Abandoning disaster relief and stimulating insurance demand through premium subsidies*

Tim Philippi[a,b]

Jörg Schiller[a]

12 April 2024

Abstract

Premium subsidies are an instrument to address low demand for natural hazard insurance, which is partly caused by governmental disaster relief payments. We analyze how the introduction of ex ante premium subsidies affects the frost insurance demand of German winegrowers after the government changed insurance regimes to avoid ex post disaster relief payments. We find that the implementation of a premium subsidy in an immature market with low levels of participation, presumably caused by strong anticipation of disaster relief, is effective in increasing overall frost insurance demand. Receiving disaster relief payments three years prior to the introduction of the subsidy seems to make farmers more responsive toward the premium subsidy.

* We would like to thank the Vereinigte Hagel VVaG for providing the data, and the German Insurance Science Association (Deutscher Verein für Versicherungswissenschaft e.V.) and the "Universitätsbund Hohenheim e.V." for financial support. We also thank Andreas Blickle, Kylie Braegelmann, Richard Peter, two anonymous referees and a senior editor, and participants at the Hohenheim Finance Seminar 2021, the MRIC Winter Workshop 2022, the annual meeting of the German Association for Insurance Science 2022, the annual ARIA meeting 2022, the annual EGRIE meeting 2022 and the CEAR/MRIC Behavioral Insurance Workshop 2022 for helpful comments and suggestions.

[a] University of Hohenheim, Chair for Insurance Economics & Social Security.

[b] Corresponding author, tim.philippi@uni-hohenheim.de.

1 Introduction

Accelerating climate change appears to make many extreme weather events more frequent and more severe (IPCC, 2012). Heatwaves in the Southwest of the US in 2023, severe droughts in Western-Central Europe in 2022, and heavy rainfall and flooding in Western Europe in 2021 were all exacerbated by climate change (Schumacher, Zachariah, & Otto, 2022; Tradowsky et al., 2023; Zachariah et al., 2023). In such a changing risk environment, adequate risk management becomes increasingly important (Collier, Skees, & Barnett, 2009). One valuable instrument to prepare for financial losses from extreme weather events is insurance. In addition to speeding up recovery from disasters through efficient claims handling, insurance coverage can provide information about risk exposure, which may also incentivize investments in prevention (Kousky, 2019).

A primary challenge in natural hazard insurance markets is low insurance demand when insurance is not mandated or subsidized (Glauber, 2013; Holzheu & Turner, 2018; Lamond & Penning-Rowsell, 2014; Meuwissen, Mey, & van Asseldonk, 2018). For two of the largest natural hazard insurance markets–crop insurance and flood insurance–Swiss Re estimates that 60% of insurable crop losses and 83% of global economic losses from flooding are uninsured (Aggarwal & Xing, 2023; Bevere & Remondi, 2022). The most cited reasons for this protection gap are misperception of risk, often caused by a lack of awareness, and anticipation of governmental disaster relief payments (e.g. Kunreuther, 1996; Mulder, 2021). Anticipation of disaster relief payments is often referred to as charity hazard, a term introduced by Browne and Hoyt (2000) to express anticipation of receiving some sort of charity when a catastrophic loss occurs. Anticipating charity is argued to lower insurance demand and incentives for prevention.[1]

To overcome low demand caused by charity hazard, governments can introduce premium subsidies. Premium subsidies lower the price of insurance and they may reduce charity hazard as their introduction is often bound to the ostensibly credible condition that no further disaster relief payments will be made. In general, the more price elastic insurance demand and the more premium subsidies reduce charity hazard, the more effective premium subsidies are at overcoming low demand. By increasing insurance demand through premium subsidies, governments also benefit from shifting claims handling to insurance companies, as disaster relief payments usually impose significant bureaucratic burdens onto governments (Kousky, 2019). Insurance may also help to uphold creditworthiness after disasters occur enabling individuals

[1] See Asseldonk, Meuwissen, and Huirne (2002), Miglietta, Porrini, Fusco, and Capitanio (2020) and Deryugina and Kirwan (2018) for evidence of charity hazard on crop insurance markets. Andor, Osberghaus, and Simora (2020) review the empirical evidence on charity hazard on flood insurance markets. Cookson, Gallagher, and Mulder (2023) discuss crowdfunding as an alternative to governmental disaster relief payments.

to maintain their access to credit markets (Collier & Babich, 2019). Thus far, premium subsidies are most widely used on crop insurance markets. In particular, the U.S. has been actively shifting from ex post disaster relief toward ex ante premium subsidies on their crop insurance markets (Glauber, 2013; Kramer, 1983).

We study the German frost insurance market for winegrowers, which is part of the fragmented European agricultural insurance landscape. With warming climate, the buds of grapevine break earlier in the year leaving them more susceptible to spring frost in March or April.[2] The insurance market for this frost peril was barely existent in Germany until 2020, with low levels of insurance participation even after two major frost events in 2011 and in 2017, both of which triggered large amounts of governmental disaster relief payments (dpa, 2017; Wissenschaftlicher Dienst des Deutschen Bundestages, 2018). In the state of Baden-Württemberg, the second largest wine producing state in Germany and the focus of this study, only 1.5% of vineyards were covered against frost risks in 2017 (Landtag Baden-Württemberg, 2017). Thereafter, insurance demand slightly increased, but remained low, with the share of vineyards insured at the largest insurance company not exceeding 5% of all vineyards in 2019 (based on the data introduced in Section 4). To put an end to disaster relief payments and help establish a private frost insurance market, the state government of Baden-Württemberg decided to subsidize premiums from 2020 onwards. The government explicitly communicated in a press release that the introduction of the subsidy implies a shift from ex post disaster relief payments to ex ante premium subsidies (Ministerium für Ländlichen Raum und Verbraucherschutz, 2019a).

This policy change provides us with an opportunity to analyze whether a shift towards ex ante subsidies can increase coverage levels in an immature insurance market with evident charity hazard. The frost risk of winegrowers serves as an example for a risk that has become increasingly relevant over recent years but is not covered by established insurance markets. Other climate-related risks that have become more salient recently but are not part of common insurance products (e.g. drought, wildfires, excessive rainfall or heat waves) may run into similar dynamics with governmental disaster relief payments and subsequent need for policy changes. We aim to provide a better understanding about policymaking in these contexts where climate change alters risk profiles.

We study how the introduction of premium subsidies in Baden-Württemberg affects insurance demand and whether farmers who received recent disaster relief payments react differently to the subsidy compared to farmers who did not receive disaster relief payments.

[2] Vautard et al. (2022) show how climate change increases the risk of spring frost referring to a frost event in France in 2021.

Our analysis is based on municipality-level data of winegrowers provided by the largest German crop insurance company. We examine changes in insurance demand at the extensive margin (insured acreage). Changes at the intensive margin (coverage level) are not part of the analysis as insurance products and especially deductibles are mostly standardized, and farmers have little freedom in adjusting their coverage levels.[3] Typical contracts have coverage sums of around 10,000 € per hectare and deductibles of 20% of the coverage sum.

We focus on winegrowers, as no frost insurance markets for fruit growers, who are similarly affected by the frost risk, existed before the subsidy was introduced. Exploiting the federal structure of Germany, we use a difference-in-differences approach to analyze the subsidy introduction in the federal state of Baden-Württemberg, which was the first state to introduce the subsidy. The neighboring state of Rhineland-Palatinate serves as the control group. Rhineland-Palatinate and Baden-Württemberg are the two largest winegrowing states in Germany, accommodating approximately 63% and 26% of German vineyards, respectively (BMEL, 2021).

In our research, we find the premium subsidy to be effective in increasing insurance take-up at the extensive margin. Many new farmers buy frost insurance after the premium subsidy is introduced. Additionally, we find that farmers who have recently received disaster relief payments show a much stronger immediate increase in insurance demand compared to farmers who have not received any disaster relief payments. Our results also suggest that receiving higher disaster relief payments in the past is linked to higher increases in insurance demand.

We add to the literature in two ways. We provide evidence of the effectiveness of premium subsidies in an immature insurance market with low participation levels. The premium subsidy marks the change from ex post disaster relief payments to ex ante premium subsidies, which, to our knowledge, has not been studied elsewhere. Other studies analyze subsidy rate changes in existing subsidy programs to estimate their effectiveness (Garrido & Zilberman, 2008; O'Donoghue, 2014). Their initial implementation has not yet been studied. We demonstrate that the introduction of a premium subsidy can be highly effective in markets with low participation rates and where regular disaster relief payments are common.

Our work proposes that farmers are more responsive to the introduction of a premium subsidy if they have received recent disaster relief payments. We hypothesize that the effect is driven by loss experience, which has been shown to increase insurance demand (Cai & Song, 2017; Che et al., 2019; Gallagher, 2014; Kousky, 2017). In our context, we hypothesize charity hazard prior to the premium subsidy to be large enough to depress insurance demand

[3] The terms extensive and intensive margin are based on Che, Feng, and Hennessy (2019). See Hinck (2023) for an analysis of the effects of disaster relief payments on optimal insurance contract design.

so that most people remain uninsured. For the uninsured, the effect of loss experience cannot be observed through their insurance demands. Only when premium subsidies eliminate charity hazard does the effect of prior loss experience become observable, resulting in differing levels of insurance demand. It is predicted that farmers who experienced larger losses will show stronger increases in insurance demand.

Overall, the paper contributes to policy-making on insurance markets covering losses from natural hazards that are not part of established insurance products. Understanding the shift from ex post disaster relief payments to ex ante premium subsidies provides insights into how premium subsidies function and guidance for similar future policies. Premium subsidies can be an effective instrument in early markets to boost insurance participation. Recent experience with disaster relief payments may create advantageous situations for policy introductions, as such an experience seems to increase responsiveness.

2 Frost Insurance for Winegrowers

We analyze a premium subsidy that was introduced in Baden-Württemberg, a state of Germany, in 2020. It subsidizes insurance premiums against frost[4], storm, and heavy rainfall in viticulture and fruit growing by 50% (for contracts with at least 20% deductible) (Ministerium für Ländlichen Raum und Verbraucherschutz, 2019b). We focus on the risk of frost, as it is the most relevant of the three. The premium subsidy provides subsidization to almost all farmers. Only farmers covering less than 0.3 hectares of acreage and farmers choosing coverage sums above 30,000 € per hectare are not eligible for subsidization. These are exceptional cases such that only very few farmers do not meet the conditions of the subsidy. Prior to the introduction of the premium subsidy, the market for frost insurance contracts had been operating at low take-up levels. In 2017, only 1.5% of vineyards in Baden-Württemberg were covered against frost damage (Landtag Baden-Württemberg, 2017). In 2021, after the premium subsidy was implemented, overall insurance participation in Baden-Württemberg rose to 35% of vineyards (Fial, 2021).

As a severe frost event in 2011 already led to large losses and disaster relief payments in Baden-Württemberg, we expect that a lack of risk awareness cannot by itself explain low demand prior to the premium subsidy. The most plausible reasons for low demand prior to the premium subsidy are (high) prices of insurance coverage and charity hazard. From the insurer's data, which this study is based on and which is further described in Section 4, we

[4] Insurance against frost includes coverage against damages from winter frost and spring frost. Losses in 2011 and 2017 were caused by spring frost which is the main risk of interest within frost insurance contracts and policymaking.

observe that the loss ratios–the ratio of indemnity payments to premiums–in Baden-Württemberg were well above 1 in 2016, 2017 and 2019. Loss ratios equal to 1 imply that insured on average receive indemnity payments that are just as high as the premiums they pay. Loss ratios above 1 as in Baden-Württemberg either suggest high levels of adverse selection or insurance prices to be generally in favor of the insured. As frost risk exposure depends on the location and elevation of vineyards and the sort of grapevine grown, all of which insurers can observe, we argue that premium differentiation should be able to prevent large amounts of adverse selection. Given that substantial disaster relief payments were made in 2011 (~7 million €) and in 2017 (~50 million €), we argue that charity hazard is the most likely cause for low insurance demand (dpa, 2017; Wissenschaftlicher Dienst des Deutschen Bundestages, 2018).

The introduction of the subsidy arose from a debate that started in 2017 when the state of Baden-Württemberg made an ex post disaster relief payment to their fruit and winegrowers after cold temperatures in April had caused major damage to many farmers' harvests. According to the Research Services of the national German parliament, approximately 8,000 hectares, which make up around 30% of total vineyards in Baden-Württemberg, reported damages to 50% or more of their harvest in 2017 (Wissenschaftlicher Dienst des Deutschen Bundestages, 2018). The Research Services report that these losses to wine and fruit growers led Baden-Württemberg to pay 49.44 million € in overall disaster relief, 14.91 million € of which to winegrowers. Disaster relief payments had to abide by EU regulations, thus payments were only made to farmers whose losses exceeded 30% of their average harvest and only 50% of losses were reimbursed (see article 39 in EU regulation no 1305/2013).[5] Payments were also capped at 100,000 € per farmer.

Baden-Württemberg reportedly set limits on the total funds used for premium subsidies at 5 million € per year. From the government's perspective, the subsidy pays off financially when disaster relief payments that would be made if no premium subsidies were in place exceeded the funds used for subsidizing premia. In our studied example, disaster relief payments to fruit and winegrowers are just below 50 million € whereas the subsidization costs the government up to 5 million € per year. If there is one similar disaster as in 2017 within the next ten years and the state does not make any disaster relief payments, the government's policy breaks even. If more than one of such disasters takes place within the next ten years, the government saves money by its premium subsidy policy.

Rhineland-Palatinate followed Baden-Württemberg with the introduction of a similar premium subsidy in 2021. In Rhineland-Palatinate, premiums against frost and hail, which are usually bought as bundled contracts, are subsidized by 50%, capped at 200 € per hectare in

[5] The threshold for reception of income stabilization was lowered to 20% at the end of 2017 (see PE-CONS 56/17 of the EU Parliament).

the first year (Ministerium für Wirtschaft, 2021).[6] All farmers receive subsidies as long as premium subsidies are larger or equal to 200 €. Only very few farmers, who buy low levels of coverage and whose premiums do not exceed 400 € do not receive subsidies. In Rhineland-Palatinate, no disaster relief payments were made in 2017. The ministry rationalized their decision based on the availability of insurance products before the disaster had occurred.

Prior to the premium subsidy offered in Baden-Württemberg, subsidies on German crop insurance markets for winegrowers have played a negligible role in recent years. Saxony-Anhalt (0.7% of German vineyards) and Saxony (0.5% of German vineyards) subsidize premiums for all insurable risks by 50%. Rhineland-Palatinate subsidized insurance premiums against all insurable risks by 50% capped at 40 € per hectare until 2013, which is significantly less than the cap from 2021 at 200 € per hectare (BMEL, 2013). The subsidy was also aimed at insurance contracts for hail, as frost insurance contracts only started to be sold in 2013. Between 2014 and 2020, there were no premium subsidies in place in Rhineland-Palatinate. The analyzed premium subsidy in Baden-Württemberg is the first subsidy of its kind within Baden-Württemberg and the first explicitly aimed at the risk of frost within Germany.

There are two types of crop insurance contracts: yield insurance and revenue insurance. While yield insurance guarantees a predetermined amount of yield at a price that is agreed upon when signing the contract, revenue insurance guarantees a share of a predefined revenue. Yield insurance does not cover any price risks because the indemnity payment is independent of market prices. Revenue insurance includes coverage against fluctuations in price as the farmer receives indemnity when he falls short of his predefined revenue irrespective of whether he falls short because of low yield or because of low market prices. In Germany, yield contracts are the predominant form. Prices are determined by farmers in the form of coverage sums per hectare. When farmers purchase coverage, they state the number of hectares they would like to insure and the coverage sum per hectare (e.g., 10.000 €). Typical deductible levels are 20% of the coverage sum. Upon damage, the insurer reimburses farmers based on the percentage yield loss per hectare. If a farmer loses 50% of her yield on a hectare covered with 10.000 € and a 20% deductible (2.000 €), she receives reimbursement of 3.000 €. As price risks are not covered by the studied insurance contracts, they are not the subject of this study.

To finance premium subsidies for crop insurance, German states can use their own tax funds as long as the subsidy is approved by the EU, which regulates agricultural markets through the Common Agricultural Policy (CAP). This is how Baden-Württemberg currently finances its premium subsidy. Alternatively, states can use EU funds allocated through the CAP. Within the CAP, there are two programs that allow for premium subsidies. States can use funds

[6] The subsidy has been raised in 2022 to 80% capped at 300 € per hectare.

targeted at the common organization of the market in wine (CMO), which is part of the so-called first pillar of CAP and was fundamentally reformed in 2008 (see EU Council Regulation No 479/2008). Rhineland-Palatinate, Saxony and Saxony-Anhalt finance their subsidies through these CMO funds. The second program within the CAP that allows for premium subsidies promotes risk management in agriculture and is part of the so-called second pillar of CAP (Article 37 of EU regulation No 1305/2013). To the authors' knowledge, Baden-Württemberg plans to finance a share of their premium subsidy through the second pillar of CAP from 2024 onward.

3 Effects of Premium Subsidies

To study the effects of premium subsidies, we first consider a model of insurance demand on the individual level. We use the model to understand the channels through which the premium subsidy affects insurance demand. To derive predictions for our empirical analysis on municipality level, we focus on the effects of a premium subsidy on the behavior of a representative farmer. We show that the general direction of the predictions is not driven by the exact specification of the farmer allowing us to infer hypotheses on the municipality level from a model of individual insurance demand.

We consider a model with two states of the world and a risk-averse individual (farmer) who assesses outcomes using a concave twice differentiable utility function $u(.)$. The individual has initial wealth w_0 and faces a loss of $L \in (0, w)$ with probability $p \in (0,1)$.[7] Individuals can buy insurance, which provides an indemnity payment $I = \alpha L$ at a premium $P = \alpha\lambda pL$, where $\alpha \in [0,1]$ denotes the coverage level and $\lambda \geq 1$ a proportional loading factor. The proportional loading factor captures transaction costs and profits of insurance companies. Under perfect competition and in absence of any transaction costs, the loading factor is 1 ($\lambda = 1$) and premiums are actuarially fair. With actuarially fair premiums, individuals can transfer their risk to the insurance company at a premium equal to the expected loss of the risk. When insurance markets are not perfectly competitive, insurers can load their premiums ($\lambda > 1$) and make profits. When $\lambda < 1$, the insurer's indemnity is on average higher than the premium payment and the insurer makes losses. We assume that individuals anticipate disaster relief payments $\theta_0 \in [0,1]$ on their uninsured losses (Raschky & Weck-Hannemann, 2007). We use the terms anticipated disaster relief payments and charity hazard synonymously from hereon. The final wealth in the no-loss state is $W_1 = w - \alpha\lambda pL$, and the final wealth in the loss state is $W_2 = w -$

[7] We do not include farmers' production decisions as other agricultural models of insurance demand may (e.g. Du, Feng, & Hennessy, 2017; Yu, Smith, & Sumner, 2017; Yu & Sumner, 2018). The reason is that vineyards are permanent crops which are not planted yearly and usually have lifetimes between 20 to 30 years.

$\alpha\lambda pL - (1-\theta_0)(1-\alpha)L$. The expected utility of the individual to be maximized with respect to α is:

$$\max_{\alpha} E[u(\alpha)] = (1-p) * u(w-P) + p * u(w-P-(1-\theta_0)(1-\alpha)L) \quad (1)$$

We can derive optimal insurance demand $\alpha^* \in [0,1]$ from equation (1). It can be optimal to not buy any insurance ($\alpha^* = 0$) in which case $\frac{\partial E[u(\alpha)]}{\partial \alpha}\Big|_{\alpha=0} \leq 0$. Individuals buy full insurance ($\alpha^* = 1$) when $\frac{\partial E[u(\alpha)]}{\partial \alpha}\Big|_{\alpha=1} \geq 0$. Partial insurance ($0 < \alpha^* < 1$) is optimal when α^* solves the following first-order condition:

$$FOC: (1-p) * u'(W_1)[-\lambda pL] + p * u'(W_2)[-\lambda pL + (1-\theta_0)L] = 0 \quad (2)$$

We follow other analyses of insurance demand such as Mossin (1968) or Jaspersen, Peter, and Ragin (2022) and derive an upper bound loading factor $\bar{\lambda}$ as well as a lower bound loading factor $\underline{\lambda}$ to study the effect of charity hazard on insurance demand. It holds that for any $\lambda \geq \bar{\lambda}$, individuals do not buy any insurance ($\alpha^* = 0$). Similarly, individuals buy full insurance ($\alpha^* = 1$) at any $\lambda \leq \underline{\lambda}$. Partial insurance is optimal for any λ between the upper bound and the lower bound, such that $\underline{\lambda} < \lambda < \bar{\lambda}$. Based on equation (2) we derive $\bar{\lambda}$ and $\underline{\lambda}$ from $\frac{\partial E[u(\alpha)]}{\partial \alpha}\Big|_{\alpha=0} = 0$ and $\frac{\partial E[u(\alpha)]}{\partial \alpha}\Big|_{\alpha=1} = 0$:

$$\underline{\lambda} = 1-\theta_0 \qquad \bar{\lambda} = \frac{u'(w-(1-\theta_0)L)(1-\theta_0)}{(1-p)u'(w) + pu'(w-(1-\theta_0)L)} \quad (3)$$

When $\lambda \geq 1$, which holds in most cases, $\underline{\lambda}$ shows that individuals never buy full insurance when charity hazard exists ($\theta_0 > 0$). We can further show that both $\underline{\lambda}$ and $\bar{\lambda}$ decrease when charity hazard increases (derivatives of $\underline{\lambda}$ and $\bar{\lambda}$ with respect to θ_0 are shown in Appendix A). A decrease of $\bar{\lambda}$ implies that individuals stop purchasing insurance at lower premium loadings. A lower $\underline{\lambda}$ implies that a lower premium loading factor is required for individuals to buy full insurance. Both effects represent a decrease in insurance demand. The effect is enhanced as the corridor between $\underline{\lambda}$ and $\bar{\lambda}$–the interval of λ, on which partial insurance is optimal–decreases in θ_0 (we show in Appendix A that $\frac{\partial \underline{\lambda}}{\partial \theta_0} \geq \frac{\partial \bar{\lambda}}{\partial \theta_0}$).

When partial insurance is optimal with $\underline{\lambda} < \lambda < \bar{\lambda}$, we derive the effect of θ_0 on α^* by applying the implicit function theorem:

$$\frac{\partial \alpha}{\partial \theta_0} = -\frac{\partial^2 E[u(\alpha)]/\partial\alpha\partial\theta_0}{\partial^2 E[u(\alpha)]/\partial\alpha^2} = -\frac{EU_{\alpha\theta_0}}{EU_{\alpha\alpha}} \quad (4)$$

As $EU_{\alpha\alpha} < 0$, it follows that $sgn\left(\frac{\partial\alpha}{\partial\theta_0}\right) = sgn(EU_{\alpha\theta_0})$, which is given by:

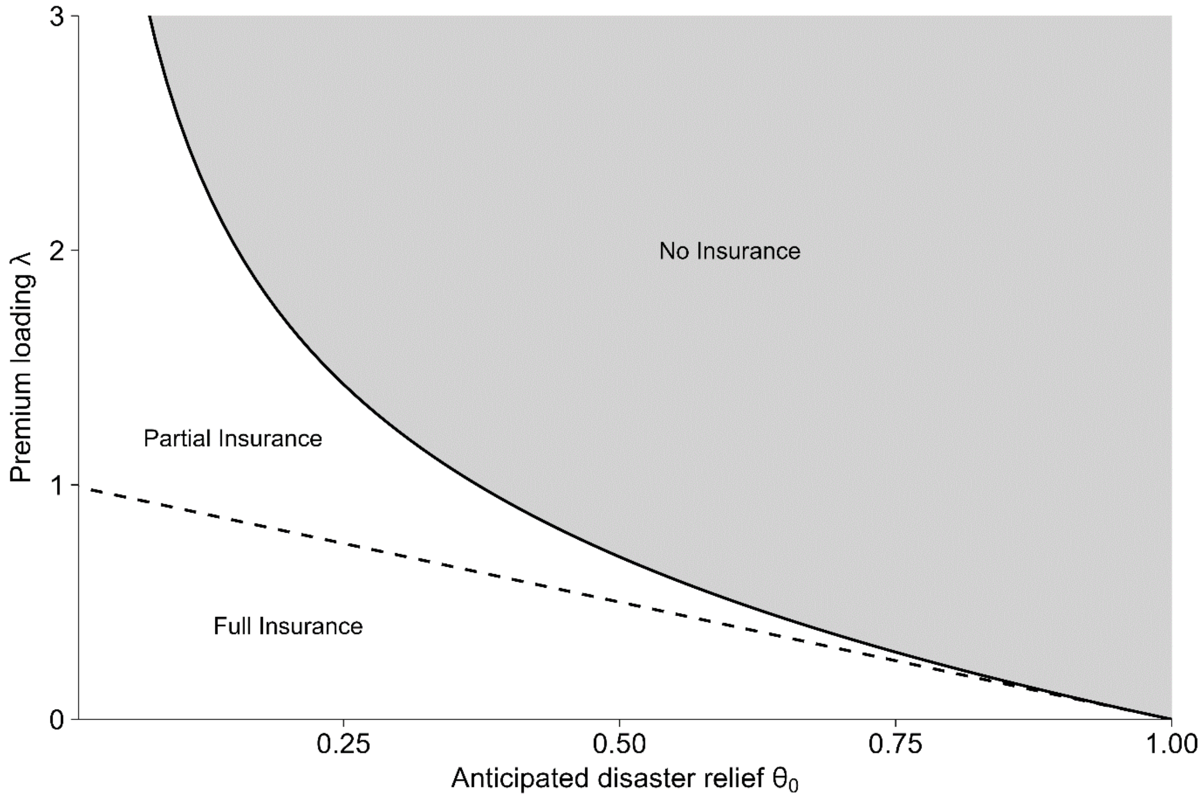
$$EU_{\alpha\theta_0} = pu''(W_1)(1-\theta_0-\lambda p)(1-\alpha)L^2 - pLu'(W_2) \quad (5)$$

Partial insurance demand decreases in θ_0 when $EU_{\alpha\theta_0} < 0$, which holds when $1-\theta_0-\lambda p > 0$. We can show that $1-\theta_0-\lambda p < 0$ only holds when $\lambda > \bar{\lambda}$, in which case no inner solution exists (see Appendix A). Partial insurance can only be optimal when $1-\theta_0-\lambda p > 0$ and it then decreases in θ_0 with $\frac{\partial\alpha}{\partial\theta_0} < 0$.

Charity hazard crowds out insurance demand through three mechanisms. It lowers the boundary loading levels $\underline{\lambda}$ and $\bar{\lambda}$. It decreases the distance between $\underline{\lambda}$ and $\bar{\lambda}$, thereby reducing the range of λ, on which partial insurance is optimal. And charity hazard lowers partial insurance demand.

We provide an example to show how charity hazard crowds out insurance demand in Figure 1. We assume an iso-elastic utility function $u(W) = \frac{W^{1-\gamma}}{1-\gamma}$ with a constant relative risk aversion parameter of $\gamma = 0.5$, a loss probability p of 5% and a loss size L that is equal to initial wealth. Figure 1 shows how both $\underline{\lambda}$ and $\bar{\lambda}$ decrease with higher levels of charity hazard θ_0. The figure also demonstrates how the corridor between $\underline{\lambda}$ and $\bar{\lambda}$ decreases in θ_0. The area on which individuals buy insurance shrinks as charity hazard increases.

Figure 1: Insurance demand under charity hazard



Given our setup of charity hazard, we study the effect of a premium subsidy. We assume that the government can subsidize a fraction $s \in [0,1]$ of the insurance premium. The subsidized insurance premium for an individual is $P^s = \alpha(1-s)\lambda pL$. When the government communicates that with the introduction of the premium subsidy, disaster relief payments will be held back in the future, we assume that the premium subsidy affects the anticipation of disaster relief payments. We model the reduction in charity hazard by the premium subsidy s with a function for anticipated disaster relief $\theta: s \to [0,1]$ with $\theta' \leq 0$ and $\theta(0) = \theta_0$. With premium subsidies s and disaster relief anticipation $\theta(s)$, the individual's objective function is:

$$\max_{\alpha} E[u(\alpha)] = (1-p) * u(w - P^s) + p * u\big(w - P^s - (1-\alpha)\big(1-\theta(s)\big)L\big) \quad (6)$$

Equivalent to equation (3), we can derive boundary loading levels. We now denote them as $\underline{\lambda}^s$ and $\bar{\lambda}^s$:

$$\underline{\lambda}^s = \frac{1-\theta(s)}{1-s} \qquad \bar{\lambda}^s = \frac{u'\big(w - \big(1-\theta(s)\big)L\big)\big(1-\theta(s)\big)}{(1-s)\Big((1-p)u'(w) + pu'\big(w - \big(1-\theta(s)\big)L\big)\Big)} \quad (7)$$

We can study the effect of a premium subsidy on both boundary loading factors $\underline{\lambda}^s$ and $\bar{\lambda}^s$ by determining the first-order derivatives with respect to s. We now denote final wealth in the no-loss state as $W_1^s = w - \alpha(1-s)\lambda pL$ and final wealth in the loss state as $W_2^s = w - \alpha(1-s)\lambda pL - \big(1-\theta(s)\big)(1-\alpha)L$. With $k = (1-p)u'(w) + pu'\big(w - \big(1-\theta(s)\big)L\big) > 0$, the derivatives are:

$$\frac{\partial \underline{\lambda}^s}{\partial s} = \frac{\overbrace{\big(1-\theta(s)\big)}^{\text{(a) } (+)} \overbrace{- \frac{\partial \theta(s)}{\partial s}(1-s)}^{\text{(b) } (+)}}{(1-s)^2} > 0 \quad (8)$$

$$\frac{\partial \bar{\lambda}^s}{\partial s} = \frac{\left(\begin{array}{c} \overbrace{u'(W_2^s)\big(1-\theta(s)\big)k}^{\text{(a) } (+)} \\ \overbrace{-\frac{\partial \theta(s)}{\partial s}\Big(u'(W_2^s)(1-s)k - u''(W_2^s)\big(1-\theta(s)\big)(1-s)L\big((1-p)u'(W_1^s)\big)\Big)}^{\text{(b) } (+)} \end{array}\right)}{\big((1-s)k\big)^2} > 0 \quad (9)$$

The premium subsidy increases the insurance demand by increasing both boundary loading factors $\underline{\lambda}^s$ and $\bar{\lambda}^s$ through two channels: (a) a price effect from reducing premiums and (b) a charity hazard effect from reducing anticipated disaster relief payments. Both effects are positive. The lower $\frac{\partial\theta(s)}{\partial s}$, that means, the more the premium subsidy lowers charity hazard, the more does the introduction of a premium subsidy increase $\underline{\lambda}^s$ and $\bar{\lambda}^s$.

The effect of premium subsidies on partial insurance demand is also characterized by a price effect and a reduction in charity hazard. Applying the implicit function theorem, we derive $\frac{\partial\alpha}{\partial s}$:

$$\frac{\partial\alpha}{\partial s}=\frac{\left(\begin{array}{c}\overbrace{\begin{array}{c}\lambda pL(1-p)\big(u''(W_1^s)(-\alpha(1-s)\lambda pL)+u'(W_1^s)\big)\\ +\lambda p^2L\big(u''(W_2^s)\alpha L(1-\theta(s)-(1-s)\lambda p)+u'(W_2^s)\big)\end{array}}^{\text{(a) }(+/-)}\\ \overbrace{-\frac{\partial\theta(s)}{\partial s}\Big(pL\big(u'(W_2^s)-u''(W_2^s)(1-\alpha)L(1-\theta(s)-(1-s)\lambda p)\big)\Big)}^{\text{(b) }(+)}\end{array}\right)}{-\underbrace{\left((1-p)u''(W_1^s)(-\lambda(1-s)pL)^2+pu''(W_2^s)\Big(\big(1-\theta(s)\big)L-(1-s)\lambda pL\Big)^2\right)}_{EU_{\alpha\alpha}<0}} \qquad (10)$$

The sign of $\frac{\partial\alpha}{\partial s}$ is determined by the sign of the numerator as the denominator is strictly positive. The first two terms in the numerator show the effect of the subsidy through lowering the premium. The sign of the price effect is ambiguous in equation (10). The ambiguity of the sign of the premium effect (a) is caused by the possibility of insurance to be a Giffen good. The conditions under which insurance is a Giffen good are analyzed by Briys, Dionne, and Eeckhoudt (1989), Hau (2008) and Hoy and Robson (1981). We show in Appendix B that a highly unlikely combination of large losses, high loadings and high loss probabilities would be necessary for insurance to turn into a Giffen good in our context. Hence, we expect the first term to be positive in most cases and insurance to be an ordinary good for which lower prices through subsidization lead to higher demand. The third term of the numerator shows how lowering charity hazard through the introduction of a premium subsidy increases insurance demand. We can show that $1-\theta(s)-(1-s)\lambda p<0$ holds for all inner solutions (analogous to the proof in Appendix A, where we show that $1-\theta_0-\lambda p<0$ for all inner solutions without premium subsidies). The size of the effect depends on $\frac{\partial\theta(s)}{\partial s}$. The more effective premium subsidies lower charity hazard, the more do they increase partial insurance demand.

We use the model to illustrate the effects of premium subsidies on German winegrowers. Based on the context of our study, we characterize a representative winegrower in Baden-Württemberg to form predictions about the effects of the subsidy. As discussed below in more detail, the main predictions are insensitive to changes in the winegrower's characteristics. We argue that the derived hypothesis holds even if the parameter specification of winegrowers may vary across municipalities. We assume winegrowers to follow an iso-elastic utility function with constant relative risk aversion of 0.5. We consider a farmer facing the risk of losing 30% of his wealth, the average loss among farmers in Baden-Württemberg in 2017 in our sample. With a 30% loss, the farmer is barely eligible for disaster relief payments in our setting. The disaster relief payments reimburse him for 50% of his loss, which makes up 15% of his initial wealth. As the government also made disaster relief payments in 2011, we assume that the farmer anticipates such disaster relief payments and set the initial level of charity hazard to $\theta_0 = 0.5$. The premium subsidy amounts to 50% of the insurance premium. We additionally assume premium loadings to be weakly above 1 and loss probabilities to be weakly below 25%. The data-providing insurance company reports loss ratios of 65.5% in 2022, 81% in 2021 and 60.6% in 2020 implying loading factors of 1.53, 1.23 and 1.65 respectively (Vereinigte Hagel, 2021, 2022). Based on these values, we use a loading factor of 1.5 as reference point for the following discussion. We find the aggregated loss ratio in our sample to be above 1 and thereby the loading factor in our dataset to be lower than 1 in most years. We expect these low loading factors to be caused by large losses in recent years and little pricing experience by the insurance company. As we do not know the exact loading factor, we discuss the theoretical predictions for different loading factors. Among the insured winegrowers from our dataset, the probability of losing more than 30% of the coverage sum are 5.83%. The probability of losing more than 10% of the coverage sum are 15.06%. Reliable loss probabilities are difficult to obtain which is why we only make the weak assumption that the probability of losing 30% of the coverage sum lies below 25%. Table 1 summarizes:

Table 1: Parameter specification of a representative winegrower in Baden-Württemberg

Parameter specification of a representative winegrower

Constant relative risk aversion	γ	0.5
Initial wealth and loss size	w, L	$w = 0.3L$
Loss probability	p	$p \leq 0.25$
Premium loading	λ	$\lambda \sim 1.5$
Charity hazard	θ_0	0.5
Premium subsidy	s	0.5

Figure 2: Insurance demand of a representative winegrower

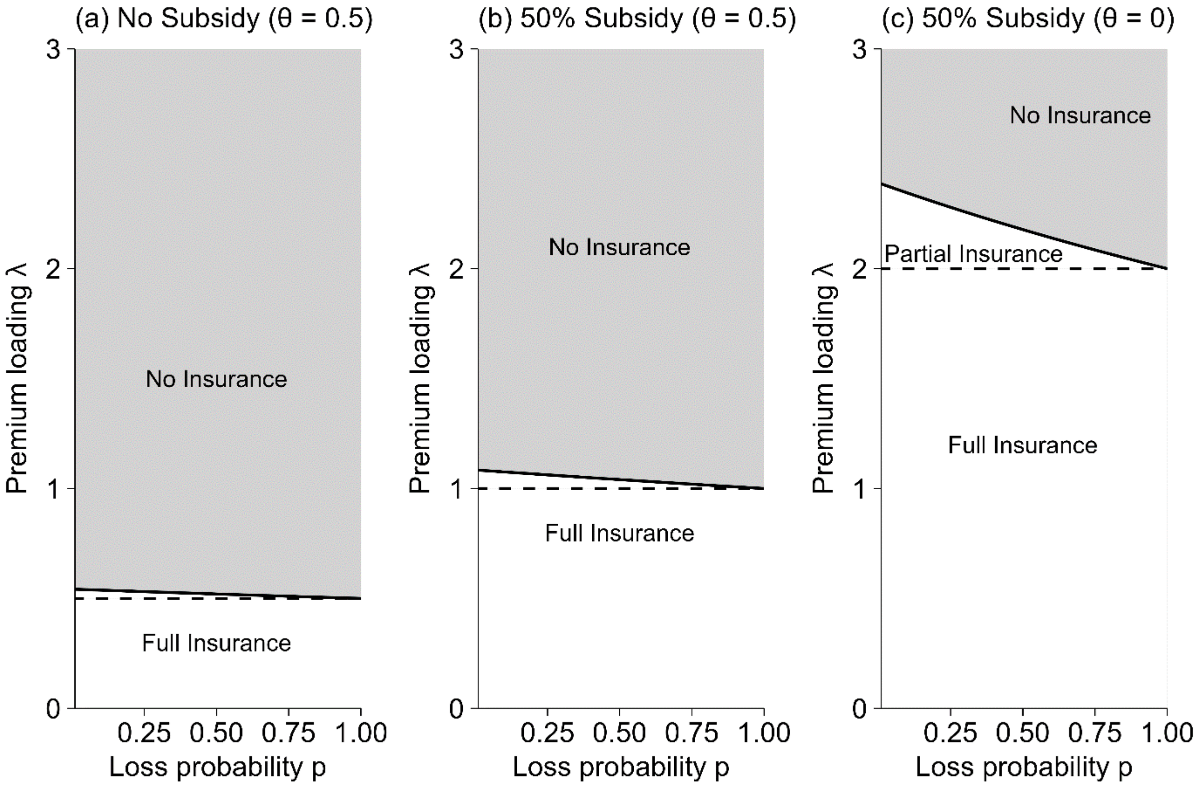


Figure 2 shows the effects of the premium subsidy on insurance demand of the farmer specified in Table 1. We present other specifications in Appendix C showing that the model predictions are not driven by our assumption of risk aversion or loss size. Panel (a) shows insurance demand prior to the premium subsidy. Even at fair premiums ($\lambda = 1$), the farmer would not buy insurance when he anticipates disaster relief payments of 50%, which is in line with low insurance demand in Baden-Württemberg prior to 2020. Panel (b) describes the situation in which the premium subsidy does not affect anticipation of disaster relief payments and charity hazard remains at $\theta(0.5) = 0.5$. Without a reduction of charity hazard, the premium subsidy affects insurance demand only through its price effect. In our example, the price effect only matters when the premium loading factor λ is very low. For a loss probability of 1%, the individual does not buy any insurance when λ is larger than ~1.08. The individual only buys full insurance when $\lambda \leq 1$. For loading factors between 1 and ~1.08, the individual buys partial coverage. Given the reference loading factor of 1.5 from above, it seems unlikely that the pure price effect would be able to increase insurance demand meaningfully. The size of the price effect crucially depends on the initial level of charity hazard θ_0. The higher the level of initial charity hazard, the more depressed insurance demand without premium subsidies and the less visible the price effect.

Panel (c) shows the effect of the premium subsidy on insurance demand when the premium subsidy fully removes charity hazard. An example of a charity hazard function $\theta(s)$ which would completely eliminate charity hazard in the given example is a linearly decreasing function $\theta(s) = \theta_0(1-s)$. The elimination of charity hazard has a strong impact on insurance demand. Full insurance is optimal for any loading factors below 2. Under the reference loading of 1.5, the representative farmer would buy full insurance. Figure 2 shows that in our specification the price effect appears small compared to the effect from lowering charity hazard. The effectiveness of the premium subsidy seems to mainly depend on how much charity hazard the premium subsidy can eliminate. Our model captures this ability of the premium subsidy by the charity hazard function $\theta(s)$. The exact form of this function depends on the risk and especially the political context. We would expect that the more credible a government communicates a reduction in future disaster relief payments alongside the introduction of a premium subsidy, the steeper $\theta(s)$. Other factors such as upcoming election years and the political power of the exposed population in demanding disaster relief payments may also define the slope and curvature of $\theta(s)$.

On the German frost insurance market for winegrowers, we expect that the active communication by the state of Baden-Württemberg about eliminating future disaster relief programs once the premium subsidy is implemented leads to a substantial decrease in charity hazard. In combination with the price effect of the subsidy, we hypothesize insurance demand to increase when premiums are subsidized:

Hypothesis 1: The introduction of a premium subsidy, which a policymaker uses to replace disaster relief payments, leads to an increase in insurance demand.

Besides intensifying charity hazard, disaster relief payments also imply severe loss experience for individuals. Gallagher (2014) uses the reception of disaster relief payments as a proxy for loss experience and shows that individuals buy more insurance after they experience a severe flood. Other studies show similar effects supporting the notion that experiencing severe losses leads to a subsequent increase in insurance demand (Cai & Song, 2017; Che et al., 2019; Kousky, 2017).

Gallagher (2014) suggests that the effect of loss experience can be explained by updated probability perception. Individuals follow a Bayesian learning model in estimating probabilities and their probability estimation goes up after experiencing a catastrophic loss. The size of the increase in probability estimation depends on the amount and quality of initial information and learning experience prior to the loss event (the strength of the prior in Bayesian language). He shows that the pattern in insurance demand that he observes can either be explained by discounting learning experiences over time or by lack of prior information.

Jaspersen et al. (2022) show that individuals who overestimate probabilities buy more insurance. Similarly, Collier, Schwartz, Kunreuther, and Michel-Kerjan (2022) demonstrate how overestimation of small probabilities can explain unexpectedly high insurance demand. When individuals experience losses and update their probability estimation, loss experience leads to an increase in insurance demand. Alternatively, experiencing losses may affect insurance demand through changing risk preferences. Especially, when risk aversion decreases in wealth usually represented by decreasing absolute risk aversion (DARA), a loss of wealth makes farmers more risk averse (Guiso & Paiella, 2008; Haushofer & Fehr, 2014). Higher risk aversion increases insurance demand and may also explain why loss experience increases insurance demand.

As assumed in Figure 2 and the derivation of Hypothesis 1, we expect frost insurance demand of German winegrowers to be widely suppressed by charity hazard prior to the introduction of premium subsidies. The largest insurance company covers less than 5% of all vineyards just before the premium subsidy is introduced (based on the data introduced in Section 4). It follows that the effect of the catastrophic loss experience in 2017 on insurance demand is not visible because charity hazard depresses insurance demand. When the premium subsidy eliminates large parts of charity hazard and individuals buy more insurance, the effects from different loss experiences become visible. We expect individuals who experienced larger losses in 2017 to demand more insurance when the premium subsidy is introduced. Hypothesis 2 follows:

Hypothesis 2: The introduction of a premium subsidy, which aims to replace disaster relief payments, leads to a larger increase in insurance demand among individuals who have recently received disaster relief payments.

4 Data

The main data source for this study is a panel dataset provided by the largest German crop insurance company (“Vereinigte Hagel VVaG”). In 2017, it covered a market share of 57.3% of the German crop insurance market measured by the sum of premiums (BMEL, 2019). Based on information from the agricultural ministry of Baden-Württemberg, the company insured more than half of the total acreage covered by subsidized frost insurance contracts within Baden-Württemberg in 2022, and numbers have been relatively constant since the subsidy was introduced in 2020. The dataset includes information on frost insurance contracts that were taken out by winegrowers from Baden-Württemberg and Rhineland-Palatinate between 2013 (when frost insurance was first sold) and 2021.

We aggregate individual contract data on the municipality level because we analyze insurance demand at the extensive margin (insured acreage). We focus on the extensive margin as there is very little variation in contract specification within individuals, as they usually stay with their initially chosen contract. Individuals are also obliged to cover all their acreage such that there is no variation of the extensive margin within farmers over time. Farmers only appear in our sample once they buy insurance and we do not know their behavior prior to purchasing insurance at the data-providing insurer. There is no variation at the individual level of insurance purchasing behavior that we can use to infer the effect of the premium subsidy.

By aggregating the data to the municipality level, we can retrieve an easily interpretable measure of how the premium subsidy affects insured acreage per municipality. We aggregate insurance demand per year by adding premiums, coverage sums, insured hectares and insured losses of all farmers within a municipality. If a farmer owns vineyards located in different municipalities, we attribute each vineyard to the municipality it lies in. For example, a farmer owns 10 hectares of vineyards of which 3 hectares lie in one municipality and 7 hectares in a different municipality, the coverage sum per hectare is 10,000 € and the resulting premium is 300 € per hectare. We would attribute 3 hectares of insured acreage, 900 € premiums and 30,000 € coverage sum to the first municipality and 7 hectares of insured acreage, 2,100 € premiums and 70,000 € coverage sum to the second municipality. Our sample contains for a given year all municipalities in which the data-providing insurer covers vineyards.

There are 3,557 individual-year observations from 1,973 unique individuals in the original sample. We exclude 18 farmers (36 individual-year observations), who cover less than 0.3 hectares, and 5 farmers (16 individual-year observations), who choose coverage sums above 30,000 € per hectare in Baden-Württemberg after the premium subsidy is introduced. We also exclude 12 farmers (19 individual-year observations) in Rhineland-Palatinate. These are farmers, whose total premiums for combined hail and frost coverage is below 400 € in 2021 such that they do not receive premium subsidies as they do not reach the minimum subsidy of 200 €. These farmers are excluded from the premium subsidy and do not receive treatment. As all of these farmers are spread out across different municipalities and all other farmers within these municipalities are eligible for premium subsidies, we cannot use these farmers as control group in our municipality-level analysis and exclude them from the sample. The final sample is based on 3,486 individual-year observations from 1,938 unique individuals and includes 2,058 municipality-year observations with 598 unique municipalities. For regression analyses, 2021 is excluded for the reasons elaborated below. Excluding 2021, there are 1,464 municipality-year observations and 412 unique municipalities in the dataset.

Data on disaster relief payments from 2017 are provided by the agricultural ministry of Baden-Württemberg ("Ministerium für Ländlichen Raum und Verbraucherschutz Baden-Württemberg"). The information includes the absolute amounts of disaster relief payments that were transferred to each municipality and the number of farmers receiving disaster relief per municipality. Data about the total size of vineyards per municipality in Baden-Württemberg are downloaded from the statistical office of Baden-Württemberg ("Statistisches Landesamt Baden-Württemberg"). Information on vineyards per municipality in Rhineland-Palatinate is provided by the statistical office of Rhineland-Palatinate ("Statistisches Landesamt Rheinland-Pfalz"). Data for modeling spring frost risks per municipality include weather data, which are downloaded from the German meteorological service ("Deutscher Wetterdienst"), and phenological data on the budbreak of different types of grapevine, which are provided by a German public research institution on winegrowing ("Staatliche Lehr- und Versuchsanstalt für Wein- und Obstbau Weinsberg").

Based on the available data, we construct variables to empirically analyze the introduction of the premium subsidy. We measure insurance demand using relative insurance participation as the share of insured vineyards in hectares per municipality. The variable is calculated by dividing the size of vineyards in hectares covered by the data-providing insurer by the total size of vineyards within a municipality based on the numbers from the statistical offices. As the number of covered hectares is based on one insurer only, the variable only captures a fraction of the market. There are 3 municipalities in our sample for which the statistical offices do not record any vineyards. Within these municipalities, we assume the total size of vineyards to be equal to insured vineyards.

Premium levels are defined as the premium per € coverage sum per municipality. As Goodwin (1993), Smith and Baquet (1996) and Feng, Du, and Hennessy (2019) suggest, an important determinant of insurance demand is the relation of indemnities to premiums. Using the terminology of Goodwin (1993), we define the loss ratio per municipality as the sum of claims over the sum of premiums and lag the variable by one period. We lag the variable to ensure that we capture the effect of loss ratios on insurance demand. To capture diverse levels of frost insurance participation within municipalities prior to the introduction of the subsidy, we measure past insurance demand by lagging the dependent variable of insurance participation by one year.

Last, we construct a variable capturing spring frost risk exposure, which is the main risk that the premium subsidy is aimed at. The variable is based on temperature data of the closest weather station of each municipality. Temperature data are an average of the temperature measured at five centimeters over the ground and two meters over the ground. Spring frost occurs when the temperature drops below 0 °C after the buds of plants have opened up

(Chmielewski, Blümel, Henniges, Müller, & Weber, 2010; Vitasse & Rebetez, 2018). Data from a local agricultural research institute ("Staatliche Lehr- und Versuchsanstalt für Wein- und Obstbau Weinsberg") provides dates for all years of the time series, at which budbreaks of several types of grapevine have taken place. Choosing the most conservative way to model spring frost risks, temperatures below 0 °C after the date at which the earliest budbreak among all documented sorts of grapevine has taken place are cumulated. The more negative the temperature is after budbreak occurs, the higher the risk of spring frost within a municipality. The cumulative temperature is multiplied by minus one for ease of interpretation. As weather stations are not located in every municipality, frost risk measures are averaged across counties based on all municipalities in which insured farmers are located. We lag the variable as farmers buy insurance prior to the potential frost events in a given year.

The absolute amount of disaster relief payments per municipality (DR) indicates the amount of disaster relief payments in €. As absolute disaster relief payments are highly correlated to municipality size, we create two relative measures of disaster relief payments that are more robust to differences in municipality size. The first variable (DR/ha) measures the amount of disaster relief payments per municipality size by dividing disaster relief payments per municipality by the total amount of vineyards in hectares per municipality. The second variable (DR/farmer) measures the amount of disaster relief payments per farmer per municipality by dividing disaster relief payments per municipality by the number of farmers receiving disaster relief payments per municipality.

Panel (a) of Table 2 provides descriptive statistics of the variables used in the regression split by pre-treatment years 2013 – 2019 and post-treatment year 2020. Frost risk in Baden-Württemberg appears to be higher than frost risk in Rhineland-Palatinate as shown by the frost risk variable and slightly higher premium rates in Baden-Württemberg. Within municipalities in which the data-providing insurer covers farmers between 2013 and 2019, it covers on average 11% of vineyards in Baden-Württemberg and 5.1% in Rhineland-Palatinate. The average insurance participation per municipality increases to 24% in Baden-Württemberg and to 9.4% in Rhineland-Palatinate in 2020. Pre-treatment, there are also more municipality-year observations (n) in Rhineland-Palatinate than in Baden-Württemberg. This difference in the number of observations can be explained by overall more municipalities in Rhineland-Palatinate that grow wine (493 municipalities) than in Baden-Württemberg (296 municipalities) as shown in Panel (b) of Table 2.

Panel (b) of Table 2 shows descriptive statistics of the disaster relief payments in Baden-Württemberg in 2017. Of 296 wine-growing municipalities in Baden-Württemberg, 152 or 51.35% received disaster aid in 2017. These 152 municipalities cover 21,967.83 hectares of vineyards or 80.45% of the overall 27,295.69 hectares in Baden-Württemberg. There are

6,464 winegrowers in Baden-Württemberg, of which 947 or 14.65% received disaster relief payments (Statistisches Bundesamt, 2020). The overall disaster relief payments to winegrowers in 2017 are 14,905,209 € of which 14,224,769 € went to municipalities within our sample. The municipalities within our sample that received disaster relief payments cover 21,266.05 € hectares of vineyards and 899 of the farmers who applied for disaster relief payments. The resulting average disaster relief payment per appyling farmer within our sample is 15,822.88 € and the resulting average disaster relief payment per hectare of vineyard is 668.90 €.

Table 2: Summary statistics of municipality-year observations and disaster relief payments excluding 2021

Panel (a) – Descriptive statistics of regression variables (2013 – 2020)

Variables	Pre-treatment (2013 – 2019)			Post-treatment (2020)		
	n	**mean**	**Sd**	**n**	**mean**	**Sd**
Baden-Württemberg (treatment group)						
Insurance participation	284	0.11	0.17	185	0.24	0.24
Premium per coverage sum (in €)	284	0.031	0.010	185	0.030	0.0079
Loss ratio (lagged)[1)]	167	>1	7.11	117	>1	3.37
Frost risk (lagged)	167	7.5	10.03	117	5.99	4.48
Insurance participation (lagged)	167	0.11	0.17	117	0.12	0.18
Rhineland-Palatinate (control group)						
Insurance participation	788	0.051	0.092	207	0.094	0.16
Premium per coverage sum (in €)	788	0.023	0.0067	207	0.025	0.0051
Loss ratio (lagged)[1)]	586	>1	4.47	182	<1	4.08
Frost risk (lagged)	586	3.94	5.73	182	2.46	2.44
Insurance participation (lagged)	586	0.040	0.053	182	0.086	0.16

[1)] Exact loss ratios are not reported to ensure confidentiality of the data.

Panel (b) – Descriptive statistics of disaster relief payments from 2017

	All wine-growing municipalities		Wine-growing municipalities receiving disaster relief	
	Overall	**In-Sample (2013 – 2020)**	**Overall**	**In-Sampe (2013 – 2020)**
Baden-Württemberg				
# municipalities	296	185	152	123
Size of vineyards	27,295.69 ha[1]	25,287.79 ha	21,967.83 ha[1]	21,266.05 ha
Rhineland-Palatinate				
# municipalities	493	227	-	-
Size of vineyards	64,735.84 ha	49,400 ha	-	-

Specifics of disaster relief payments		
Total disaster relief to winegrowers (DR)	14,905,209 €	14,224,769 €
Number of applying farmers	947	899
Disaster relief per farmer (DR/farmer)	15,739.40 €	15,822.88 €
Disaster relief per hectare vineyard (DR/ha)	678.80 €	668.90 €

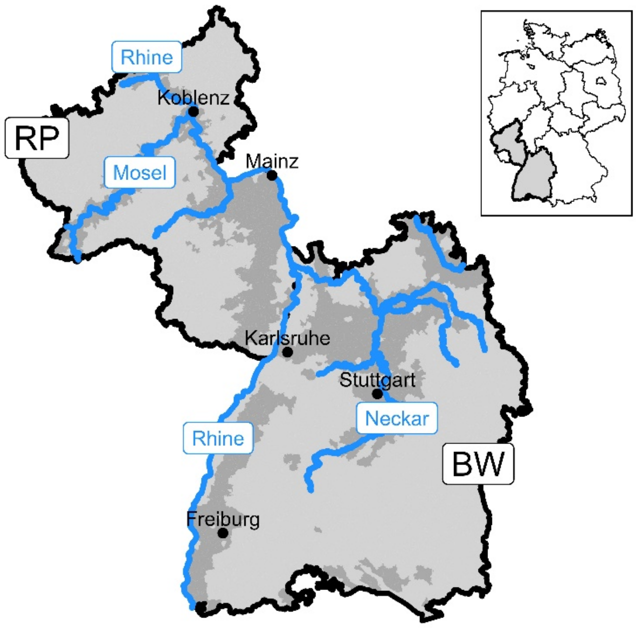
[1)] There are 9 municipalities outside our sample, which are not recorded by the statistical offices of Baden-Württemberg. The size of vineyards of municipalities within Baden-Württemberg may therefore be slightly underestimated.

5 Methodology

To estimate the causal effect of the premium subsidy on insurance demand in Baden-Württemberg, we follow a difference-in-differences approach at the municipality level, whereby Baden-Württemberg is the treatment group and Rhineland-Palatinate the control group. With this approach, we can exploit the quasi-natural experimental setting, which allows us to estimate the effect of the subsidy on insurance demand without the need for access to extensive firm-level data. For the introduction of the premium subsidy in Baden-Württemberg in 2020, Rhineland-Palatinate serves as the control group. As Rhineland-Palatinate introduces a subsidy on its own in 2021, it cannot serve as a control group for 2021, as it also receives a treatment. For this reason, we exclude data on 2021 from all regression analyses and only provide an estimate of the initial effect of the subsidy in 2020.

Rhineland-Palatinate is a direct neighbor state to Baden-Württemberg with a common border along the River Rhine. Their special geography and climate provide favorable conditions for wine cultivation, which makes them the two largest wine producing states in Germany. The wine producing areas in Germany are shown dark grey in Figure 3. Most wine is grown along the Rhine. Rhineland-Palatinate grows large amounts of wine to the west of the Rhine, Baden-Württemberg to the east of the Rhine. Each state has an additional wine growing region at tributaries of the Rhine. The Mosel region in Rhineland-Palatinate and the area around the Neckar in Baden-Württemberg are the second largest wine-growing regions in each state. The geographic proximity and similarity in growing wine along the Rhine makes the two states closely related. The two states also agreed on a close cooperation between their agricultural ministries in 2015 making their agricultural policy environments intertwined and comparable (Ministerium für Laendlichen Raum und Verbraucherschutz, 2015).

Figure 3: Wine growing areas in Baden-Württemberg (BW) and Rhineland-Palatinate (RP) (wine growing municipalities in dark grey)



The identifying assumptions for difference-in-differences analyses are parallel trends and no anticipatory effects (Roth, Sant'Anna, Bilinski, & Poe, 2023). The parallel trends assumption implies that insurance demand for frost insurance in Rhineland-Palatinate and Baden-Württemberg would have followed the same trends had Baden-Württemberg not introduced the premium subsidy. Assuming no anticipatory effects implies that farmers in Baden-Württemberg do not anticipate the introduction of the premium subsidy. They are assumed to behave, prior to the treatment, as if no premium subsidy was introduced the following year. The year of treatment is 2020, in which Baden-Württemberg started to subsidize premiums.

In all specifications, insurance participation is the dependent variable. We include municipality fixed effects to control for time-invariant confounding factors such as municipality size or specific geography of a municipality and year fixed effects to control for municipality-invariant confounding factors such as inflation or other common economic shocks. To control for confounding factors that affect insurance demand, and that differ across Baden-Württemberg and Rhineland-Palatinate and vary over time, we use additional control variables. Our specification is a dynamic two-way fixed effects model by Roth et al. (2023) with added control variables. We add control variables based on the assumption from Meyer (1995) that they have the same effect on insurance participation in treatment and control group. The resulting specification adapts notation from Angrist and Pischke (2009, p. 237) and can be formalized as follows:

$$y_{it} = \mu_t + \omega_i + \sum_{\tau=-T_{Pre}}^{-2} \delta_\tau^{lead} * D_{it}^\tau + \sum_{\tau=0}^{T_{Post}} \delta_\tau^{lag} * D_{it}^\tau + X_{it}'\beta + \varepsilon_{it} \tag{11}$$

where i and t denote municipalities and years with T_{Pre} denoting the total number of years prior to the year of treatment and T_{Post} the total number of years after the year of treatment. In our panel dataset from 2013 to 2020 with treatment taking place in 2020, there are 7 potential pre-treatment years ($T_{Pre} = 7$) and 0 post-treatment years ($T_{Post} = 0$) as we only observe the initial treatment year 2020 where $\tau = 0$. μ and ω denote year and municipality fixed effects, D_{it}^{τ} is a dummy variable that turns 1 when the treatment is τ periods away and municipality i is part of the treatment group. X_{it} denotes a vector of control variables that vary over time and municipality. The coefficients δ_{τ}^{lead} describe the effects of the dummy variable D_{it}^{τ} turning 1 when the treatment lies in the future, δ_{τ}^{lag} describe the effects of the dummy variable D_{it}^{τ} turning 1 when the treatment lies in the past. δ_{-1}^{lead} is excluded for interpretability. The coefficient δ_{0}^{lag} describes the difference between Baden-Württemberg and Rhineland-Palatinate between 2019 and 2020, which is the immediate treatment effect. δ_{-2}^{lead} describes the difference between Baden-Württemberg and Rhineland-Palatinate between 2019 and 2018 (δ_{-3}^{lead} the difference between Baden-Württemberg and Rhineland-Palatinate between 2019 and 2017 and so on). We can use the coefficients δ_{τ}^{lead} to test for parallel trends and anticipation of treatment. The coefficients δ_{τ}^{lag} are the treatment effects relative to the last year before the treatment, which is 2019 in our context.

Standard errors are clustered at the municipality level. Recent literature has questioned the assumption of independence across cross-sectional units (e.g., municipalities) when the treatment takes place at a higher level (e.g., state) and suggests clustering at the treatment level for reliable inference (e.g. MacKinnon, Nielsen, & Webb, 2023). As our data limitations do not allow for clustering on the state level, we must assume that municipalities react independently to the state-level treatment. Bertrand, Duflo, and Mullainathan (2004) have shown that this may result in a significant underestimation of standard errors and over rejection of t tests. Thus, we must interpret the inferential results with caution.

We add control variables that affect insurance demand but change over time and vary between Rhineland-Palatinate and Baden-Württemberg. We control for premiums per coverage sum to account for different prices of insurance. Woodard and Yi (2020) show that premiums are endogenous to coverage levels because premiums are linked to coverage levels by a rate curve. Measuring insurance demand as coverage level and using premiums as independent variable leads to biased results. Our measure of insurance demand is based on insured acreage and independent of coverage levels such that including premiums as control variable should not bias the results. To control for favorability of insurance contracts based on Goodwin (1993), we control for lagged loss ratios (indemnity payments divided by premium). To additionally control for different levels of risk exposure based on weather data, we control for lagged frost risk exposure. Lastly, we control for lagged insurance participation to capture potential serial correlation of insurance demand. Including lagged dependent variables as control variables can cause biases (Nickell, 1981). We present the effect of including the potentially biasing lagged dependent variable separately and provide further discussion in the results section (Section 6). We observe serial correlation of insurance demand in our data, but it seems that including a lagged dependent variable does not strongly affect the coefficients, which suggests that the resulting bias is small.

The second part of the regression analysis evaluates whether treatment effects are heterogeneous among groups having received different amounts of disaster relief payments. To analyze the heterogeneity of the treatment, we split the treated sample into subsamples. We run separate regressions for each subsample of the treatment group excluding observations outside the subsample. First, the sample is split into two subsamples ("none", "some") separating municipalities that did not receive any disaster relief payments and municipalities that received some positive amount of disaster relief. A municipality in Baden-Württemberg does not receive any disaster relief payments ("none"), when no farmer within the municipality had uninsured losses above 30% of his harvest. In municipalities, which receive disaster aid ("some"), there is at least one farmer, whose uninsured losses are above 30% of his harvest, which makes him eligible for disaster relief. These specifications compare subsamples of different loss experiences in 2017 measured by disaster relief payments in Baden-Württemberg to the full sample of municipalities in Rhineland-Palatinate.

A more accurate control group would only include municipalities in Rhineland-Palatinate that had similar losses in 2017. The "none" group in Baden-Württemberg would be compared to municipalities in Rhineland-Palatinate, in which all farmers lost less than 30% of their uninsured harvest in 2017. The "some" group in Baden-Württemberg would be compared to municipalities in Rhineland-Palatinate where at least one farmer lost more than 30% of her uninsured harvest in 2017. We use the full sample of municipalities from Rhineland-Palatinate as control group because we do not observe uninsured losses in Rhineland-Palatinate in 2017. We provide results on a restricted sample in Rhineland-Palatinate in Appendix D. There, we use insured losses from 2017 as a proxy for uninsured losses and construct a control group, that may better match the loss experience of the treatment group from 2017.

We further split up municipalities that received disaster relief payments into three subsamples ("low", "medium", "high") according to the amount of disaster relief payments they received. As described in Section 4, absolute disaster relief payments (DR) are highly correlated with municipality size, which is why we construct the variables DR/ha and DR/farmer. We set up all subsamples in such a way that the number of treated municipalities and treated municipality-year observations is nearly equal in all groups. Using a variety of variables to split up the sample can rule out the possibility that municipality size drives the results. Table 3 shows how the subsamples are constructed:

Table 3: Subsamples for analysis of heterogeneous treatment effects

	low	**medium**	**high**
DR			
Intervals	[2,905.4; 34,216.41)	[34,216.41; 106,301.57)	[106,301.57; 942,507.19]
# Municipalities	45	39	39
# Municipality-year observations	102	111	112
DR/ha			
Intervals	[9.25; 428.85)	[428.85; 1,071.59)	[1,071.59; 18,234,21]
# Municipalities	44	40	39
# Municipality-year observations	102	110	113
DR/farmer			
Intervals	[2,905.4; 11,212.31)	[11,212.31; 15,683.52)	[15,683.52; 100,000]
# Municipalities	42	39	42
# Municipality-year observations	103	112	110

Political factors leading to the introduction of the treatment are a potential source of endogeneity that may bias the estimation. Besley and Case (2000) show that policy introductions may be endogenous to differences in the treatment and control groups even though parallel trends hold. The argument against an endogenous policy introduction in our setting is the fact that the control group (Rhineland-Palatinate) agrees on introducing a similar policy one year after the treatment group (Baden-Württemberg). Factors that lead to the introduction of a premium subsidy must therefore be comparable in both groups.

As we only observe insurance demand from one insurance company, there may be an underlying selection bias within the data. When farmers who are insured at the Vereinigte Hagel VVaG are different from farmers represented by other insurance companies with respect to their insurance demand, the estimated treatment effects may be biased. As the Vereinigte Hagel VVaG is the largest player on the German crop insurance market, covering over 57% of overall premiums, we expect the sample to be generally representative and potential selection biases to be negligible (BMEL, 2019). The composition of our sample also seems to represent the overall German wine growing population based on data of the national German statistical office (Statistisches Bundesamt, 2020). Table 4 presents how overall vineyards are distributed across winegrowers of different size. For example, winegrowers owning between 10 and 20 hectares of vineyards manage 29.89% of overall vineyards in Germany. In our sample 33.21%

of vineyards are managed by winegrowers who own between 10 and 20 hectares of vineyards. Within our sample, large farmers seem to be overrepresented compared to the overall distribution in Germany. Prior research suggests that smaller farmers are less likely to buy insurance (Coble, Knight, Rulon, & Williams, 1996; Enjolras, Capitanio, & Adinolif, 2012; Wąs & Kobus, 2018). We expect that this holds for all insurance companies and is not specific to the Vereinigte Hagel VVaG making our sample representative of the population of insured farmers.

Table 4: Sample composition

Size of winegrowers' vineyards (in ha)	Share of acreage in Germany	Share of acreage in sample
< 5	16.26%	8.56%
5 to 10	17.88%	17.90%
10 to 20	29.89%	33.21%
> 20	35.96%	40.61%

6 Results

Figure 4 presents the insurance demand of municipalities in Baden-Württemberg (BW)–split into the "none" and "some" group–and in Rhineland-Palatinate (RP). Before 2016, insurance participation is below 2% in all groups. In 2013, no farmer in Baden-Württemberg buys frost coverage. Around the loss event in 2017, participation slightly increases to around 3% in 2018. There appears to be a small descriptive effect of loss experience on insurance demand in 2018. It also appears that municipalities that did not receive disaster relief payments had higher insurance coverage in 2017 compared to municipalities that did receive disaster relief payments. Contracts are bought at the beginning of the year such that insurance participation in 2017 is independent of disaster relief payments later on in the year. The effect of disaster relief payments only shows from 2018 onwards. We use disaster relief payments as a measure for catastrophic loss size per municipality. When the amount of disaster relief payments is driven by insurance coverage prior to the loss event, disaster relief payments may not be an accurate measure of loss experience. In our data, insured losses per coverage sum are positively correlated at the municipality level with disaster relief payments in 2017 in Baden-Württemberg at 10% significance (Pearson's correlation coefficient: 0.2597, p-value: 0.066). Municipalities that do not receive disaster relief payments tend to have also had lower insured losses in 2017, suggesting that slightly higher insurance coverage in 2017 does not drive the size of disaster relief payments. The changes of insurance demand between 2016 and 2018 are relatively small changes compared to the effect sizes of the premium subsidies in 2020 and 2021.

Insurance participation strongly increases in the year in which the premium subsidy is introduced in either state. In Baden-Württemberg, insurance participation in the first year of subsidization increases by 14.15 percentage points and an additional 7.20 percentage points in the second year after introduction. The overall effects are averages of the subgroup effects weighted by the size of vineyards in either subgroup (21,967.83 ha in the “some” group and 5,327.86 ha in the “none” group, see Panel (b) of Table 2). Insurance participation in the “some” group increases by 15.86 percentage points and insurance participation in the “none” group by 7.12 percentage points in the first year of subsidization. The descriptive effect of the subsidy on insurance participation in the first year after implementation is much stronger in those municipalities that receive disaster relief payments in 2017. In the second year after the introduction, the increases are 6.94 percentage points in the “some” group and 8.24 percentage points in the “none” group. It appears that in the second year after the introduction of the subsidy, the two groups no longer differ showing a similar increase from 2020 to 2021. According to our hypothesis 2, the main difference between the two groups is their loss experience, which leads to different insurance coverage once the premium subsidy eliminates charity hazard. We expect that all other determinants of insurance demand affect both groups similarly such that once the effects of loss experience become visible, both groups follow similar trends again. In Rhineland-Palatinate, insurance participation increases by 16.07 percentage points in 2021, the first year of subsidy introduction in the state.

Figure 4: Insurance participation by state and disaster relief group

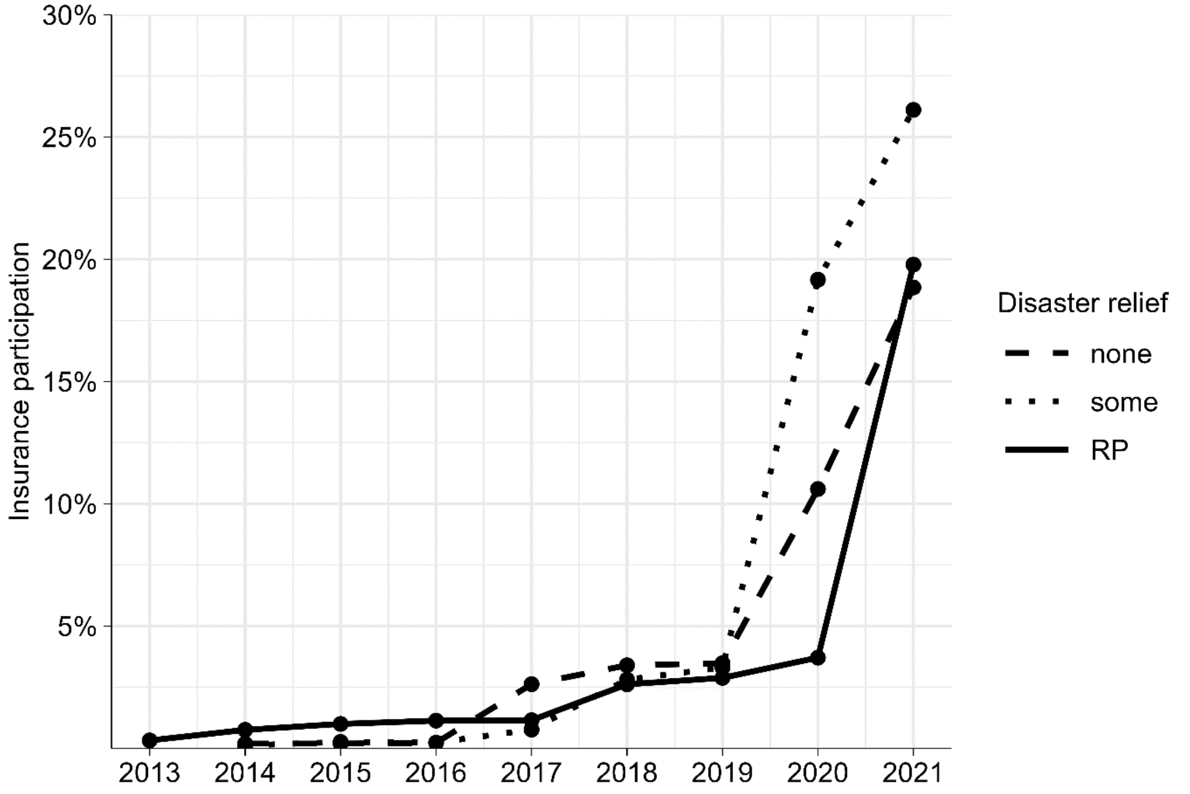
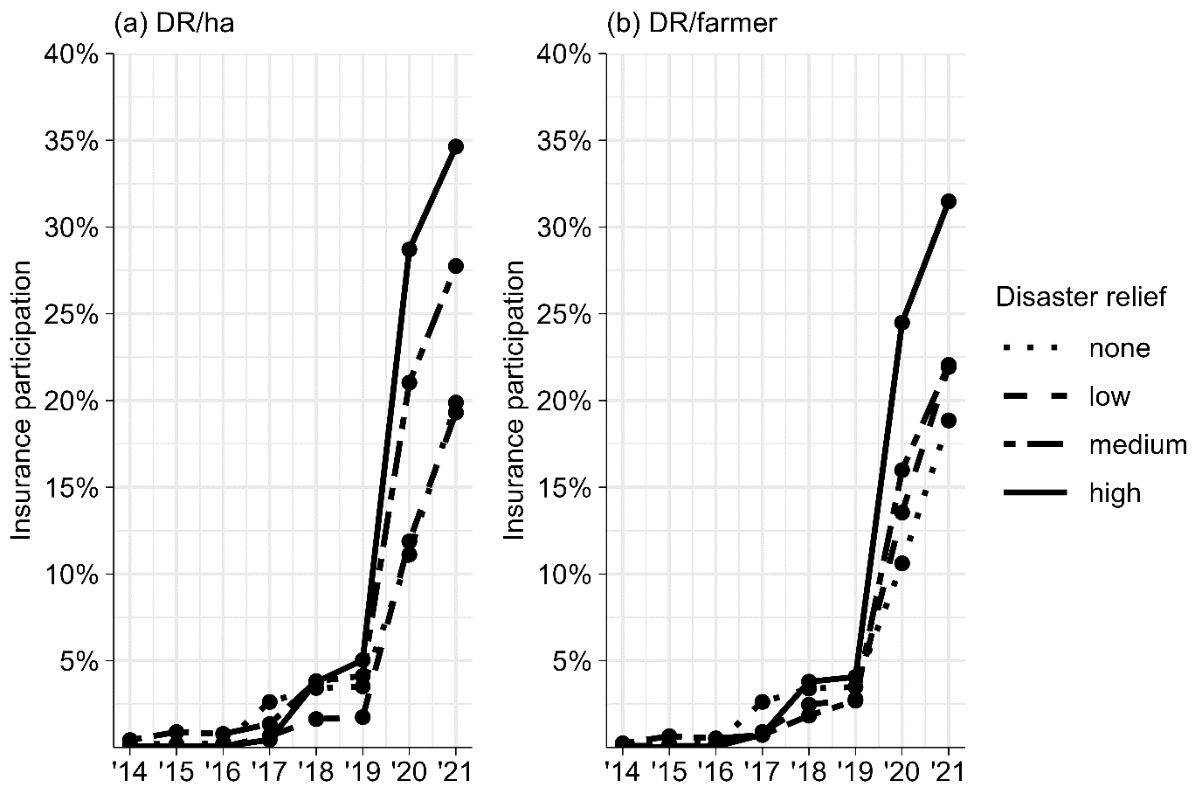


Figure 5: Insurance participation in Baden-Württemberg by disaster relief group



To further analyze how the effectiveness of the premium subsidy is linked to the reception of disaster relief payments, we split the sample of treated observations into four groups according to the amount of disaster relief payments, measured by DR/ha and DR/farmer (see Table 3). Figure 5 shows the development of insurance participation for these groups. Further splitting the sample underlines that the importance of recent disaster relief reception is primarily visible in the immediate reaction toward the subsidy in 2020. The immediate increase in insurance demand seems to be stronger for those municipalities that receive higher amounts of disaster relief payments, whereby the municipalities that receive the highest amounts of disaster relief payments are most responsive when the subsidy is introduced. Within the second year after subsidy introduction, differences in the groups are not visible, and all groups develop in an approximate parallel manner. As above, we hypothesize that once the premium subsidy reduces charity hazard and the effects of loss experience become visible, the groups follow similar trends as their insurance demand is based on similar determinants.

We present regression results in Table 5, 6 and Table 7. We show our main analysis in the specifications (1), (2) and (3) of Table 5. Specifications (4) – (9) of Table 5 show subsample analyses based on the “some” and “none” group in Baden-Württemberg and Figure 4. Table 6 and Table 7 show regression results on subsamples based on DR/farmer and DR/ha. Regression results on subsamples based on DR are shown in Appendix E. We show the effect of lagged insurance participation separately and discuss the potential bias from including the lagged dependent variable in the following.

Table 5: Regression results of main specification

	Insurance participation								
	Full sample			**Disaster relief in 2017 = 0 ("none")**			**Disaster relief in 2017 > 0 ("some")**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\boldsymbol{\delta_0^{lag}}$	**0.1376*** (0.012)**	**0.1385*** (0.014)**	**0.1330*** (0.014)**	**0.07067** (0.022)**	**0.06137** (0.021)**	**0.05611** (0.020)**	**0.1618*** (0.014)**	**0.1702*** (0.016)**	**0.1629*** (0.017)**
δ_{-2}^{lead}	-0.007933 (0.0054)	-0.003921 (0.010)	0.006853 (0.012)	0.0003634 (0.015)	0.01576 (0.018)	0.02405 (0.025)	-0.01142* (0.0049)	-0.01895 (0.011)	-0.007386 (0.013)
δ_{-3}^{lead}	-0.03370** (0.013)	-0.05978* (0.030)	-0.03873 (0.026)	-0.02148 (0.026)	0.06542 (0.040)	0.06452* (0.029)	-0.04502*** (0.013)	-0.07952** (0.024)	-0.04945* (0.020)
δ_{-4}^{lead}	-0.06210** (0.022)	-0.05146 (0.036)	-0.03472 (0.033)	0.02670 (0.038)	0.05677 (0.051)	0.06281 (0.051)	-0.08036*** (0.018)	-0.07592* (0.029)	-0.05195* (0.024)
δ_{-5}^{lead}	-0.05721* (0.028)	-0.05971 (0.049)	-0.04789 (0.049)	0.004744 (0.024)	0.03467 (0.036)	0.04084 (0.036)	-0.07195* (0.031)	-0.08465 (0.063)	-0.07037 (0.063)
δ_{-6}^{lead}	-0.06262 (0.034)	-	-	0.004744 (0.024)	-	-	-0.09086* (0.040)	-	-
Premium per coverage sum	-	0.2968 (0.66)	-0.4479 (0.53)	-	-0.001926 (0.36)	-0.7236 (0.49)	-	0.7392 (0.64)	-0.1081 (0.46)
Loss ratio (lagged)	-	0.0007416 (0.00067)	0.0009578 (0.00068)	-	0.002463*** (0.00072)	0.002455*** (0.00071)	-	0.001093 (0.00071)	0.001410* (0.00069)
Frost risk (lagged)	-	0.0002170 (0.00034)	0.0006103 (0.00034)	-	-0.0007222* (0.00033)	-0.00008034 (0.00028)	-	0.00006025 (0.00034)	0.0005526 (0.00035)
Insurance participation (lagged)	-	-	0.6268*** (0.13)	-	-	0.6764*** (0.12)	-	-	0.7399*** (0.086)
Two-way FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# obs.	1,464	1,052	1,052	1,139	850	850	1,320	970	970
# treated obs.	469	284	284	144	82	82	325	202	202
# control obs.	995	768	768	995	768	768	995	768	768
R2	0.36	0.34	0.46	0.062	0.071	0.37	0.43	0.43	0.57

Significance code: *** = 0.1%; ** = 1%; * = 5%

Table 6: Regression results on subsamples (split by DR/ha)

Subsample analysis of insurance participation (split by DR/ha)									
	low			**medium**			**high**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\boldsymbol{\delta_0^{lag}}$	**0.1156*** (0.019)**	**0.1169*** (0.023)**	**0.1035*** (0.027)**	**0.1528*** (0.016)**	**0.1587*** (0.017)**	**0.1550*** (0.018)**	**0.2079*** (0.029)**	**0.2226*** (0.033)**	**0.2134*** (0.033)**
δ_{-2}^{lead}	-0.01084 (0.0092)	-0.02579* (0.013)	-0.01859 (0.018)	-0.006895 (0.0090)	-0.02680 (0.014)	0.009022 (0.017)	-0.01558* (0.0076)	-0.02424 (0.023)	-0.03155 (0.024)
δ_{-3}^{lead}	-0.04746* (0.020)	-0.09594*** (0.015)	-0.04553** (0.017)	-0.07002** (0.027)	-0.1064*** (0.023)	-0.05092** (0.016)	-0.02253 (0.018)	-0.01788 (0.053)	-0.02294 (0.050)
δ_{-4}^{lead}	-0.1004*** (0.0090)	-0.09632*** (0.015)	-0.04550** (0.017)	-0.1009*** (0.019)	-0.1237*** (0.016)	-0.06600*** (0.013)	-0.03879 (0.037)	-0.01829 (0.053)	-0.02835 (0.049)
δ_{-5}^{lead}	-0.1004*** (0.0090)	-	-	-0.06990 (0.062)	-0.01967 (0.11)	0.01959 (0.091)	-0.05172 (0.042)	-0.1231*** (0.031)	-0.1313*** (0.035)
δ_{-6}^{lead}	-	-	-	-0.05663 (0.072)	-	-	-0.1048*** (0.022)	-	-
Premium per coverage sum	-	0.04915 (0.62)	-0.8047* (0.35)	-	0.4508 (0.62)	-0.3630 (0.34)	-	0.7784 (0.66)	-0.05079 (0.41)
Loss ratio (lagged)	-	0.002137** (0.00072)	0.002487*** (0.00070)	-	0.002220** (0.00070)	0.002330*** (0.00068)	-	0.001657* (0.00075)	0.001712* (0.00075)
Frost risk (lagged)	-	-0.0004997 (0.00033)	0.00003807 (0.00032)	-	-0.0005339 (0.00030)	0.0001906 (0.00027)	-	-0.0001637 (0.00034)	0.0006623 (0.00034)
Insurance participation (lagged)	-	-	0.7726*** (0.081)	-	-	0.8233*** (0.063)	-	-	0.8326*** (0.062)
Two-way FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# obs.	1,097	826	826	1,105	838	838	1,108	842	842
# treated obs.	102	58	58	110	70	70	113	74	74
# control obs.	995	768	768	995	768	768	995	768	768
R2	0.16	0.17	0.50	0.28	0.29	0.60	0.35	0.36	0.59

Significance code: *** = 0.1%; ** = 1%; * = 5%

Table 7: Regression results on subsamples (split by DR/farmer)

Subsample analysis of insurance participation (split by DR/farmer)

	low			**medium**			**high**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\boldsymbol{\delta_0^{lag}}$	**0.09954*** (0.020)**	**0.1074*** (0.025)**	**0.09877*** (0.028)**	**0.1609*** (0.018)**	**0.1697*** (0.022)**	**0.1575*** (0.023)**	**0.2270*** (0.026)**	**0.2354*** (0.030)**	**0.2297*** (0.030)**
δ_{-2}^{lead}	-0.009716 (0.010)	-0.02515 (0.019)	-0.005148 (0.023)	-0.01519 (0.0084)	-0.02495 (0.015)	-0.01965 (0.017)	-0.005472 (0.0043)	-0.007112 (0.016)	-0.003492 (0.020)
δ_{-3}^{lead}	-0.06078 (0.031)	-0.2017*** (0.011)	-0.1336*** (0.017)	-0.03328* (0.015)	-0.04227 (0.026)	-0.01591 (0.017)	-0.03663* (0.020)	-0.1179*** (0.016)	-0.09219*** (0.025)
δ_{-4}^{lead}	-0.1590*** (0.011)	-0.1818*** (0.013)	-0.1262*** (0.016)	-0.05021* (0.021)	-0.03978 (0.034)	-0.02120 (0.024)	-0.1149*** (0.0089)	-0.1336*** (0.014)	-0.1169*** (0.015)
δ_{-5}^{lead}	-0.1612*** (0.011)	-0.1847*** (0.013)	-0.1320*** (0.016)	-0.01676 (0.038)	0.1901*** (0.023)	0.1911*** (0.023)	-0.1325*** (0.025)	-0.1407*** (0.024)	-0.1377*** (0.029)
δ_{-6}^{lead}	-0.1562*** (0.011)	-	-	0.05994** (0.020)	-	-	-0.1316*** (0.025)	-	-
Premium per coverage sum	-	-0.02830 (0.62)	-0.8506* (0.37)	-	0.4160 (0.60)	-0.4414 (0.32)	-	0.8308 (0.66)	-0.07305 (0.38)
Loss ratio (lagged)	-	0.002428** (0.00076)	0.002511*** (0.00073)	-	0.001782* (0.00070)	0.002007** (0.00070)	-	0.001884** (0.00070)	0.002122** (0.00068)
Frost risk (lagged)	-	-0.0005936 (0.00035)	0.00009574 (0.00035)	-	-0.0003157 (0.00031)	0.0003539 (0.00029)	-	-0.0003855 (0.00032)	0.0002999 (0.00030)
Insurance participation (lagged)	-		0.7720*** (0.081)	-	-	0.8324*** (0.062)	-	-	0.8075*** (0.065)
Two-way FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# obs.	1,098	829	829	1,107	841	841	1,105	836	836
# treated obs.	103	61	61	112	73	73	110	68	68
# control obs.	995	768	768	995	768	768	995	768	768
R2	0.15	0.17	0.50	0.27	0.27	0.59	0.40	0.40	0.63

Significance code: *** = 0.1%; ** = 1%; * = 5%

From specification (1) – (3) in Table 5, we see that the premium subsidy leads to an average increase of insurance demand per municipality of 13.30 to 13.85 percentage points depending on the set of control variables. In the "none" group, shown in specification (4) – (7) from Table 5 the premium subsidy increases insurance demand on average 5.61 to 7.07 percentage points. As in Figure 4, the premium subsidy has the strongest effect on the "some" group with an average increase per municipality of 16.18 to 17.02 percentage points (see specification (7) – (9) in Table 5). All treatment coefficients are in line with the descriptive Figure 4. The treatment effects are also robust across specifications suggesting that no single control variable drives the effects. Dividing farmers who have received disaster relief payments into three groups reveals that treatment effects tend to be higher when more disaster relief has been received. When the sample is split by DR/ha, treatment effects are 10.35, 15.50 and 21.34 percentage points for the low, medium and high levels of disaster relief payments (specifications (3), (6) and (9) in Table 6). Splitting the subsample by DR/farmer, treatment effects are 9.88, 15.75 and 22.97 percentage points respectively (specifications (3), (6) and (9) in Table 7). Treatment effects in Table 6 and Table 7 also only slightly vary by covariate specification. The results suggest that the size of the treatment effect is positively correlated with the amount of disaster relief payments received in 2017. In Figure 4 there is a small descriptive increase of insurance demand after the loss event in 2017. If the effect of loss experience was different between Baden-Württemberg and Rhineland-Palatinate, insurance demand in 2018 should differ between the states. The coefficients δ_{-2}^{lead} are however insignificant in the regression results with control variables in Table 5. Insurance demand in 2018 does not differ between Rhineland-Palatinate and Baden-Württemberg suggesting a similar effect of loss experience on both groups.

To summarize the results, Figure 6 presents regression results in an event-study plot. Panel (a) refers to specification (3) of Table 5, Panel (b) to specifications (6) and (9) of Table 5 and Panel (c) to specifications (3), (6) and (9) of Table 6 with subsamples based on DR/ha. Panel (a) shows the overall treatment effect of 13.30 percentage points and Panel (b) shows treatment effects of 5.61 and 16.29 percentage points. For the specifications shown in these two panels, none of the pre-trends is significantly different from 0 ensuring that the parallel trends assumption holds (at the 99% significance level). Panel (c) presents treatment effects of 10.35, 15.50 and 21.34 percentage points. While the treatment effects in Panel (c) are all significant, the results are to be taken with caution, as some of the pre-trends are significantly different from 0, violating the identifying assumption of parallel trends. The results merely provide an indication that receiving higher disaster relief payments may increase responsiveness to premium subsidies.

Figure 6: Event-study plot of regression results shown in Table 5 and Table 6 (confidence intervals at 99% significance)

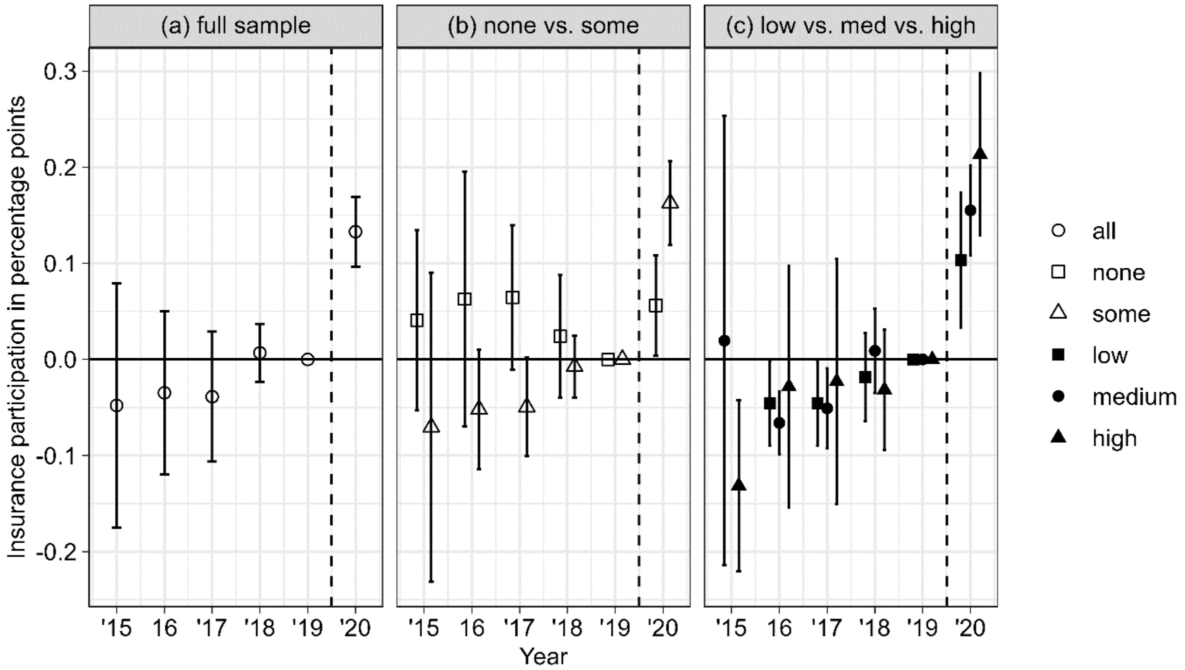


Figure 6 also shows that there are no visible anticipatory effects. The last trend before the policy implementation δ_{-2}^{lead} does not differ between the two states in any of the specifications. As Rhineland-Palatinate also introduces a similar policy one year after Baden-Württemberg, both states were similarly close to introducing premium subsidies in 2019, making it unlikely that farmers in Baden-Württemberg behaved differently just before the subsidy was introduced. Farmers also do not benefit from anticipating the introduction of premium subsidies. They can forgo purchasing insurance in 2019, but they do not benefit from purchasing less insurance prior to the introduction of premium subsidies. Based on insignificant pre-trends, similar policy situations in Baden-Württemberg and Rhineland-Palatinate and no benefit from anticipation, we do not expect any anticipatory behavior of farmers in Baden-Württemberg.

As shown in Figure 6 and discussed above, the parallel trends assumption is not violated in Panel (a) and Panel (b). For the “some” group–the subsample of municipalities that receive disaster relief payments–we can however only reject all pre-trends in specification (9) of Table 5. The trend δ_{-3}^{lead} is significantly different from 0 at 99% significance in specification (7) and (8). Specification (9) includes the lagged dependent variable as a control variable potentially biasing the coefficients. We argue that the lagged dependent variable does not severely bias the regression as all coefficients remain roughly the same as in specification (7) and (8). Following Nickell (1981), we can also analyze the direction of the bias. To identify the direction of the bias we regress lagged insurance participation on all independent variables from specification (9). The regression results of this auxiliary regression are shown in Appendix

F. We find that the coefficient δ_{-3}^{lead}, which violates the parallel trends assumption in specification (8), is negative (δ_{-3}^{lead}: -0.04064) in this auxiliary regression. Based on Nickell (1981), that means that the coefficient δ_{-3}^{lead} is downward biased when including the lagged dependent variable in the regression. As the coefficient is negative in specification (9) and biased downwards, the unbiased coefficient is expected to be larger and closer to zero which makes it even more likely that the trend is not significantly different from zero. We do not expect the bias to be so large that the unbiased coefficient is positive and significant as all other treatment coefficients also only marginally change in specification (9) compared to specification (8). Overall, we argue that parallel trends hold in specification (9) and that the potential bias from including the lagged dependent variable is negligible as all treatment coefficients remain close to the values from specifications (7) and (8).

7 Discussion & Conclusions

The descriptive analysis and the regression results show that the premium subsidy in Baden-Württemberg has been an effective instrument in increasing overall insurance participation. Although the analysis focuses on Baden-Württemberg, descriptive results suggest that a similar increase takes place in Rhineland-Palatinate in 2021 after a similar subsidy is introduced. The size of the increase in Baden-Württemberg is highly relevant, as insurance participation increases by on average 13.30 percentage points per municipality. The data-providing insurer covers approximately 30% of all winegrowers within the sampled area against hail damage. Given that the hail insurance market is usually referred to as a functioning market, 13.30 percentage points is a sizeable increase. We find support for Hypothesis 1.

Based on our hypothesis development in Section 3, the price effect of the subsidy by itself is unlikely to explain the entire increase of insurance demand. The size of the increase in insurance demand suggests that the premium subsidy is also able to lower the anticipation of future disaster relief payments. The additional decrease of charity hazard is also able to explain how our results are in contrast to a variety of crop insurance studies from the U.S. (e.g., O'Donoghue (2014)), which find inelastic demand among farmers and question premium subsidies. It may be that the price effect of the premium subsidy in our study is also small, which would be in line with inelastic demand, and that the results are mostly driven by a decrease in charity hazard. Garrido and Zilberman (2008) show that premium subsidies are an important driver of insurance demand on Spanish crop insurance markets, which our results can confirm for the German frost insurance market.

Analyzing the role of disaster relief payments shows that receiving recent disaster relief payments seems to be an important parameter in farmers' immediate response to the premium subsidy. Those municipalities that experienced catastrophic losses and received disaster relief payments are significantly more responsive toward premium subsidies than those municipalities that have not been subject to severe losses. There also seems to be a tendency that higher disaster relief payments make farmers even more responsive compared to lower disaster relief payments. We hypothesize in Section 3, that receiving large amounts of disaster relief payments implies catastrophic loss experience, which has been shown to increase insurance demand (Cai & Song, 2017; Che et al., 2019; Gallagher, 2014; Kousky, 2017). In our setting, the effect of loss experience is initially not visible because charity hazard depresses insurance demand. Once the premium subsidy reduces charity hazard, different levels of loss experience become visible, leading to higher insurance demand in municipalities that experienced losses and received disaster relief payments. We find the premium subsidy to be more effective among farmers who have received disaster relief payments, supporting Hypothesis 2.

Both findings suggest that the state eliminated or at least lowered charity hazard by introducing the premium subsidy. The state was able to use the introduction as a credible commitment device to lower anticipation of future ex post disaster relief payments. We cannot identify what share of the overall increase in insurance demand is attributable to the lowering of charity hazard and the reduction of prices. The long-term effects of the premium subsidy are also unclear. Based on the data for this study and if trends from the first two years of the premium subsidy continue (~13 percentage points increase in the first year and ~7 percentage points in the second year), insurance demand could converge to a level of insurance participation around 30% in a couple of years. 30% insurance participation would be the same market share of the data-providing insurer as in the private hail insurance market. Farmers would routinely add frost coverage to their hail insurance contracts. The state would be able to observe the costs of premium subsidies necessary to uphold frost insurance coverage and could assess how premium subsidies compare to disaster relief payments.

Other climate-related risks such as drought, wildfires and heat waves have become more salient recently. Coverage against damages from these events is not always part of standard insurance products. When people are not aware of risks and do not buy insurance, states are often pressured into making disaster relief payments when losses are large. The resulting anticipation of future disaster relief payments depresses insurance demand. Premium subsidies as on the German frost insurance market are one potential policy change to eliminate charity hazard and to promote private insurance markets. Once a private market establishes, people experience payouts themselves, or see others receiving payouts. It has been shown that such experience makes them more likely to buy insurance, as they have a better understanding of the insurance product and its potential benefits (Cai, de Janvry, & Sadoulet, 2020; Cole, Stein, & Tobacman, 2014; Karlan, Osei, Osei-Akoto, & Udry, 2014; Santeramo, 2018). The findings of this study suggest that premium subsidies aimed at eliminating charity hazard work especially well when severe losses have recently been experienced and disaster relief payments have been received. Temporary premium subsidies or other monetary incentives may be used as an instrument to boost initial insurance demand and lower charity hazard after severe loss events have occurred. Once individuals' evaluation of insurance contracts has increased, monetary support may then be terminated.

Appendix

Appendix A – Proofs

The effect of charity hazard on $\underline{\lambda} = 1 - \theta_0$ and $\bar{\lambda} = \frac{u'(w-(1-\theta_0)L)(1-\theta_0)}{(1-p)u'(w)+pu'(w-(1-\theta_0)L)}$ with $k = (1-p)u'(w) + pu'(w-(1-\theta_0)L)$ is given by:

$$\frac{\partial \underline{\lambda}}{\partial \theta_0} = -1 < 0$$

$$\frac{\partial \bar{\lambda}}{\partial \theta_0} = \frac{-u'(w-(1-\theta_0)L)k + u''(w-(1-\theta_0)L)(1-\theta_0)L(1-p)u'(w)}{k^2} < 0$$

Next, we can show, that $\frac{\partial \bar{\lambda}}{\partial \theta_0} \leq \frac{\partial \underline{\lambda}}{\partial \theta_0}$ by rearranging:

$$\frac{-u'(w-(1-\theta_0)L)k + u''(w-(1-\theta_0)L)(1-\theta_0)L(1-p)u'(w)}{k^2} \leq -1$$

$$\frac{u''(w-(1-\theta_0)L)(1-\theta_0)L(1-p)u'(w)}{k} \leq u'(w-(1-\theta_0)L) - k$$

The left-hand side of this equation is weakly negative as $u''(w-(1-\theta_0)L)(1-\theta_0)L(1-p)u'(w) \leq 0$ and $k > 0$. We can show that the right-hand side is weakly positive completing the proof. Inserting $k = (1-p)u'(w) + pu'(w-(1-\theta_0)L)$ and rearranging gives:

$$(1-p)u'(w-(1-\theta_0)L) - (1-p)u'(w) \geq 0$$

Lastly, we show that $1 - \theta_0 - \lambda p < 0$ only holds when $\lambda > \bar{\lambda}$ to rule out the possibility that $\frac{\partial \alpha}{\partial \theta_0} > 0$ and to prove that $\frac{\partial \alpha}{\partial \theta_0} < 0$ for all inner solutions. From $1 - \theta_0 - \lambda p < 0$ follows $\frac{1-\theta_0}{p} < \lambda$. We show that $\frac{1-\theta_0}{p} > \bar{\lambda}$ which implies $\lambda > \bar{\lambda}$ and completes the proof:

$$\frac{1-\theta_0}{p} > \frac{u'(w-(1-\theta_0)L)(1-\theta_0)}{(1-p)u'(w) + pu'(w-(1-\theta_0)L)}$$

$$(1-p)u'(w) > 0$$

Appendix B – Discussion of Elasticities

To assess the empirical plausibility of insurance being a Giffen good and to be able to hypothesize about the effect of premium subsidies in the context of frost insurance, we follow Hoy and Robson (1981), assume CRRA and use an isoelastic utility function specified as follows:

$$initial\ wealth: w_0, loss\ L = \eta * w_0\ where\ \eta \in [0,1]$$

$$u(w) = \begin{cases} \frac{w^{1-\gamma}}{1-\gamma}, \gamma \neq 1 \\ \ln(w), \gamma = 1 \end{cases}$$

$$w_{loss} = w_0 - \alpha(1-s)\lambda pL - (1-\alpha)L$$

$$w_{No\ loss} = w_0 - \alpha(1-s)\lambda pL$$

Following Jaspersen et al. (2022), the optimal insurance demand for isoelastic utility functions is given by:

$$\alpha^* = \frac{\eta - (1-k)}{\eta(1-(1-k)(1-s)\lambda p)} \quad with\ k = \left(\frac{p}{1-p} * \frac{1-(1-s)\lambda p}{(1-s)\lambda p}\right)^{\frac{1}{\gamma}} \tag{12}$$

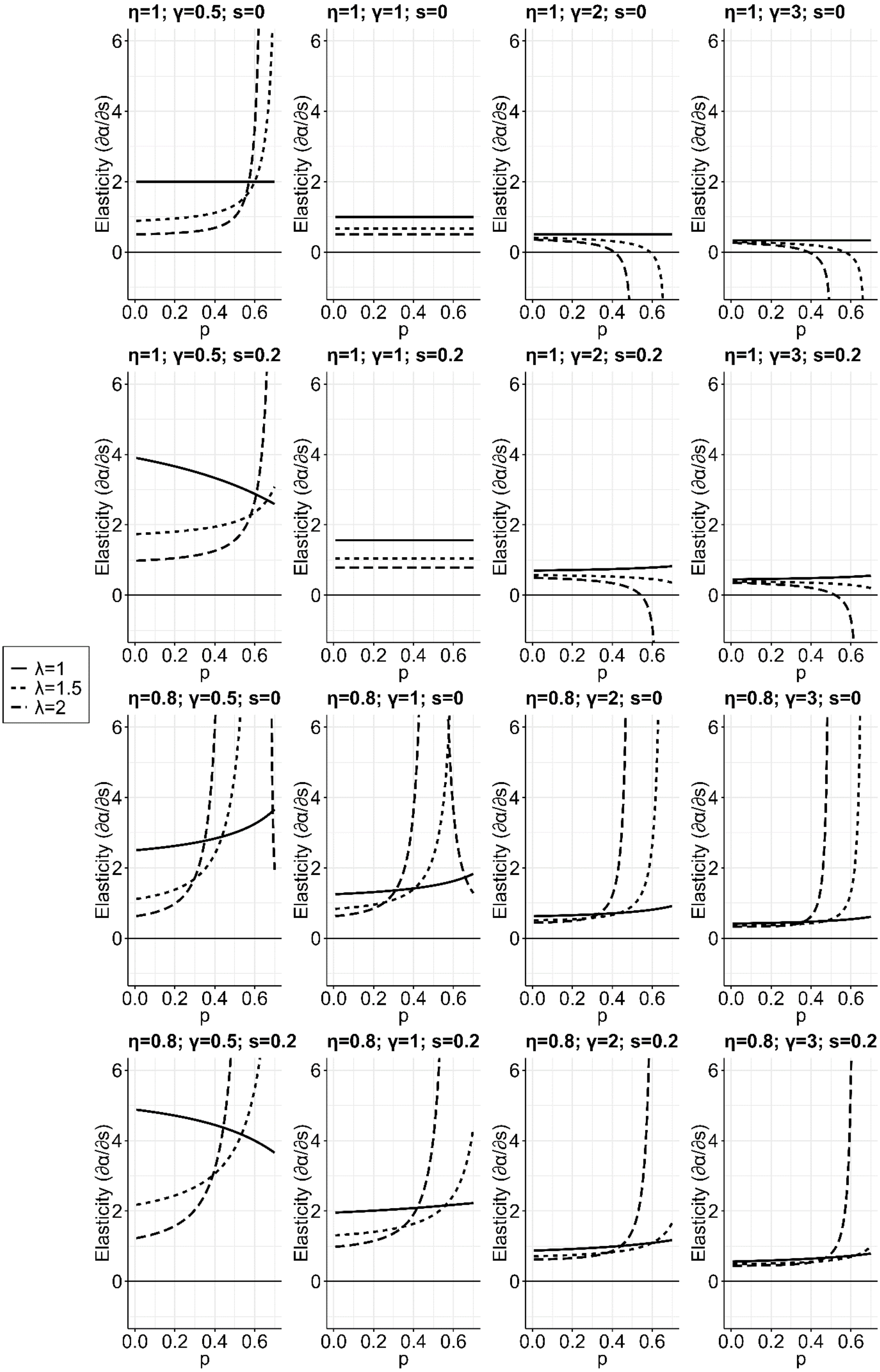
Based on equation (12), we calculate the marginal change in optimal insurance demand when premium subsidies marginally increase:

$$\frac{\partial \alpha^*}{\partial s} = \frac{\frac{\partial k}{\partial s} * \left(\eta(1-(1-k)(1-s)\lambda p)\right) - (\eta-(1-k)) * \left(\eta\left(\left(\frac{\partial k}{\partial s}\right)(1-s)\lambda p + (1-k)\lambda p\right)\right)}{\left(\eta(1-(1-k)(1-s)\lambda p)\right)^2} \tag{13}$$

$$with\ \frac{\partial k}{\partial s} = \frac{1}{\gamma}\left(\frac{p}{1-p} * \frac{1-(1-s)\lambda p}{(1-s)\lambda p}\right)^{\frac{1}{\gamma}-1} * \left(\frac{p}{1-p} * \frac{(1-s)(\lambda p)^2 + (1-(1-s)\lambda p)\lambda p}{\left((1-s)\lambda p\right)^2}\right)$$

Figure 7 examines the plausibility of equation (13) turning negative and insurance being a Giffen good by showing different parameter specifications. It shows the elasticities of insurance demand for various levels of damages η, risk aversion γ, loading factors λ and subsidy levels s. Consistent with Hoy and Robson (1981), relative risk aversion must be above 1 for insurance to be a Giffen good. Furthermore, insurance must be loaded. Insurance with fair premia is never Giffen. Overall, the elasticities of insurance demand turn negative only for combinations of large losses, high loadings, high risk aversion and high loss probabilities. For example, when losses are high ($\eta = 1$), no subsidy is in place ($s = 0$), individuals are very risk averse ($\gamma = 2$) and loadings are high ($\lambda = 2$), loss probabilities would still have to be above 40% for insurance to turn into a Giffen good. The combination of parameters, especially such high loss probabilities, seems unrealistic in the given context.

Figure 7: Elasticity of insurance demand for different parameter specifications



Appendix C – Robustness checks of model prediction

To ensure that the predictions based on Figure 2 are not driven by the parameter specification from Table 1, we present similar graphs with varying risk aversion and varying loss size in the following. We assume a loss probability of 5% in both figures. The loss size is assumed to be 30% of initial wealth in Figure 8 and risk aversion is assumed to be 0.5 in Figure 9. Both figures show the same pattern as in Figure 2**.** The price effect by itself, comparing Panel (a) to Panel (b), is only meaningful for low levels of the loading factor λ. Only once the charity hazard is removed in Panel (c) of both Figures, does the insurance demand go up. The robustness checks show that the key parameters driving the results are the initial amount of charity hazard θ_0, the charity hazard function $\theta(s)$ and the price effect of the premium subsidy.

Figure 8: Insurance demand of a representative winegrower with varying risk aversion

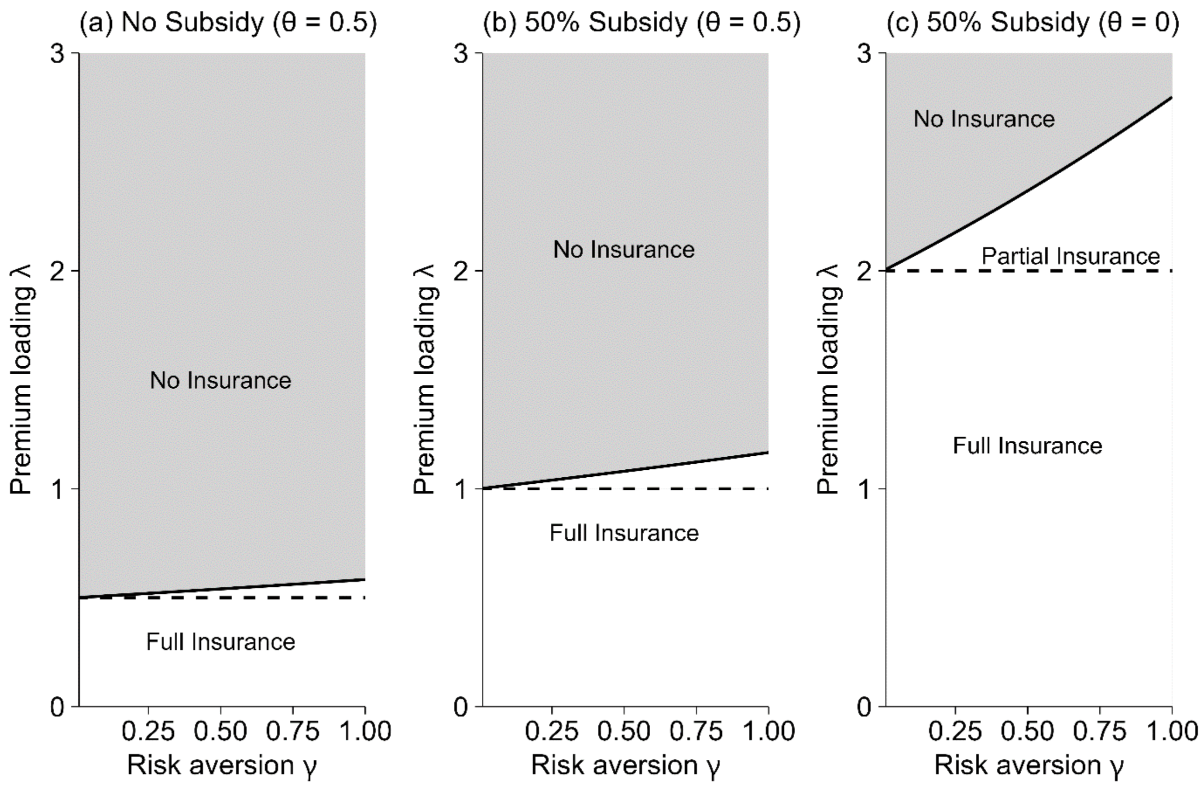
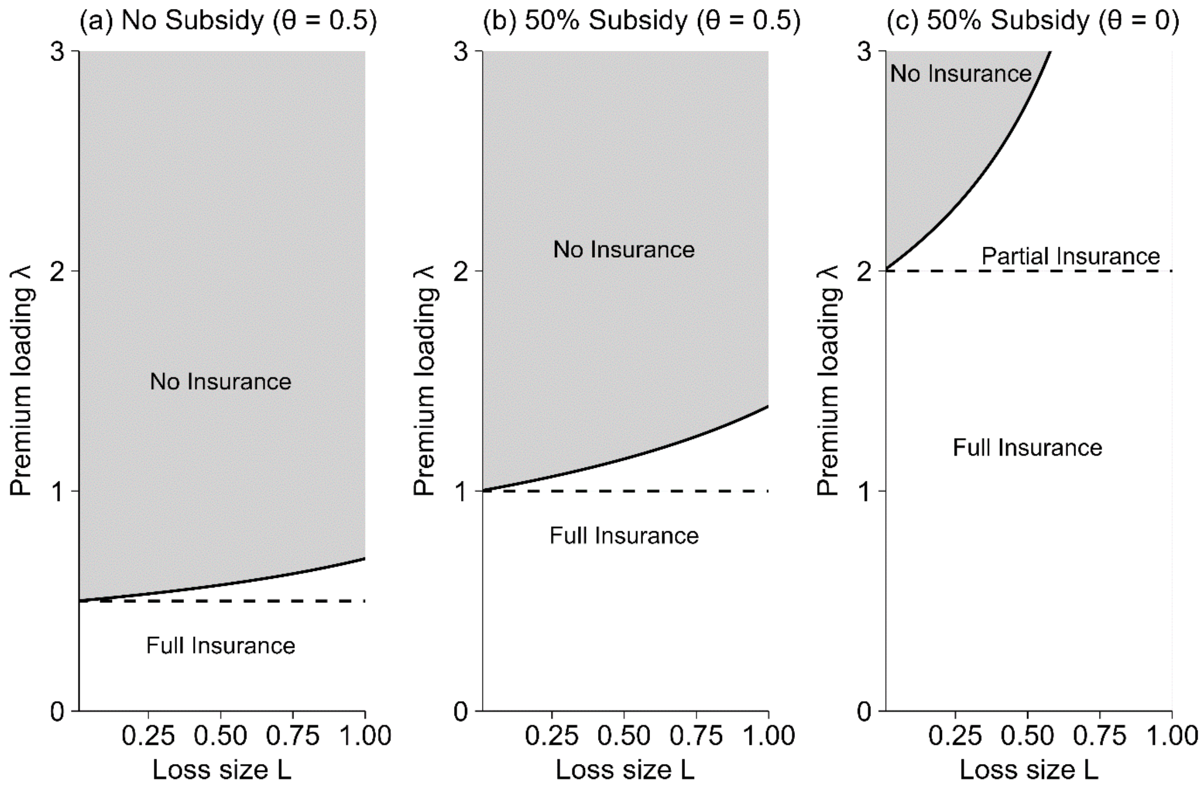


Figure 9: Insurance demand of a representative winegrower with varying loss size



Appendix D – Regression results with adjusted control group

In Table 8 we restrict the control group such that it resembles the treatment group better. Disaster relief payments measure uninsured losses in Baden-Württemberg. We use insured losses in Rhineland-Palatinate to proxy uninsured losses. To match the "none" municipalities from Baden-Württemberg, where no farmer had uninsured losses above 30%, we use municipalities in Rhineland-Palatinate, where average uninsured losses in 2017 were below 30% of the coverage sum. Respectively, we compare the "some" municipalities from Baden-Württemberg to municipalities in Rhineland-Palatinate, where average uninsured losses in 2017 were above 30%. The treatment coefficients barely change compared to the results from Table 5 when restricting the control group. The effect of the premium subsidy does not seem to be driven by the composition of the control group. The parallel trends assumption is however violated with δ_{-3}^{lead} being significantly different from zero at 99% significance in specification (6) even after including the lagged dependent variable. As in the main analysis in Section 6, the trend from 2016 to 2017 appears to be partially violating the parallel trends assumption. Given the consistency of the treatment effects of interest δ_0^{lag}, the imprecise proxy of uninsured losses in Rhineland-Palatinate and the qualitative similarity of treatment and control group, we argue that the results are still robust.

Table 8: Regression results on subsamples with adjusted control group

	Insurance participation					
	Disaster relief in 2017 = 0 ("none")			**Disaster relief in 2017 > 0 ("some")**		
	(1)	(2)	(3)	(4)	(5)	(6)
$\boldsymbol{\delta_0^{lag}}$	**0.07067** (0.022)**	**0.06144** (0.020)**	**0.05764** (0.020)**	**0.1618*** (0.014)**	**0.1681*** (0.017)**	**0.1614*** (0.017)**
δ_{-2}^{lead}	0.0003634 (0.015)	0.01426 (0.018)	0.02367 (0.022)	-0.01142* (0.0049)	-0.02588* (0.012)	-0.01446 (0.014)
δ_{-3}^{lead}	-0.02148 (0.026)	0.06491 (0.040)	0.06517* (0.032)	-0.04502*** (0.013)	-0.08201** (0.025)	-0.05462** (0.020)
δ_{-4}^{lead}	0.02670 (0.038)	0.05195 (0.051)	0.05958 (0.052)	-0.08036*** (0.018)	-0.07433* (0.030)	-0.05539* (0.024)
δ_{-5}^{lead}	0.004744 (0.024)	0.02990 (0.037)	0.03764 (0.037)	-0.07195* (0.031)	-0.08423 (0.064)	-0.07388 (0.063)
δ_{-6}^{lead}	0.004744 (0.024)	-	-	-0.09086* (0.040)	-	-

Premium per coverage sum	-	-0.1794 (0.71)	-0.5597 (0.60)	-	1.5105 (1.32)	0.1124 (1.07)
Loss ratio (lagged)	-	0.001680* (0.00098)	0.001284 (0.0010)	-	0.0005698 (0.00094)	0.001176 (0.00095)
Frost risk (lagged)	-	-0.0004381 (0.00033)	0.00006460 (0.00031)	-	0.0006801 (0.00084)	0.0009459 (0.00088)
Insurance participation (lagged)	-	-	0.5656** (0.18)	-	-	0.6903*** (0.14)
Two-way FEs	Yes	Yes	Yes	Yes	Yes	Yes
# obs.	703	559	559	491	343	343
# treated obs.	144	82	82	325	202	202
# control obs.	559	477	477	166	141	141
R2	0.095	0.069	0.28	0.53	0.54	0.62

Appendix E – Subsample regression results of insurance participation (split by DR)

Table 9: Regression results on subsamples (split by DR)

	low			medium			high		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\boldsymbol{\delta_0^{lag}}$	**0.09207*** (0.022)**	**0.1015*** (0.026)**	**0.09300** (0.030)**	**0.1416*** (0.016)**	**0.1439*** (0.018)**	**0.1368*** (0.019)**	**0.2431*** (0.024)**	**0.2573*** (0.029)**	**0.2475*** (0.029)**
δ_{-2}^{lead}	-0.01110 (0.010)	-0.04152* (0.021)	-0.04999* (0.021)	-0.01112 (0.0073)	-0.0001279 (0.012)	0.03742* (0.018)	-0.007824 (0.0070)	-0.02053 (0.016)	-0.01670 (0.017)
δ_{-3}^{lead}	-0.03360 (0.018)	-0.07382** (0.027)	-0.05428*** (0.015)	-0.06500* (0.026)	-0.03303 (0.057)	0.004121 (0.040)	-0.02964* (0.017)	-0.09361*** (0.013)	-0.05851** (0.021)
δ_{-4}^{lead}	-0.07669*** (0.023)	-0.07421** (0.027)	-0.06430*** (0.015)	-0.05061 (0.039)	-0.02491 (0.071)	0.01046 (0.051)	-0.09238*** (0.0096)	-0.1126*** (0.014)	-0.08295*** (0.023)
δ_{-5}^{lead}	-0.06383* (0.032)	-	-	-0.02265 (0.064)	-0.003391 (0.10)	0.02987 (0.082)	-0.1110*** (0.015)	-0.1253*** (0.020)	-0.1223*** (0.026)
δ_{-6}^{lead}	-	-	-	-0.04060 (0.076)	-	-	-0.1173*** (0.018)	-	-
Premium per coverage sum	-	0.08946 (0.63)	-0.7600* (0.36)	-	0.3672 (0.61)	-0.4256 (0.33)	-	0.8853 (0.63)	0.02427 (0.37)
Loss ratio (lagged)	-	0.002154** (0.00074)	0.002387** (0.00074)	-	0.002059** (0.00072)	0.002305** (0.00073)	-	0.002137** (0.00068)	0.002280*** (0.00066)
Frost risk (lagged)	-	-0.0005173 (0.00035)	0.0001195 (0.00037)	-	-0.0004872 (0.00031)	0.0001419 (0.00031)	-	-0.0005132 (0.00031)	0.0002208 (0.00029)
Insurance participation (lagged)	-	-	0.7858*** (0.080)	-	-	0.8212*** (0.063)	-	-	0.8198*** (0.062)
Two-way FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# obs.	1,097	825	825	1,106	840	840	1,107	841	841
# treated obs.	102	57	57	111	72	72	112	73	73
# control obs.	995	768	768	995	768	768	995	768	768
R2	0.11	0.14	0.48	0.24	0.21	0.56	0.44	0.46	0.67

Significance code: *** = 0.1%; ** = 1%; * = 5%

Appendix F – Auxiliary regression

We run an auxiliary regression to identify the direction of the bias from including a lagged dependent variable as control variable. Nickell (1981) shows that the direction of the bias on exogenous variables from including a lagged dependent variable in a regression can be derived from regressing the lagged dependent variable on all exogenous variables. The resulting coefficients are given in the following. Our coefficient of interest δ_{-3}^{lead} is negative suggesting that δ_{-3}^{lead} is downward biased when including a lagged dependent variable in specification (9) of Table 5.

Table 10: Auxiliary regression to elicit the direction of bias

Dependent variable: Insurance participation (lagged)

	Disaster relief in 2017 > 0 ("some")
$\boldsymbol{\delta_0^{lag}}$	0.009935** (0.0038)
δ_{-2}^{lead}	-0.01563 (0.011)
δ_{-3}^{lead}	-0.04064** (0.012)
δ_{-4}^{lead}	-0.03155* (0.016)
δ_{-5}^{lead}	-0.01930 (0.015)
Premium per coverage sum	1.1451** (0.44)
Loss ratio (lagged)	-0.0004284 (0.00040)
Frost risk (lagged)	-0.0006654** (0.00024)
Two-way FEs	Yes
# obs.	970
# treated obs.	202
# control obs.	768
R2	0.070

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