oster bounds) and unobserved heterogeneity in the choice of marketing channels that we address by using a multinomial treatment effects model. Moreover, we find that producers that use resistant varieties are younger, have larger farms, a higher share of revenues from wine production for farm-level income and are more likely organic. Additionally, we find adopters to be more risk loving in both the marketing and production domain. Finally, we find that the use of fungi-resistant varieties is highly regionally specific within Switzerland. For example, uptake rates are higher in wine production regions in the German speaking part of Switzerland, Geneva and the Three Lakes region. In contrast, the uptake of fungi-resistant varieties is lower in wine production regions of Ticino, Valais, and Vaud.

The remainder of this paper is structured as follows. Next, we present a background on wine production in Switzerland and the role of resistant varieties. Then, we present a background on possible determinants and barriers of the adoption of resistant varieties and discuss the relevance of marketing channels. Based on this background we present the design of our survey as well as the regression analysis used. Next, we present our data and results. Finally, we conclude and provide policy conclusions.

Background on wine production and resistant varieties

Wine production is highly relevant for the Swiss agricultural sector. For example, the gross value of grape production in Switzerland was ca. 17% of the total crop production in 2012 (a higher share than in Italy), with a total of 15,000 hectares across highly diverse production regions covering a wide range of climatic zones and a large diversity of varieties used (Figure 1)[3] (Andersen et al., 2013; Anderson and Nelgen, 2012). Swiss wines are especially consumed within Switzerland and the market is structured in two segments. First, direct marketing where especially small family wineries sell most of their production directly to final consumers. Second, there are cooperatives and larger wineries that sell

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[3] With this acreage, Switzerland is the 20th largest global wine producer (Nelgen and Anderson, 2011).

mainly through supermarkets (Masset and Weisskopf, 2019). Most Swiss grapes are produced for winemaking, table grapes are usually imported, with a share of imports at ca. 99% (BioAkutell, 2017).

Swiss wine production is pesticide intensive. The (moist) climatic conditions especially require frequent application of fungicides. Analyzing a sample of ca. 500 vineyards over the period 2009-2012, de Baan et al. (2015) show that on average 10 pesticide applications (implying more than 20 kg of active ingredients applied per hectare)[4] take place (with the 1st quartile being 8; and the 3rd quartile being 13 applications per year). Among these applications, herbicide and insecticides use are usually 10- 20%. The remaining pesticide applications is fungicide use. The active ingredient Folpet was found to be especially relevant, reflecting 25% of applications (de Baan et al. 2015). The use of copper and sulfur that are also used in organic production represented 9-12% of all fungicide applications in the investigated Swiss grapevine production (de Baan et al., 2015).

Under the Swiss national action plan on pesticides, a 50% risk reduction in pesticide use is envisioned (e.g. Möhring et al., 2020, Finger, 2021). Also, the reduction of the use of copper is an explicit goal. Reducing fungicide use in vineyards here has a high leverage to achieve these goals and the use of resistant varieties is a major entry point in that respect. After the introduction of *P. viticola* (downy mildew) and *E. necator* (powdery mildew) from America to Europe at the end of the 19th century, growing traditional *Vitis vinifera* varieties was no longer possible without significant fungicide use (Pertot et al., 2017). Since then, efforts have been undertaken to cross resistant grapevine species (e.g. from the Americas or Asia) with traditional European varieties to obtain resistant varieties with traditional characteristics. Resistance is predominantly against powdery and downy mildew and grey rot (*Botrytis cinerea*) (Pedneault and Provost, 2016). Initially, these new or ‘hybrid’ varieties suffered from undesirable off-flavors. However, due to new breeding techniques which evolved radically over time, new resistant varieties with improved enological profiles have come to the market. Example varieties are Divico (0.28% from total plantation area in Switzerland), Regent (0.23%), Cabernet Jura (0.22%) or Solaris (0.17%) (Bundesamt für Landwirtschaft, n.d.). New breeding activities have been initiated by public research institutions (Spring and Dupraz, 2021).

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[4] Note that both number of application and quantity per hectare not necessarily indicate how problematic pesticide use is for human health and the environment (e.g. Möhring et al., 2019), but we can conclude that pesticide use in vineyards poses critical risks.

Figure 1. Vineyards and wine regions in Switzerland

Source: Schweiz Tourismus

The adoption of fungi resistant varieties provides possibly a triple benefit. First, reducing reliance on pesticide use poses environmental benefits. Fungicide applications in the here studied grapevine production systems in Switzerland are expected to be reduced by ca. 80%, i.e. to 2-4 applications, if fungi-resistant varieties are adopted (BioAkutell, 2020), compared to 10-16 without resistant varieties (de Baan et al., 2015; Linder et al., 2006, Viret et al. 2019). Along these lines, Rousseau et al., (2013) report possible reductions of fungicide use due to resistant varieties in France by 60 to 90%. This means lower environmental risks, reduced copper accumulation in soils and less soil compaction and emissions from spraying machines. Second, reduced fungicide applications imply reduced potential human health impacts on field workers and bystanders. Third, this also implies tangible cost reductions as expenditures for pesticides,labor and machinery costs can be reduced if less spraying events take place. Additionally, the risk of yield losses from fungal infections is lowered.

Yet, the current share of fungi resistant grapes is only ca. 1.9% in Switzerland (Offizielle Weinlesekontrolle der Kantone 2018).[5] However, there is a strong regional clustering within Switzerland. More specifically, Siegfried and Temperli (2008) indicate a higher adoption in German and Italian speaking Switzerland vis-à-vis French speaking wine production regions. Baumann (2019) conducted surveys with experts to identify key challenges of fungi resistant varieties in Switzerland. They find that lack of experience with different wine styles pose challenges for vinification and the marketing of new, unknown varieties and uncertainty in the choice of varieties have been identified as

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[5] Note that also in organic production, the uptake is limited. For example, resistant varieties covered only less than 8% of organic vineyard surface areas in 2003 in Germany (Sloan et al., 2010).

relevant. Experts also indicate that education, information and gaining experiences can be a way forward (Baumann, 2019).

Adoption of Resistant Grapevine Varieties and Marketing Channels

New grapevine varieties are only adopted if expected benefits exceed perceived costs. Especially relevant in the context of resistant varieties is the long-term nature of the investment, i.e. the lifetime of a plant is at least 20 to 30 years, and the associated uncertainties. Especially the large uncertainty about future costs and benefits arising from the use of resistant varieties due to the marketing potential is assumed to make adoption decisions, ceteris paribus, less attractive (see Spiegel et al., 2021).

Fungi-resistant varieties offer two main direct economic benefits for farmers.[6] Firstly, the number of fungicide applications is decreased massively, which reduces production costs due to less materials and labour (Rousseau et al., 2013). Secondly, yields are high and more vigorous due to fungi-resistance, i.e. production risk can be reduced (Siegfried and Temperli, 2008)[7].

The main cost of resistant varieties stems from marketing risks, i.e. the uncertainty regarding consumers' preferences and marketing channel stability, especially due to a lack of knowledge of new varieties. In a survey of fungi-resistant winegrowers in Germany, 40% stated that the varieties being unknown was the biggest difficulty of marketing the wine (Becker, 2013). Also, there is the perception that fungi-resistant wines are lower quality in terms of oenological characteristics. Yet, increasingly taste tests with consumers and producers show that they score just as well as traditional varieties (Rousseau et al., 2013). A study with Swiss consumers found 70-90% of participants rated fungi-resistant wine equivalent to conventional wine and 23-30% rated fungi-resistant wine as superior (Van Der Meer and Lévite, 2010).[8] Similarly, Siegfried and Temperli, (2008) report positive results from blind tastings on Swiss fungi-resistant wines. In contrast, on a sensory level French consumers had difficulty accepting wine from a resistant variety. However, after communicating the pesticide treatment frequency, type of viticulture and pesticide residues for several wine types, the wine from the resistant variety was ranked with the highest average quality evaluation (Espinoza et al., 2018). This highlights the importance of communication when marketing wine from resistant varieties. However, results from taste testing do not necessarily translate into wine sales. Previous studies found consumers are willing to pay less for organic wine (compared to conventional) and less for varieties they are not familiar with which is likely the case for many fungi-resistant varieties (Mann et al., 2012; Nesselhauf et al., 2019).

Marketing channels and especially shorter supply chains can contribute to overcoming obstacles mentioned above and thus can contribute to reducing marketing risks. For example, direct marketing of wine to consumer may facilitate efficient communication of characteristics of fungi-resistant

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[6] In addition to environmental and human health benefits that farmers also may value.

[7] Additionally, reduced health impacts on the producer themselves may provide short- and long-term economic benefits (e.g. Chatzimichael, 2021).

[8] Fungi-resistant wine were Solaris and Maréchal Foch and to conventional wine varieties were Zweigelt and Riesling (Van Der Meer and Lévite, 2010).

varieties and ensure stable marketing conditions. As consumer demand is uncertain, retailers and wholesalers may not be interested in fungi-resistant wine, they may prefer well established varieties. Farmers who sell their wine via direct marketing may be more likely to adopt fungi-resistant varieties as they are not constrained by retailers' preferences. In the former case, the adoption of fungi-resistant varieties is attractive because it allows for a 'winemaker's unique selling story', while in the latter case its adoption is unattractive because well-established quality criteria (like varieties, Parker points, geographic denominations, etc.) matter. For example, French grape growers who produce organic are more likely to sell through short supply chains (Aubert and Enjolras, 2016). In contrast, supply chain length had no influence on environmentally sustainable practices for French peach and apricot producers (Enjolras and Aubert, 2018).

Based on this background, our main hypothesis to be tested is that producers with shorter supply chains (direct marketing of their own wines vis-à-vis for example marketing of grapes or marketing via retailers) are more likely to engage in the cultivation of fungi-resistant grapevine varieties.

Moreover, additional characteristics of farms and farmers may affect adoption, which we consider as control variables in our empirical analysis. For example, the fungi pressure may reflect the expected benefits from adopting fungi-resistant varieties. Higher fungi-pressure may imply larger potential savings on fungicide use and labor costs if adopting fungi-resistant varieties. Environmental conditions at the farm influence the fungal pressure. Thind et al. (2004) show that humid conditions and free moisture in the form of dew or rain are supporting the infection of downy mildew and rainy conditions lead to their epidemic build up. On the contrary, powdery mildew requires relatively dry conditions and moderate temperature.

Furthermore, risk exposure and farmers' risk attitudes are also relevant, especially for long-term investments (e.g. Spiegel et al., 2021). More risky production system (e.g. uncertainty of yield or profit) are less likely adopted, especially by more risk averse farmers. For example, risk averse farmers have been found to be less likely to adopt organic farming practices and agri-environmental practices (Bougherara et al., 2017; Chèze et al., 2020; Kallas et al., 2010; Serra et al., 2008). This stems from the observation that usually, the more environmentally friendly farming practices lead to greater variability in yield and cost (Knapp and van der Heijden, 2018). Fungi-resistant varieties are an exception here, as they should reduce yield variability due to a reduced threat of fungi infection. Since they are risk reducing, risk averse farmers may be more likely to adopt (e.g. Ward and Singh, 2015). However, fungi-resistant varieties increase uncertainty in profits due to uncertainty of consumers' preferences. For this reason, the effect of risk attitudes may depend on the domain they are measured in as fungi-resistant varieties reduce the production risk but increase the marketing risk.

Additional farmer and farm characteristics may also affect adoption decisions. For example, younger farmers are often associated with more likely adoption of practices like organic production (Sapbamrer and Thammachai, 2021). But also, farm size has been found to be associated with adoption of new technologies and environmental-friendly farming practices like organic farming (Sapbamrer and Thammachai, 2021; Sunding and Zilberman, 2001). Moreover, the overall strategy of the producer may matter. Specifically, it may influence decisions whether production is mainly hobby and for own consumption vs professional use. In fact, non-professional wine production matters in Switzerland (e.g. they represent 11.4% of our sample).

Finally, characteristics of the market influence wine production decisions.[9] Resistant variety use may be connected to labels such as Geographical Indications (GI).[10] In Switzerland, the labelling system is appellation of origin (AOC/DOC). There are 62 AOCs/DOCs which are based on regions and the varieties allowed for each are decided at the canton level (see Appendix A). If a farmer sells their wine under the AOC label and the fungi-resistant variety they are considering adopting is not permitted, this will increase the cost of adopting.

Econometric Strategy

Econometrically, we aim to test and quantify the effect of the choice of marketing channels on the adoption of fungi-resistant grapevine varieties. To this end, we take three steps. First, we specify a simple Ordinary Least Squares (OLS) regression model. Second, we employ Oster bounds and a multinomial treatment effect model to account for potential sources of bias. Third, we conduct a series of additional robustness checks to validate our results.

Our initial specification uses a simple OLS specification, i.e.

$$(1)\quad RV_i = \alpha + \beta_{1,j} MC_{i,j} + x_i' \beta_2 + \tau_t + \omega_r + \varepsilon_i$$

We define the farm i as an adopter of resistant varieties (RV) if the farm has one or more fungi-resistant varieties grown on the farm[11], i.e.

$$(2)\quad RV_i = \begin{cases} 1 & \text{if fungi resistant grapes are grown on farm } i \\ 0 & \text{otherwise} \end{cases}$$

A key variable of interest for our analysis is the marketing channel j of farm i, $MC_{i,j}$. We consider three marketing channels. First, we identify whether producers sell unprocessed grapes or wine. Second, we identify which marketing channels farmers use to sell their wine, namely whether wine reaches consumers directly or via retail.[12] Retail includes sales to commerce and large distributors. For the sake of interpretative power, we codify the respective variable $MC_{i,j}$ as follows:

$$(3)\quad MC_{i,j} = \begin{cases} 1 \text{ if sales through marketing channel } j \text{ on farm } i > 50\% \\ 0 \text{ otherwise} \end{cases}$$

For example, if farm i sells the majority of its grapes as wine directly to consumers (e.g. share of direct marketing > 50%), Direct marketing equals 1 and remains 0 otherwise.[13]

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[9] Heritage and tradition also influence wine production decisions (De Steur et al., 2020). New varieties may be viewed as less traditional than well-established varieties acting as a disincentive for farmers to adopt.

[10] For example, under the EU GI system, resistant grape varieties can be used for Protected Geographical Indication wine but not for the stricter Protected Designation of Origin.

[11] In a robustness check, we also extend this to i) the share of the acreage under fungi-resistant varieties as well as ii) the number of fungi-resistant varieties used (see below).

[12] Although information about marketing wine via gastronomy is available, we do not consider it in the analysis due to only few observations.

[13] In a robustness check, we also account for marketing channel percentages, allowing for mutually non-exclusive marketing forms (e.g. a farm can sell wine through multiple marketing channels, see Appendix G). Note that some

In our analysis we aim to explain the adoption decisions with the marketing channels used, while controlling for structural components that may also affects the adoption decision (e.g. farm and farmer characteristics and environmental conditions).

Therefore, $x_i'$is a vector of farm-level controls, and τ_t is a dummy for the year of the survey to capture time-specific effects of the different (in total 3) years of data collection. In addition, we add dummy variables for the 6 wine regions in Switzerland (cp. Figure 1) ω_r to account for regional specificities in grapevine growing (e.g. tradition, grape choice, trellis systems).

We account for a wide range of control variables such as producer's age and gender, for farm size and production system (dummy indicating organic production). We also account for the relevance of viticulture in terms of income, by accounting for dummy variables identifying farms that earn less than 25% or more than 75% from viticulture, respectively. Additionally, we control for non-professional growers (e.g. those who cultivate grapes as a hobby, for private consumption or research purposes). We control for site-specific past powdery mildew infection risk (using the Oidium index from Dubuis et al., 2014), which proxies the necessity to use fungicides. We cluster error terms at the wine region level (Figure 1), which represents the important decision-making unit for labeling, marketing and coordination. Due to the low number of wine regions, we use a wild bootstrap approach (e.g. Wooldridge, 2003).

Omitted variable bias is a concern for our analysis. We try to approach this in several ways. Firstly, we account for a large set of farm and farmer characteristics and a rich set of environmental and regional characteristics. These covariates are chosen because they could possibly be correlated with the choice of resistant varieties. In addition, we estimate how much selection on unobservables would be required to explain away estimated relationships (Oster, 2019). The rationale of the test is that the larger selection on observables becomes, the greater our concern about selection in general, including on unobservables. Technically, we proceed as follows. The estimated coefficient of the specification that includes all control variables is denoted as $\hat{\beta}_F$. The estimated coefficients of a model specification without control variables is denoted as $\hat{\beta}_R$. The ratio of $\hat{\beta}_F$ to the difference $\left(\hat{\beta}_R - \hat{\beta}_F\right)$ gives an indicator for how much stronger selection on unobservables (δ^U) relative to selection on observables (δ^O) would need to be to fully explain away an estimated relationship (move the previously estimated coefficient to zero) $(\delta^{\beta=0})$:$\delta^{\beta=0} = \hat{\beta}_F / \left(\hat{\beta}_R - \hat{\beta}_F\right)$. See Oster (2019) for more information and Schaub (2020) for the here used implementation in R.

Another concern for our analysis is endogeneity. Specifically, the choice of a marketing channel may not be exogenous. For example, specific marketing channels could be associated with particular locations and types of farms, as well as with specific characteristics of producers which all may also correlate with the uptake of fungi-resistant varieties. We address this unobserved heterogeneity by using a multinomial treatment effects model (Deb and Trivedi, 2006a, 2006b). Specifically, we introduce latent factors (l_{ij}) in the treatment selection equation:

$$(4) \qquad EV_{i,j}^{*} = z_i'\alpha_j + \delta_j l_{i,j} + \vartheta_{i,j}$$

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marketing channels are mutually exclusive to each other, and we thus do not present a model with all marketing channels in one specification.

EV_{ij}^{*} denotes the indirect utility of farm i from specializing in marketing channel j. The latent utility is modelled with an exogenous vector of covariates (z_i') and latent factors (l_{ij}) that incorporate unobserved characteristics of individual i's marketing channel choice j and the uptake of fungi-resistant varieties. ϑ_{ij} are independently and identically distributed errors. The vector z_i' includes cantonal market characteristics ($C_{i,c}$) to proxy demand-side factors in addition to farm and farmer related variables collected in the survey. For example, to account for the fact that better access to consumers may facilitate marketing wine directly or to retail, we control for income per capita as well as the number of supermarkets per drinking age population (e.g. the number of individuals aged 18 or more) at the cantonal level. In addition, we consider that a higher willingness to take risks in the marketing domain may stimulate direct marketing and thus use risk preferences in the marketing domain (Knapp et al., 2021a).

Subsequently, we model the probability of each observed marketing channel choice ($d_{i,j}$), given exogenous (z_i') and latent factors ($l_{i,j}$), with a mixed multinomial logit structure[14]:

$$(5) \qquad \Pr\left(d_{i,j} \middle| z_i', l_{i,j}\right) = \frac{\exp(z_i' \alpha_j + \delta_j l_{i,j})}{1 + \sum_{k=1}^{J} \exp(z_i' \alpha_k + \delta_k l_{i,k})}$$

Tthe expected uptake equation of farm i of fungi-resistant grapes (RV_i) is then given by:

$$(6) \qquad E\left(RV_i \middle| d_{i,j}, x_i, l_{i,j}\right) = \alpha + \sum_{j=1}^{J} \gamma_j d_{i,j} + \sum_{j=1}^{J} \lambda_j l_{i,j} + x_i' \theta$$

where γ_j measures the effect of marketing channel j on the uptake decision of fungi-resistant varieties of farm i. As such, the uptake of fungi-resistant varieties is affected by unobserved characteristics that affect both the uptake and the choice of a marketing channel, and are estimated with the parameter λ_j (Deb and Trivedi, 2006b).

Finally, we conduct a series of further robustness checks to explore the stability of our findings. First, we use logit and probit specifications to estimate the model in equation 2. Second, we use percentages values of the relevance of respective marketing channels (direct marketing or retail) instead of binary dummies. Third, we investigate the extent of the adoption, i.e. we go beyond the 0/1 decision. We use two alternative specifications, a) the area under fungi-resistant varieties and b) the number of fungi-resistant varieties at the farm[15]. Third, we apply the estimation for several sample splits. We split the sample by language regions (German, French, Italian). Next, we split by spatial past powdery mildew infection risk, i.e. splitting high and low infestation risk regions (using the Oidium index distribution (Dubuis et al. 2014)). This allows differences in adoption determinants within our sample to be explored.

Data

We use data collected by an online survey to Swiss grape growers. Surveys, datasets and the codebooks describing the variables are publicly available (see Knapp et al., 2019). Surveys were sent via a link provided to the growers by email in collaboration with several Swiss cantonal agricultural services as well as via information leaflets issued by Agroscope (the Swiss Center of excellence for agricultural

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[14] The base group is defined as $j = 0$ with $EV_{i0}^{*} = 0$ (Deb and Trivedi, 2006b).

[15] We also used a Tobit specification for both instead of OLS and find similar results in terms of significance and coefficients.

research). The survey was conducted in the three main official languages of Switzerland (i.e. German, French and Italian). Surveys were pre-tested with fifteen experts from cantonal advisory services.[16]

The survey collected detailed information on the grapes used by each producer, providing a menu of the 30 most widely used grapes in Switzerland, where producers indicated the acreage on their farm for each variety. Producers could add further varieties manually as an open-text answer. These answers were harmonized in a subsequent step. To identify fungi-resistant varieties from this information, we follow the Bundesamt für Landwirtschaft (n.d.) (see Appendix A for details).

In total, we rely on responses from 775 different producers, which is about 21% of total Swiss grape growers. Main production regions are covered, and farm and farmer characteristics are line with the population at large (see Knapp et al., 2021b). Our collected data represents around 28% of all the area under grapes in Switzerland, i.e. 4’092 ha. Furthermore, we find that the share of resistant varieties in our sample (1.2%) is smaller than at national level but still representative (1.9% at national level) (see Appendix B for details).

We also collected how grapes are marketed (e.g. direct marketing or retail). To this end, we first asked producers which share of grapes is marketed as grapes (i.e. they sell grapes to an association or a large wine producer) or as wine (i.e. they sell the final product). Moreover, we also asked the share of their produced wine that is marketed via direct marketing, commerce and major distributors. The latter two are summarized as ‘retail’ in our study. These variables are transformed into binary variables used to characterize the marketing channel used (see previous section). Specifically, we define dummy variables that identify farms which sell the majority of their wine directly to consumers or to retail, respectively. Therefore, we refer to farms whose sales share is larger than 50% as specialized in direct marketing or to retail.

Farm characteristics were also included in the surveys such as the location (using the postal code) of the farm, the specialization of the farm (mixed or specialized), the production system (organic/conventional), the farms total work force availability, the total farmland, the share of farmland rented out and use of hail and/or frost insurance. We also collected the percentage of earnings coming from farming as well as how much grape production contributes to the farm-level total earnings. We match, based on the farms’ postal code, past[17] powdery mildew infection risk data from 92 weather stations to our sample. This risk index, the Oidium index, calculates infection risk from powdery mildew based on meteorological conditions (temperature, precipitation, and relative humidity) and the ontogenic resistance of the bunches to infection (Dubuis et al., 2014). For example, the organs and tissues of the grapevines have different infection sensitivity during their development stages. Therefore, infection risk is highest in June/July and decreases towards harvest (end of August-October, depending on year, variety and location). This Oidium indicator shows that infection risk is lower in Valais and Ticino, compared to Geneva or the German-speaking part of Switzerland (see Appendix C for details). In addition, we also match observations with income per capita as well as the share of drinking age population (e.g. the share of individuals aged 18 or more) at the cantonal level.

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[16] The survey was conducted in 3 years 2016, 2017 and 2018. For the purpose of the here presented analysis, we created a cross sectional dataset by using only one observation for each producer if they participated in more than one year. We use the last entry of those producers that responded in multiple years.

[17] We average the station-level data over the years 2012 until 2015.

Moreover, we the number of supermarkets per drinking age population to proxy potential buyers (refer to Appendix H for details) (OpenStreetMap contributors, 2021).

Collected farmer characteristics include age, gender and we also elicited producers risk preferences via Likert type contextualized self-assessment questions on attitude towards risk taking in four different domains, namely, production, marketing risks (i.e. concerning market and prices), external financing and agriculture in general (following Dohmen et al., 2011 and Iyer et al., 2020).

Before we analyse our data further, we identify and remove outliers from our datasets. We use the BACON algorithm (Béguin and Hulliger, 2008), which is a multivariate method for outlier detection accounting for all continuous variables used in the regression analysis. Using the BACON algorithm, we identified 15 observations (i.e. 2.1%) as multivariate outliers that are not considered further in our analysis (see Appendix D for details on the data preparation). The final dataset used with all variables available is N = 700. Note that due to missing values, our econometric analysis finally relies on 643 observations. Table 1 shows an overview of farm and farmer characteristics.

Table 1. Summary statistics.

		Fungi-resistant variety adoption	
	Total (N=700)	**No (N=559)**	**Yes (N=141)**
Use of fungi-resistant varieties			
No	559 (79.9%)	559 (100%)	0 (0%)
Yes	141 (20.1%)	0 (0%)	141 (100%)
Specialized Marketing grapes			
No	369 (53 %)	264 (47 %)	105 (74 %)
Yes	331 (47 %)	295 (53 %)	36 (26 %)
Specialized Marketing wine			
No	280 (40 %)	249 (45 %)	31 (22 %)
Yes	420 (60 %)	310 (55 %)	110 (78 %)
Specialized Direct selling (>50%)			
No	415 (59 %)	351 (63 %)	64 (45 %)
Yes	232 (33 %)	165 (30 %)	67 (48 %)
Missing	53 (7.6%)	43 (7.7%)	10 (7.1%)
Specialized Selling to retail (>50%)			
No	520 (74 %)	419 (75 %)	101 (72 %)
Yes	37 (5 %)	35 (6 %)	2 (1 %)
Missing	143 (20.4%)	105 (18.8%)	38 (27.0%)
Non-professional grower			
No	620 (89 %)	494 (88 %)	126 (89 %)

		Fungi-resistant variety adoption	
	Total (N=700)	No (N=559)	Yes (N=141)
Yes	80 (11 %)	65 (12 %)	15 (11 %)
Age (years)			
Mean (SD)	53 (± 13)	54 (± 13)	52 (± 12)
Gender			
Male	630 (90 %)	502 (90 %)	128 (91 %)
Female	58 (8 %)	51 (9 %)	7 (5 %)
Missing	12 (1.7%)	6 (1.1%)	6 (4.3%)
Farm surface (are)			
Mean (SD)	630 (± 1000)	620 (± 1000)	680 (± 910)
Earnings from viticulture			
0-25%	248 (35 %)	202 (36 %)	46 (33 %)
25-50%	75 (11 %)	58 (10 %)	17 (12 %)
50-75%	59 (8 %)	46 (8 %)	13 (9 %)
75-100%	211 (30 %)	163 (29 %)	48 (34 %)
Missing	107 (15.3%)	90 (16.1%)	17 (12.1%)
Production system			
Non-organic	608 (87 %)	506 (91 %)	102 (72 %)
Organic	92 (13 %)	53 (9 %)	39 (28 %)
Willingness to take risk: Market and prices			
Mean (SD)	5.2 (± 3.0)	5.0 (± 2.9)	6.0 (± 3.0)
Missing	79 (11.3%)	70 (12.5%)	9 (6.4%)
Willingness to take risk: Production			
Mean (SD)	5.7 (± 2.9)	5.4 (± 2.8)	6.6 (± 2.8)
Missing	45 (6.4%)	39 (7.0%)	6 (4.3%)

Results

Descriptive statistics of our sample shows that 20.1% of the respondents use fungi-resistant varieties. However, the acreage under fungi-resistant varieties is only about 1.2%. We find that that our sample is equally consisting of producers that market the grapes (i.e. not producing their own wine) and those marketing wine themselves. Along these lines, also direct marketing is relevant for more than 30% of producers.

The descriptive overview also reveals first clear patterns regarding the uptake of resistant varieties. More specifically, producers that use resistant varieties are younger, have larger farms, a higher share of revenues from wine production for farm-level income. Also, organic producers are more likely to be adopters of fungi-resistant varieties. Moreover, we find adopters to be more risk loving in both the marketing and production domain. Regarding marketing channels, we find that adopters are more likely marketing wine, not grapes. Also, adopters are more likely using direct marketing vis-à-vis selling to the retail. Note that some combinations (e.g. specialized focus retail and uptake of fungi-resistant varieties) are characterized only by few farms.

Figure 2 shows the spatial distribution of fungi-resistant variety adoption in our sample. While there are adopters of resistant varieties in all wine regions of Switzerland, we find some regional patterns. We find lower uptake rates in Ticino (11%), Valais (13%) and Vaud (17%), while fungi-resistant variety cultivation is more pronounced around the Three lakes (22%), Geneva (25%) and in the German speaking part (29%)[18].

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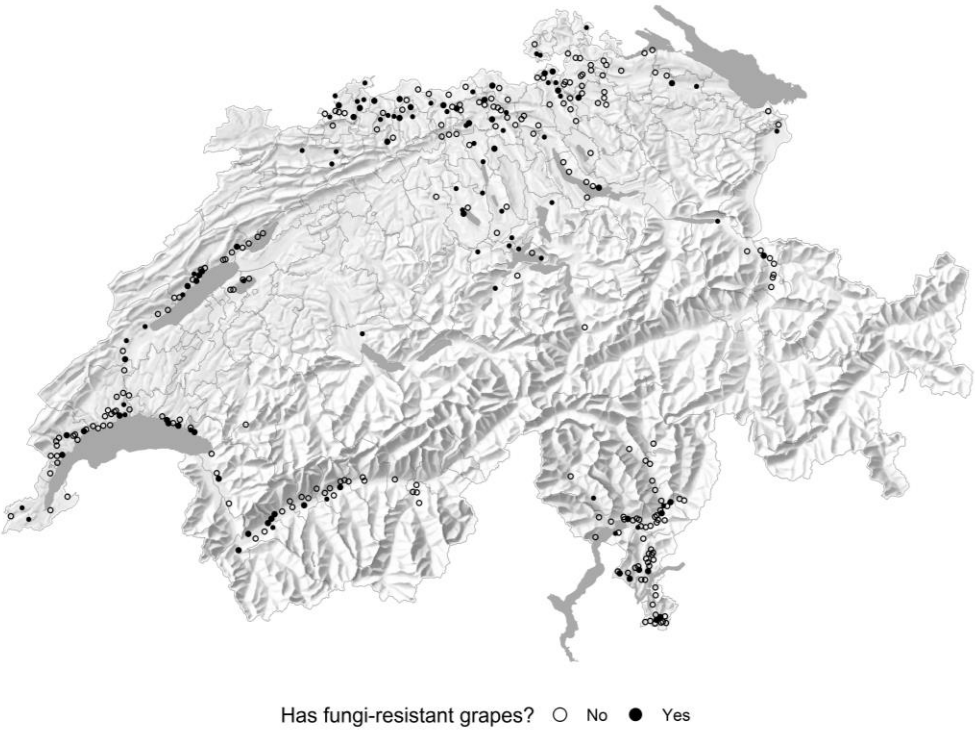
[18] These spatial tendencies partly reflect environmental conditions (e.g. powdery mildew infection risks) but also cultural and market characteristics. For example, the share of fungi-resistant varieties allowed in cantonal regulations on appellation of origin (AOC/DOC) reflects also the share of adoption of fungi-resistant in these cantons (Appendix A).

Figure 2. Spatial distribution of our adopter and non-adopter of resistant varieties.



Note: Observations are randomly positioned within the municipalities and do not represent actual locations of the farms. This is done to maintain annonymity of survey participants.

Table 2 reports coefficient estimates of our initial specification (OLS, equation 2). We here focus our analysis to the marketing channels. We find that producers who market solely unprocessed grapes are less likely to adopt resistant varieties. Being specialized in marketing grapes implies approximately a 10.9% decrease in the probability of uptake of fungi-resistant varieties. On the other hand, producers who market wine as a final product are more likely to uptake fungi-resistant varieties (8.8% increase probability of uptake of fungi-resistant varieties). Furthermore, while specialized direct marketers are more likely (8.1%) to adopt fungi-resistant varieties, we find that farms who are specialized in marketing to retail make less use (14.8%) of resistant varieties.

Table 2. Coefficient estimates for the initial specification (OLS, equation 2).

	Dependent variable: fungi-resistant variety adoption (1/0)			
	(1)	(2)	(3)	(4)
Variables on Marketing Channels				
Specialized marketing grapes (1/0)	-0.109***			
	(0.035)			
Specialized marketing wine (1/0)		0.088***		
		(0.032)		
Specialized direct marketing (1/0)			0.081***	
			(0.027)	
Specialized marketing retail (1/0)				-0.148***
				(0.029)
Control Variables	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Wine region dummies	Yes	Yes	Yes	Yes
N	643	643	600	514
R^2	0.112	0.106	0.108	0.101
Adjusted R^2	0.088	0.082	0.082	0.071

Note: *, **, and *** indicate significance at the 10%, 5% and 1% level, respectively. Clustered and wild bootstrapped standard errors at the wine region are shown in parentheses. See Appendix E for coefficient estimates of control variables.

Robustness checks

We present results for Oster bounds in Table 3. We show how much stronger selection on unobservables (relative to selection on observables (delta)), would be needed to move initial estimates to zero (beta = 0). Moreover, we test how our main estimates would change (beta) if the selection on unobservables was as strong as selection on observables (delta = 1) (Oster, 2019). Our results suggest strong stability. For example, potentially missing unobserved variables would need to be more than 2.97 times as important as the rich set of observables considered in the regression to render coefficients for direct marketing presented in Table 2 zero[19]. With equal selection (delta=1), our baseline estimate would shrink only slightly compared to initial coefficient estimates reported in Table 2.

Table 3. Oster bounds.

	Direct marketing		Retail	
	(1)	(2)	(3)	(4)
Beta	0	0.0585	0	-0.151
Delta	2.97	1	549	1
R2 max	0.1404	0.1404	0.1313	0.1313

Note: We follow Oster (2019) and chose R2 max as 1.3 times the R-squared in the regression with controls.

We present results from the multinomial treatment effect model in Table 4. Results support our findings from the initial specification, i.e. coefficients have the same signs and precision. However, the level of the individual effects increase substantially. Because we are in a dummy-dummy setting, parameters can be interpreted directly in percent changes in the outcome. Therefore, farms who are specialize in direct marketing are 38% more likely, whereas farms specialize in marketing to retail are 15% less likely to have adopted fungi-resistant grapevines. There is also significant evidence of selection on unobservables. The coefficients on the latent factors, λ(Direct marketing) and λ(Retail), are negative/positive, suggesting that farms who are more likely to market directly/to retail, on the basis of their unobserved characteristics, adopt fungi-resistant varieties less/more often, respectively.[20] We conclude that our OLS estimates in Table 2 are therefore lower-bounds, and that the effects are likely to be larger than our initial estimation. Particularly the effect of direct marketing substantially increases the likelihood of adopting fungi-resistant varieties from 8% to 35% in the multinomial treatment effect model, whereas the effect stays the same for farms specialized in marketing to retail (-14.8 in OLS vs. -15.2% in multinomial treatment effect estimation).

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[19] Very high values for Delta for Retail (5, Table 4)), may also be due to the low number of adopters of fungi-resistant varieties in this channel.

[20] Other individual characteristics are also statistically significant in the outcome equation. Refer to Appendix F for more details.

Table 4. Coefficient estimates for the Outcome equation of the multinomial treatment effect estimation (equation 6).

	Fungi-resistant variety adoption (1/0)
Difference form base category: 1 if specialized in direct marketing, 0 otherwise	0.380^{***} (0.034)
Difference form base category: 1 if specialized in marketing to retail, 0 otherwise	-0.152^{***} (0.0272)
Ln(sigma)	-2.892^{***} (0.177)
λ(Direct marketing)	-0.402^{***} (0.0207)
λ(Retail)	0.036^{**} (0.012)
Constant	-0.031 (0.145)
Controls	Yes
Year dummies	Yes
Wine region dummies	Yes
N	605

Note: *, **, and *** indicate significance at the 10%, 5% and 1% level, respectively. We use a normal (Gaussian) distribution function. Refer to Appendix F for full regression output. Note that some observations are dropped due to missing demand side factors.

Next, we summarize findings from our additional robustness checks that aim to explore the stability of our findings. First, using logit and probit specifications to estimate the model in equation 2, we find similar directed effects and levels of significance (see table G1 in Appendix G). Second, using percentage values of the relevance of respective marketing channels (instead of binary dummies) leads to similar directed effects, i.e. signs and significance levels are the same as in the initial specifications (see table G2 in Appendix G). Third, we investigate associations of marketing channels and the extent of the adoption, i.e. the area under fungi-resistant varieties and the number of fungi-resistant varieties at the farm. Results show similar signs and significance levels of the effects shown in main specifications. For example, farms specialized in direct marketing are associated with 300 m^2 higher acreage under fungi-resistant varieties (see figure G4 in Appendix G). Fourth, we split the sample by language regions (German, French, Italian speaking) and re-run the analysis. We find that coefficients consistently have similar directed signs and magnitudes (see table G5 in Appendix G). Yet, only specific coefficients were significant in subsample analysis, especially because sample splits reduce the sample sizes (and share of adopter of fungi-resistant varieties) considerably. Fifth, we split the sample by spatial past powdery mildew infection risk (using the Oidium index distribution (Dubuis et al. 2014)). More specifically, we split the sample into a high pest pressure location sample (e.g. the observations which are in the top tercile of the Oidium index distribution) and the rest. We find lower relevance of marketing channels (e.g. in terms of significant variables and magnitude) for the high pest pressure sample compared to the rest (see table G6 in Appendix G). This may indicate that here the high pest pressure is the main driver of adoption of fungi-resistant varieties, independent of marketing channels.

Discussion

We present the first analysis on the adoption of fungi-resistant grapevine varieties. Given the large economic and policy relevance of pesticide use reduction in grapevine production, we believe to shed light on a relevant but under-researched aspect of agriculture. We here show the relevance of marketing channels used by producers. Our results narrow down to a simple conclusion: the more distant the producer is from the final consumer of wine (e.g. by marketing grapes, not wine or by not using direct marketing to consumer), the less likely the producer will use fungi-resistant varieties. So shorter value chains can enable the adoption of fungi-resistant varieties and thus contribute to lower pesticide use. This especially may reflect the additional opportunities in these marketing channels to directly communicate attributes of rather new grapevine varieties, without relying on consumers association with established grapevine varieties. Thus, creating more direct connection points between producers and consumers may facilitate a transition towards low-pesticide and more sustainable grapevine production. This serves as a basis for industry and policy decisions. For example, a concerted effort may bring together activities in breeding and introduction of new fungi-resistant varieties and creation of appropriate information (e.g. labelling) and marketing channels. These steps could also be supported by policy, e.g. by supporting (more) direct marketing channels, consumer and producer information campaigns on fungi-resistant varieties and investment support for farmers' transition towards fungi-resistant varieties. Education and extension services may also be important leverage factors in such transition (e.g. Wuepper et al., 2021).

Low-pesticide grapevine production also has strong spillovers to other aspects of farm management and agricultural policy. For example, a combination of low-pesticide grapevine production, marketing of wine with other activities such as agri-tourism will be decisive (Carlsen and Boksberger, 2015; Hall et al., 2009). More general, agri-tourism is a highly relevant income source in many European countries, and contributes to resilience of farming systems but also contributes to rural economies (e.g. Dries et al., 2012; Meraner et al., 2015). Thus, exploiting new on-farm income sources, new marketing channels jointly with fungi-resistant varieties may be embedded in a larger framework of rural development. This development goes along with stronger emphasis on short supply chains in European agriculture and policy (e.g. Aubry and Kebir, 2013; Chiffoleau et al., 2019). Here also the use of specific 'low pesticide' wine production labels could be promising (Nesselhauf et al., 2019). Along these lines, the integration of fungi-resistant varieties into existing labeling structures, such as for the appellation of origin shall have priority. Varietal choice has further implications. For example, choosing a wider range of varieties may serve as a risk management strategy (Knapp et al., 2021c). By using different varieties with different vulnerabilities to weather and pests this may reduce the overall risk exposure. Hence, adding fungi-resistant varieties into the portfolio may thus also contribute to farm-level risk management. This provides further rationale to support the uptake of new varieties. Along these lines, grapevine production faces further long-term challenges. For example, climate change will affect grapevine yield and quality as well as a potential increase of pest pressure (e.g. Cook and Wolkovich, 2016; Deutsch et al., 2018; Vitasse and Rebetez, 2018).

Conclusion

The use of fungi resistant grapevine varieties could allow substantial reductions in pesticide use, but the adoption and diffusion of these varieties globally is still very limited. We here provide the first paper investigating the adoption of these varieties. More specifically, we investigate the farm-level adoption decision of resistant grapevine varieties in Switzerland and provide insights into the determinants and barriers for their wide-spread use. Using survey data from 775 producers, we especially investigate the relevance of marketing channels for the uptake of resistant varieties.

We find that 20.1% of the surveyed Swiss grapevine producers use fungi-resistant varieties. However, the acreage under fungi-resistant varieties is only about 1.2%. Our results show positive associations of adoption and the use of marketing wine, not grapes, and the use of direct marketing vis-à-vis selling to retail. The more distant the producer is from the final consumer of wine, the less likely the producer will use fungi-resistant varieties.

For industry and policy this implies that creating more direct connection points between producers and consumers may facilitate a transition towards low-pesticide and thus more sustainable grapevine production. Policy may also develop a concerted and coherent set of activities that combines breeding of new fungi-resistant varieties and creation of appropriate information and marketing channels. Next to supporting the development of fungi-resistant varieties, industry and policy can support (more) shorter supply chains such as direct marketing channels, consumer and producer information campaigns and labeling on fungi-resistant varieties and support for farmers' transition towards fungi-resistant varieties, e.g. via financial support, education, extension. Our findings highlight the possible interlinkage between combining shorter supply chains, diversification of farm activities and a shift towards more sustainable agricultural practices. Thus, there may be sweet spots for agricultural policies.

Further research may explore evidence on the uptake of fungi-resistant varieties in other countries. Further research shall establish panel datasets to exploit natural variations in marketing channels, market and environmental conditions. Future research may also shed light on other fields that matter for the adoption. For example, market mechanisms and labeling as well as education, training and extension as these may be important leverage points for the adoption of fungi-resistant varieties.

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Appendices

A: Fungi-resistant variety classification

We classify the grape varieties as fungi-resistant variety or non-fungi-resistant variety according to the classification of Federal Office for Agriculture (2018). The classified list is shown in Table A1.

Table A1. Fungi-resistant grape classification.

Grapename	Resistant variety	Eligible cantons for AOC/DOC labelling
Aligoté	No	FR, GE, LU, NW, OW, SG, UR, VD, VS, ZG
Altesse	No	FR, GE, VD
Amigne	No	FR, LU, NW, OW, SG, UR, VD, VS, ZG
Petite Arvine	No	FR, LU, NW, OW, SG, UR, VD, ZG
Ancellotta	No	FR, GE, VD, VS
Auxerrois	No	FR, GE, LU, NW, OW, SG, UR, VD, ZG
Bacchus	No	AG, BL, BS, SO, TG
Barbera	No	ZH
Baron	Yes	LU, NW, OW, UR, ZG, ZH
Bondola	No	LU, NW, OW, SG, TI, UR, ZG
Blauburgunder	No	LU, NW, OW, SG, SH, TG, UR, ZG, ZH
Bronner	Yes	AG, ZH
Cabernet Cantor	Yes	BE, JU, TG, ZH
Cabernet Cortis	Yes	AG, BE, BL, BS, FR, JU, LU, NW, OW, SH, SO, TG, UR, ZG, ZH
Cabernet Cubin	No	AG, BL, BS, GR, SH, SO, ZH
Cabernet Dorsa	No	AG, BE, BL, BS, FR, GR, LU, NW, OW, SH, SO, TG, UR, VD, ZG, ZH
Cabernet Jura	Yes	AG, BE, BL, BS, FR, GR, JU, LU, LU, NW, OW, SH, SO, TG, UR, ZG, ZH
Cabernet Mitos	No	AG, BL, BS, SH, SO, ZH
Cabernet Noir	Yes	FR, JU, SH, ZH
Cabernet Sauvignon	No	GE, GR, SH, TG, TI, VD, VS, ZH
Cabertin	Yes	AG, BE, BL, BS, SH, SO, ZH
Caladoc	No	
Carminoir	No	BE, FR, GE, LU, NW, OW, SG, TI, UR, VD, VS, ZG, ZH
Chancellor	Yes	TG, ZH
Chambourcin	Yes	AG, BE, SH, ZH
Chardonnay	No	BE, BL, BS, FR, GE, GR, LU, NW, OW, SG, SH, SO, TG, TI, UR, VD, VS, ZG, ZH
Charmont	No	BE, BL, BS, FR, GE, SO, VD, VS, ZH
Chasselas	No	BE, FR, GE, LU, NE, NW, OW, SG, TI, UR, VD, VS, ZG
Clinton	Yes	
Cornalin / Landroter	No	FR, GE, LU, NW, OW, SG, UR, VD, VS, ZG, ZH
Chenin Blanc	No	FR, LU, NW, OW, SG, TG, UR, VD, VS, ZG
Completer	No	FR, GR, LU, NW, OW, SG, UR, VS, ZG, ZH
Cornalin	No	FR, GE, LU, NW, OW, SG, UR, VD, VS, ZG

Dakapo	No	AG, BE, BL, BS, FR, GR, SH, SO, TG, VD, ZH
Doral	No	FR, GE, LU, NE, NW, OW, SG, SH, TI, UR, VD, VS, ZG, ZH
Diolinoir	No	BE, FR, GE, GR, LU, NW, OW, SG, SH, TG, TI, UR, VD, VS, ZG, ZH
Divona	Yes	BE, FR, GE, GR, JU, TG, VD, ZH
Divico	Yes	BE, FR, GE, GR, JU, LU, NW, OW, SG, SH, TG, TI, UR, VD, VS, ZG, ZH
Dornfelder	No	AG, BE, BL, BS, FR, GE, GR, LU, NW, OW, SH, SO, TG, UR, VD, ZG, ZH
Dunkelfeder	No	AG, BE, BL, BS, FR, GE, GR, NE, SH, SO, TG, VD, ZH
Freisamer / Freiburger	No	BE, GR, LU, NW, OW, SG, UR, VD, ZG, ZH
Galotta	No	BE, BL, BS, FR, GE, LU, NE, NW, OW, SG, SH, SO, TG, TI, UR, VD, VS, ZG, ZH
Gamay	No	BE, FR, GE, LU, NW, OW, SG, TG, UR, VD, VS, ZG, ZH
Gamaret	No	BE, BL, BS, FR, GE, GR, JU, LU, NE, NW, OW, SG, SH, SO, TG, TI, UR, VD, VS, ZG, ZH
Garanoir	No	BE, BL, BS, FR, GE, JU, LU, NE, NW, OW, SG, SH, SO, TG, TI, UR, VD, VS, ZG, ZH
Gewürztraminer	No	BL, BS, GR, JU, LU, NW, OW, SG, SO, TG, UR, VD, VS, ZG, ZH
Grauburgunder	No	GR, LU, NW, OW, UR, ZG
Grenache	No	GE, ZH
Humagne rouge	No	FR, LU, NW, OW, SG, UR, VD, VS, ZG
Humagne blanche	No	
Isabella	Yes	
Johanniter	Yes	AG, BE, BL, BS, FR, GE, GR, JU, LU, NW, OW, SH, SO, TG, TI, UR, VD, VS, ZG, ZH
Kalina	Yes	AG
Katawaba	Yes	
Kerner	No	BE, BL, BS, FR, GE, GR, LU, NW, OW, SG, SH, SO, TG, TI, UR, VD, ZG, ZH
Léon Millot	Yes	BE, BL, BS, FR, JU, LU, NW, OW, SG, SH, SO, TG, UR, VD, VS, ZG, ZH
Malbec	No	BE, BL, BS, FR, GE, GR, LU, NW, OW, SG, SH, SO, TG, UR, VD, ZG, ZH
Mara	No	BE, BL, BS, FR, GE, GR, JU, LU, NW, OW, SG, SO, UR, VD, ZG, ZH
Marsanne Blanche / Ermitage	No	FR, LU, NW, OW, SG, UR, VD, VS, ZG
Maréchal Foch	Yes	BE, BL, BS, FR, GR, JU, LU, NW, OW, SG, SH, SO, TG, UR, VD, ZG, ZH
Merlot	No	BE, BL, BS, FR, GE, GR, LU, NW, OW, SG, SH, SO, TG, TI, UR, VD, VS, ZG, ZH
Monarch	Yes	JU, LU, NW, OW, SH, TG, UR, ZG, ZH
Mondeuse Blanche	No	GE
Muscaris	Yes	AG, BE, BL, BS, FR, GR, JU, LU, NW, OW, SH, SO, TG, UR, ZG, ZH
Muscat Bleu	Yes	AG, BL, BS, LU, NW, OW, SH, SO, TG, UR, ZG, ZH

Muscat / Muskateller	No	BE, FR, GE, LU, NW, OW, UR, VS, ZG
Muscat Oliver	No	BL, BS, LU, NW, OW, SH, SO, TG, UR, ZG
Nebbiolo	No	AG, GR
Petit Verdot	No	TI, ZH
Pinot Meunier	No	AG, BE, GR
Plant Robert	No	VD
Prior	Yes	BE, BL, BS, JU, LU, NW, OW, SH, SO, UR, ZG, ZH
Réze	No	FR, LU, NW, OW, SG, UR, ZG
Riesling-Sylvaner / Müller Thurgau	No	BE, BL, BS, FR, GE, GR, LU, NE, NW, OW, SG, SH, SO, TG, UR, VS, ZG, ZH
Roter Räuschling	No	ZH
Rheinriesling	No	GR, TG
Regent	Yes	BE, BL, BS, FR, GR, LU, NW, OW, SG, SH, SO, UR, VD, VS, ZG, ZH
Roussanne	No	GE, LU, NW, OW, SG, UR, VS, ZG
Saint Laurent	No	TG
Scheurebe	No	AG, GE, GR, LU, NW, OW, SH, TG, UR, ZG, ZH
Sauvignon blanc	No	BE, BL, BS, GE, GR, LU, NW, OW, SG, SH, SO, TG, UR, VD, VS, ZG, ZH
Sauvignon Gris	No	AG, BE, FR, GE, TG, VD, ZH
Sauvignon Soyhiéres	Yes	BL, BS, FR, GR, SO, ZH
Savagnin blanc	No	BE, FR, GE, LU, NW, OW, SG, UR, VD, VS, ZG
Seyval Blanc	Yes	BL, BS, FR, GR, LU, NW, OW, SG, SH, SO, TG, UR, VD, ZG, ZH
Sémillon	No	BL, BS, FR, LU, NW, OW, SG, SO, TI, UR, VD, VS, ZG
Souvignier Gris	Yes	AG, BE, BL, BS, JU, LU, NW, OW, SH, SO, TG, UR, ZG, ZH
Solaris	Yes	AG, BE, BL, BS, FR, JU, LU, NW, OW, SH, SO, TG, UR, VD, VS, ZG, ZH
Sylvaner / Rhin	No	BE, FR, GE, JU, LU, NW, OW, SG, UR, VD, VS, ZG
Syrah	No	BE, BL, BS, FR, GE, GR, LU, NW, OW, SG, SO, TG, TI, UR, VD, VS, ZG, ZH
Tannat	No	VS
Triumph vom Elsass	Yes	BL, BS, SO
VB Cal 1-22	Yes	BL, BS, JU, SH, SO, TG, ZH
VB Cal 1-28	Yes	GR, JU, SH, ZH
VB Cal 1-36	Yes	BL, BS, GR, JU, SH, SO, ZH
VB Cal 1-14	Yes	BL, BS, SO
VB Cal 6-04	Yes	BL, BS, JU, SH, SO
VB Jura 25	Yes	JU
Viognier	No	BE, FR, GE, GR, LU, NE, NW, OW, SG, SH, TG, TI, UR, VD, VS, ZG, ZH
Weissburgunder	No	GR, LU, NW, OW, TG, UR, ZG
Zinfandel	No	GE
Zweigelt	No	AG, BE, BL, BS, FR, GR, LU, NW, OW, SH, SO, TG, UR, ZG, ZH

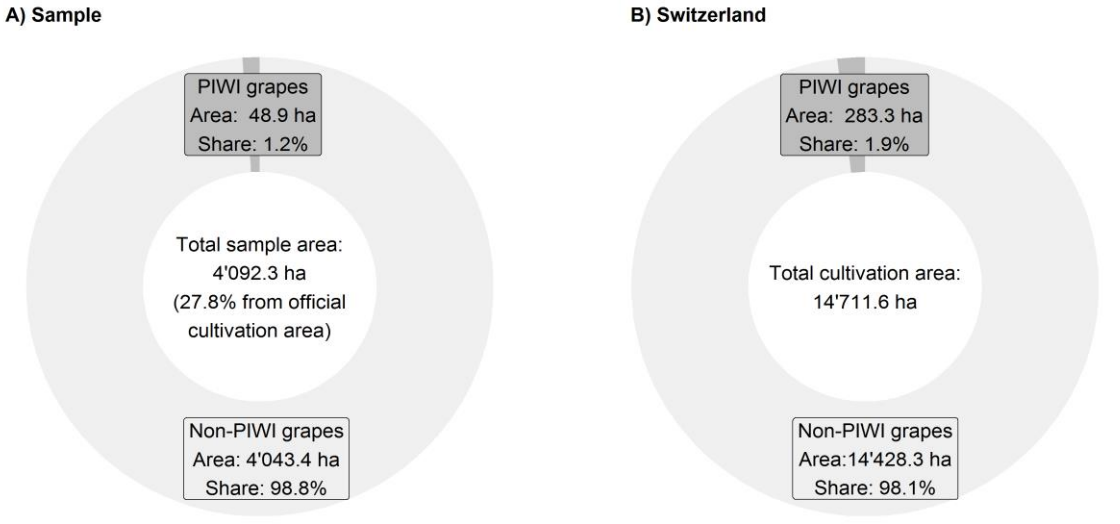
Note: Diolinoir is classified as fungi-resistant variety according to PIWI International. However, according to the Federal Office for Agriculture it is a non-resistant variety. It is a relevant grape in terms of uptake and plantation area. However, our results do not change whether it is included or not. We exclude it and follow therefore the Federal Office for Agriculture.

27 observations (3.9%) use both fungi-resistant variety and non-fungi-resistant variety grapes in the open-text answer field. In this case, we identify the number of fungi-resistant variety grapes and split the area proportionately to the number of cultivars into fungi-resistant variety and non-fungi-resistant variety. For example, if a farm reports to grow Barbera (non-fungi-resistant variety) and Baron (fungi-resistant variety) on 635 are, we allocate 317.5 are to fungi-resistant variety and non-fungi-resistant variety, respectively.

B: Sample representativeness

Here we present statistics about our samples' representativeness compared to official data. Figure B1 illustrates that our sample is representative, both in terms of the share of land under fungi-resistant grapes (1.2%) as well as total cultivation area (27.8%).

Figure B1. Sample characteristics in comparison with national statistics



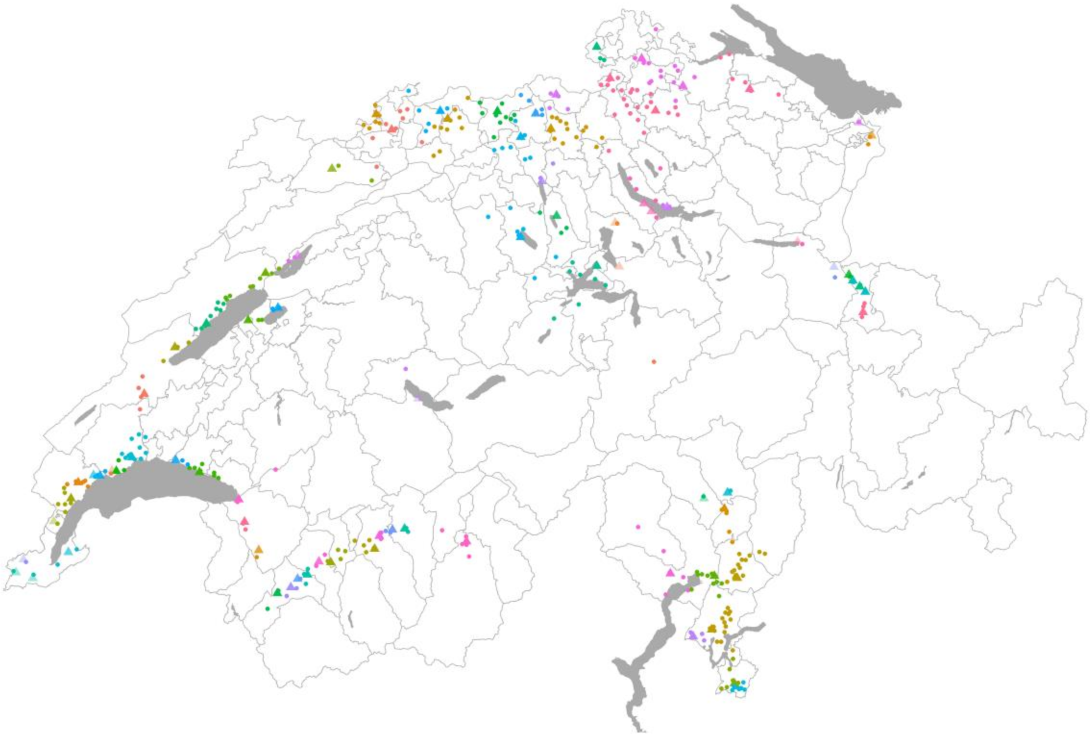
Sources: Offizielle Weinlesekontrolle der Kantone (November 2018) and own data.

C: Oidium risk index data

Part 1 - Matching

We use daily oidium risk data from Agrometeo from 92 weather stations (depicted as triangles in the figure below) to control for historical powdery mildew infection risk at the regional level (Dubuis et al. 2014). We use all available data from Agrometeo up until 2015 which is one year prior to the first data gathering round. We construct average values over the period 2012 to 2015 and match the risk data to our sample by minimizing the geographic distance between observations and stations. Figure C1 depicts the matching procedure.

Figure C1. Station matching

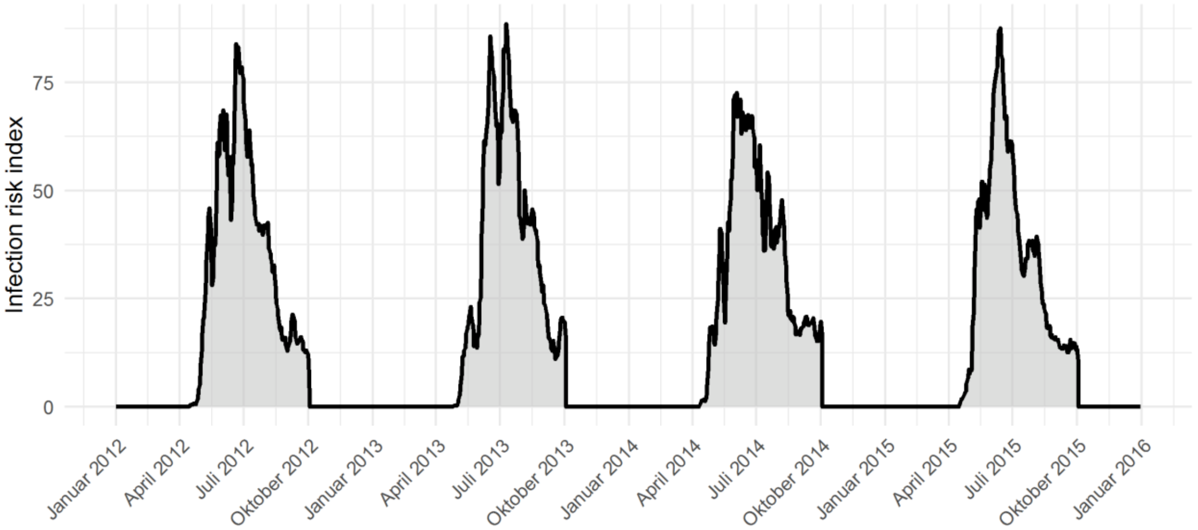


Note: Observations are randomly positioned within the municipalities and do not represent actual locations of the farms. This is done to maintain annonymity of survey participants.

Part 2 – Infection risk over time

Figure C2 illustrates infection risk over time. Infection risk is highest in June/July and decreases towards harvest (end of August-October, depending on year, variety and location).

Figure C2. Infection risk over time

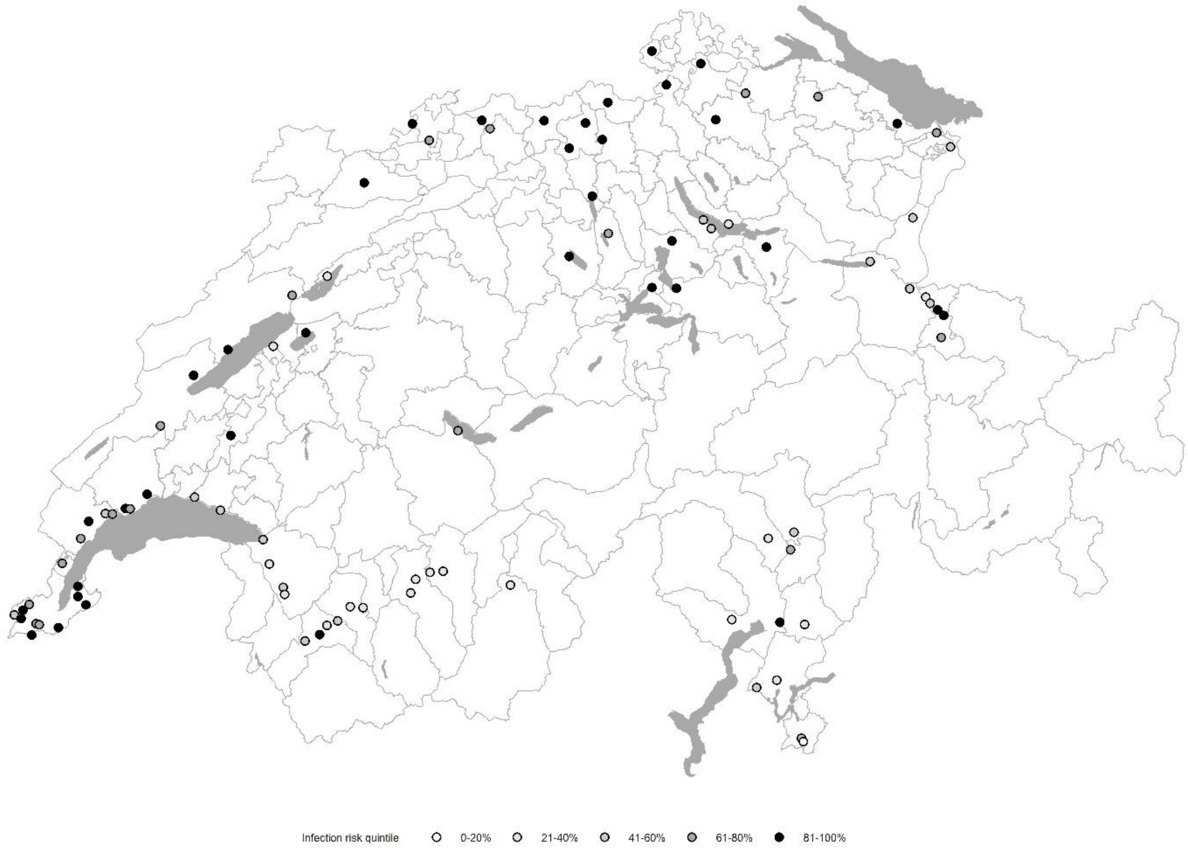


Source: Agrometeo.

Part 3 – Infection risk over space

Figure C3 shows spatial infection risk. Infection risk is lower in Valais and Ticino, compared to Geneva or the German-speaking part of Switzerland

Figure C3. Infection risk over space



Sources: Agrometeo / Federal Office of Topography.

D: Data preparation

We use from the 1’087 responding grapevine producers only the observations from the latest year (out of 2016, 2017 or 2018) if there are responses for multiple years. This results in 775 observations. Prior to outlier detection, we remove observations that are outside of Swiss territory (2), are spatially undefined (1) or with missing values for age and farm size (57). Thereafter, we test and clean our cross-sectional data for outliers. We follow Béquin and Hulliger 2008 to employ a multivariate BACON-EEM algorithm. We set alpha = 0.01 indicating the level (1 - alpha) of the cutoff quantile for good observations.

Table D1. Outlier detection

	Sample (N=700)	**Outliers (N=15)**	**p-value**
Age (years)			
Mean (SD)	53.4 (± 12.7)	52.4 (28.4)	0.764
Median [Min, Max]	54.0 [19.0, 88.0]	47.0 [26.0, 118]	
Farm surface (are)			
Mean (SD)	635 (± 1010)	119000 (383000)	<0.001
Median [Min, Max]	188 [0, 5430]	7770 [16.0, 1500000]	

We identify 15 observations as outliers for the continuous variables age and farm surface. Note that the BACON-EEM algorithm detects outliers for all considered variables jointly. Table D1 contrasts summary statistics of our sample with the excluded outliers. Mean and median values for farm surface are considerably larger for the outliers as compared to the remaining sample. In the outlier sample we exclude incredibly high values for age (118). The two samples are more similar in terms of age. However, a two-sided t-test (p-values shown) confirms that the two samples are statistically significantly different in terms of farm surface (significance level = 0.01) and justifies the removal of the outliers from the sample. Our working sample consists of 700 observations.

E: Full regression results OLS

We here report coefficient estimates on the controls for our initial specification shown in Table 2.

Table E1. Full table of Coefficient estimates for the initial specification (OLS, equation 2).

	Dependent variable: Fungi-resistant variety adoption (1/0)			
	(1)	(2)	(3)	(4)
Variables on Marketing Channels				
Marketing grapes (1/0)	-0.109***			
	(0.035)			
Marketing wine (1/0)		0.088***		
		(0.032)		
Specialized direct marketing (1/0)			0.081***	
			(0.027)	
Specialized retail (1/0)				-0.148***
				(0.029)
Control variables				
Age	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Female	-0.090**	-0.092**	-0.104***	-0.063
	(0.036)	(0.037)	(0.030)	(0.043)
Farm size (meters squared)	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.002)
Organic (1/0)	0.259***	0.268***	0.268***	0.264***
	(0.036)	(0.034)	(0.033)	(0.036)
Viti earning 0-25% (1/0)	-0.018	-0.021	-0.027*	-0.045*
	(0.023)	(0.022)	(0.016)	(0.023)
Viti earning 75-100% (1/0)	-0.020	-0.029	-0.011	0.009
	(0.036)	(0.035)	(0.035)	(0.044)

Non-professionals (1/0)	-0.013	0.010	-0.012	0.007
	(0.042)	(0.034)	(0.038)	(0.052)
Willingness to take risk: Production	0.011**	0.012***	0.013*	0.013*
	(0.004)	(0.004)	(0.007)	(0.007)
Oidium index (2012-2015)	0.008	0.006	0.005	0.005
	(0.006)	(0.005)	(0.005)	(0.005)
Constant	0.139	0.074	0.162	0.144*
	(0.132)	(0.142)	(0.119)	(0.087)
Year dummies	Yes	Yes	Yes	Yes
Wine region dummies	Yes	Yes	Yes	Yes
N	643	643	600	514
R^2	0.112	0.106	0.108	0.101
Adjusted R^2	0.088	0.082	0.082	0.071

Note: *, **, and *** indicate significance at the 10%, 5% and 1% level, respectively. Clustered and wild bootstrapped standard errors at the wine region are shown in parentheses.

F: Multinomial treatment effect model

Table F1. Regression results using Multinomial treatment effect model

	Selection equation		Outcome equation
	Specialized direct marketing	Specialized retail	Fungi-resistant variety adoption (1/0)
	(1)	(2)	(3)
Difference form base category: 1 if specialized in direct marketing, 0 otherwise			0.380*** (0.034)
Difference form base category: 1 if specialized in marketing to retail, 0 otherwise			-0.152*** (0.0272)
Age (in years)	0.002 (0.007)	-0.035 (0.021)	-0.003*** (0.0003)
Female	-0.208 (0.173)	-1.150 (0.928)	-0.155*** (0.0239)
Organic	0.463 (0.349)	-1.304 (1.291)	0.242*** (0.0500)
Farm size (meter squared)	-0.02 (0.014)	0.03 (0.019)	0.003*** (0.001)
Market risk preferences	0.139*** (0.039)	0.009 (0.065)	
Production risk preferences			0.004 (0.003)
Large viticultural income (>75 p'tile)	0.755** (0.286)	0.726 (0.489)	-0.027 (0.049)
Non-professional grower	-0.472 (0.385)	-0.937 (1.007)	0.124** (0.044)
Fungi pressure (Oidium index)			0.009 (0.005)
Income per capita	0.009 (0.01)	0.069*** (0.016)	
Supermarkets per drinking age population	-1100.9* (428.6)	1087.5 (611.6)	
Ln(sigma)			-2.892*** (0.177)
λ(Direct marketing)			-0.402*** (0.0207)

λ(Retail)			0.036^{**}
			(0.012)
Constant	-0.380	-7.226^{***}	-0.031
	(1.829)	(1.917)	(0.145)
Year dummies	Yes	Yes	Yes
Wine region dummies	Yes	Yes	Yes
N	605	605	605

G: Robustness checksPart 1 – Logit/probit

Table G1. Regressions using logit and probit

	Dependent variable: Fungi-resistant variety adoption (1/0)							
	Logit				Probit			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Marketing grapes (1/0)	-0.794***				-0.455***			
	(0.105)				(0.098)			
Marketing wine (1/0)		0.653***				0.354***		
		(0.097)				(0.100)		
Direct marketing (1/0)			0.539***				0.317***	
			(0.084)				(0.082)	
Retail (1/0)				-1.522***				-0.911***
				(0.066)				(0.062)
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wine region dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	643	643	600	514	643	643	600	514
Akaike Inf. Crit.	609.280	613.971	569.937	468.233	609.868	615.498	569.936	467.434

Notes: ***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

Clustered and wild bootstrapped standard errors at the wine region level are shown in parentheses.

Part 2 – Percentages

Table G2. Regression using percentages instead of dummies

We perform the main regressions as shown in Table 2 with percentage values of the respective marketing channels. Specifically, instead of classifying the independent variables as dummies (e.g. percentage > 50%), we use the reported percentage share of the respective marketing channels directly. Table G2 shows that our results remain robust.

OLS results with percentages

	Dependent variable: Fungi-resistant variety adoption (1/0)	
	(1)	(2)
Direct marketing (%)	0.001^{***}	
	(0.0003)	
Retail (%)		-0.002^{***}
		(0.0003)
Age	-0.001	-0.001
	(0.001)	(0.001)
Female	-0.096^{***}	-0.063
	(0.030)	(0.040)
Farm size (meters squared)	0.001	0.002
	(0.001)	(0.002)
Organic	0.263^{***}	0.270^{***}
	(0.036)	(0.036)
Viti earning 0-25%	-0.030^{*}	-0.048^{**}
	(0.016)	(0.022)
Viti earning 75-100%	-0.017	0.015
	(0.033)	(0.049)
Non-professionals	-0.008	0.005
	(0.038)	(0.050)

Willingness to take risk : Production	0.012	0.013**
	(0.007)	(0.006)
Oidium index (2012-2015)	0.005	0.004
	(0.006)	(0.005)
Constant	0.113	0.167*
	(0.127)	(0.088)
Year dummies	Yes	Yes
Wine region dummies	Yes	Yes
N	600	514
R^2	0.114	0.101
Adjusted R^2	0.088	0.070

Notes:

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

Clustered and wild bootstrapped standard errors at the wine region level are shown in parentheses.

Part 3 – Tobit

Figure G3. Censoring

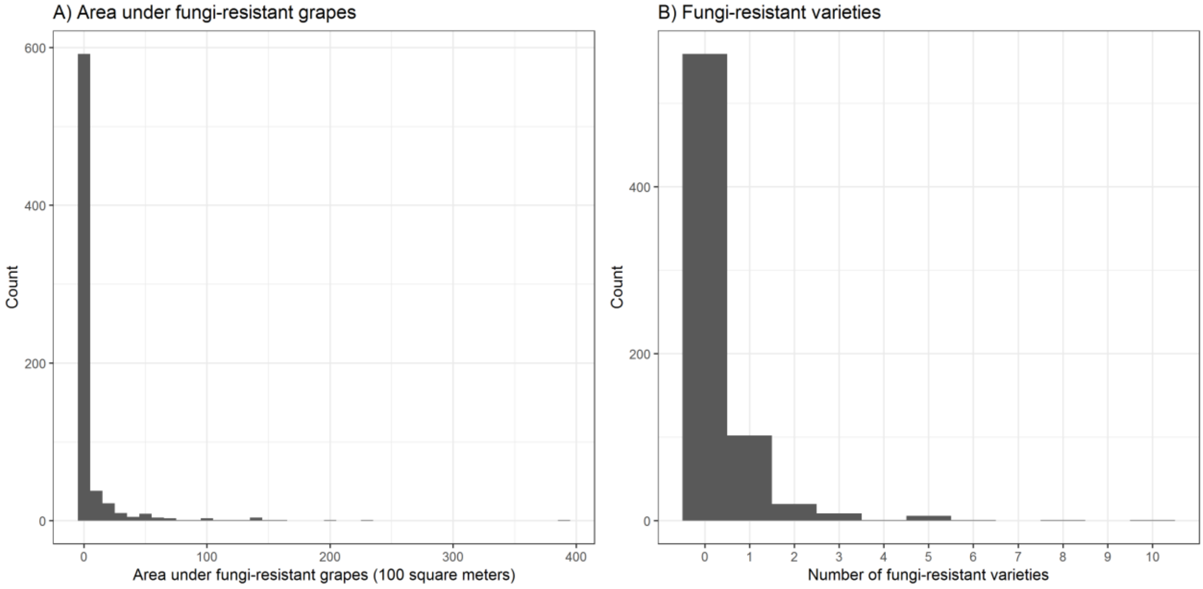


Figure H3 shows that the area under fungi-resistant grapes and the number of fungi-resistant varieties used are censored at 0. We therefore conduct a robustness check with the adoption intensity using a Tobit specification (see Figure H4).

Figure G4. Tobit marginal effects

For the area devoted to fungi-resistant grapes (A) and the number of fungi-resistant varieties adopted (B) we estimate the following Tobit specifications:

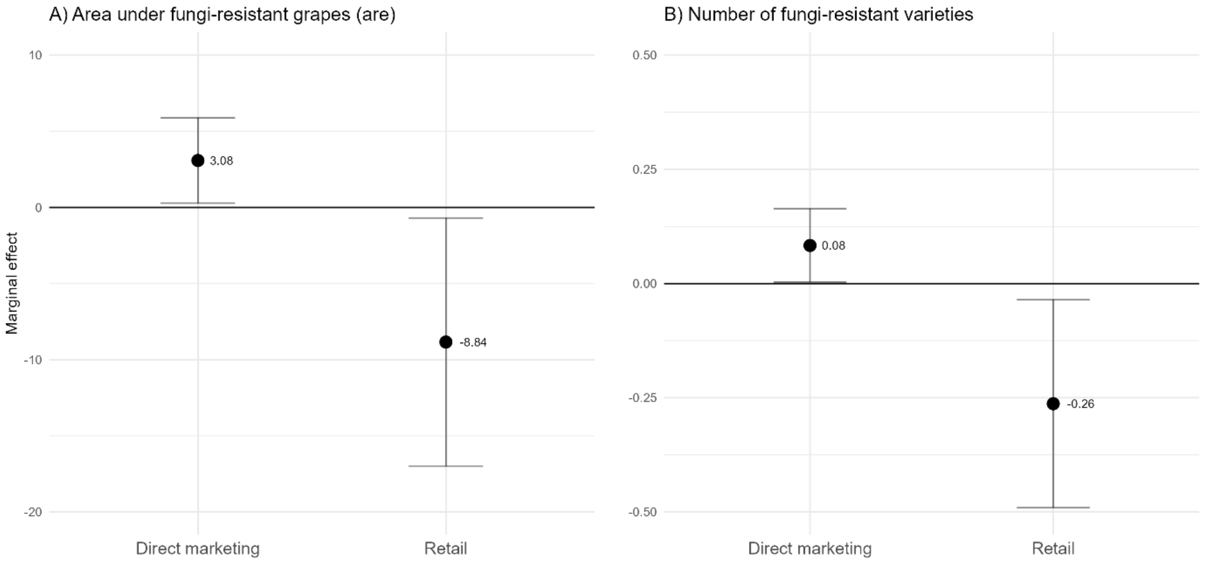
(A) $ARV_i = \alpha + \beta_{1,j} MC_{i,j} + \beta_2 X_i + \tau_t + \omega_r + \varepsilon_i$

ARV_i is the area devoted to fungi-resistant grapes of farmer i (in are). All explanatory and control variables remain as defined in our main specification (2).

(B) $NRV_i = \alpha + \beta_{1,j} MC_{i,j} + \beta_2 X_i + \beta_3 TG_i + \tau_t + \omega_r + \varepsilon_i$

NRV_i stands for the number of fungi-resistant grapes adopted by farmer i. All explanatory and control variables remain as defined in our main specification (2). In addition, we control for the total number of grapes used by farmer i (TG_i).

In both specifications, standard errors are clustered at the wine region level and marginal effects evaluated at the mean values of the explanatory variables are calculated.



Note: Marginal effects evaluated at mean values shown with corresponding 95%-CI obtained from tobit regressions with all control variables.

Part 4 – Sample splits

Table G5: Regression results for sample splits by language region

OLS results

	Dependent variable: Fungi-resistant variety adoption (1/0)											
	German-speaking				French-speaking				Italian-speaking			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Marketing grapes (1/0)	-0.165^{***}				-0.054				-0.186^{***}			
	(0.052)				(0.059)				(0.062)			
Marketing wine (1/0)		0.095^{*}				0.105^{*}				0.039		
		(0.056)				(0.059)				(0.071)		
Direct marketing (1/0)			0.033				0.109^{*}				0.201^{***}	
			(0.050)				(0.061)				(0.076)	
Retail (1/0)				-0.184				-0.123				-0.151
				(0.142)				(0.091)				(0.141)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Wine region dummies	No	No	No	No	No	No	No	No	No	No	No	No
N	291	291	272	224	221	221	212	185	131	131	116	105
R^2	0.199	0.178	0.151	0.152	0.074	0.084	0.084	0.092	0.178	0.118	0.219	0.184
Adjusted R^2	0.164	0.143	0.112	0.104	0.021	0.032	0.028	0.028	0.094	0.028	0.128	0.078

Notes: ***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

Standard errors are shown in parentheses. Observations are classified into the three language regions according to the main official language spoken in the respective municipality.

Table G6. Regression results for sample splits by oidium infection risk (high vs. rest)

OLS results

	Dependent variable: fungi-resistant variety adoption (1/0)							
	High oidium risk (67-100%)				Rest (0-66%)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Marketing grapes (1/0)	-0.137***				-0.095***			
	(0.020)				(0.018)			
Marketing wine (1/0)		0.094***				0.074*		
		(0.023)				(0.04)		
Direct marketing (1/0)			0.044				0.096***	
			(0.04)				(0.028)	
Retail (1/0)				-0.076				-0.187***
				(0.08)				(0.031)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wine region dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	220	220	199	166	423	423	401	348
R^2	0.267	0.257	0.236	0.245	0.067	0.061	0.075	0.079
Adjusted R^2	0.209	0.198	0.169	0.163	0.028	0.021	0.034	0.032

Notes: ***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

Clustered and wild bootstrapped standard errors at the wine region are shown in parentheses. High oidium risk refers to observations in the first third (67-100%) tercile in the oidium risk distribution, rest to all others.

H: Open street map data

We collect the of supermarkets from OpenStreetMap (OpenStreetMap contributors, 2021) and use only observations that lie within the geographical borders of a Swiss canton. In addition, we collect the number of drinking age population individuals (aged above 18) and the average taxable income per canton from the Federal Statistical office. Then, we weight the number of supermarkets with the number of drinking age individuals at the cantonal level.

Figure H1. Spatial distribution of supermarkets