This is a repository copy of *The presence of moral hazard regarding flood insurance and German private businesses*.

White Rose Research Online URL for this paper:
https://eprints.whiterose.ac.uk/185027/

Version: Published Version

Article:

ORIGINAL PAPER

The presence of moral hazard regarding flood insurance and German private businesses

Paul Hudson[1] · Annegret H. Thieken[2]

Abstract

There is a movement towards the concepts of integrated flood risk management and governance. In these concepts, each stakeholder prone to flooding is tasked with actively limiting flood impacts. Currently, relatively more research has focused upon the adaptation of private households and not on private businesses operating in flood-prone areas. This paper offers an extension of this literature on business-level flood adaptation by exploring the potential presence of moral hazard. The analyses are based on survey data collected in the aftermath of six floods across Germany between 2002 and 2013 to provide a first indication of the presence of moral hazard in private businesses. Moral hazard is where increased insurance coverage results in policyholders preparing less, increasing the risk they face, a counterproductive outcome. We present an initial study of moral hazard occurring through three channels: the performance of emergency measures during a flood, changes in precautionary behavior employed before a given flood occurred, and changes in the intention to employ additional precautionary measures after a flood. We find, much like for private households, no strong indication that moral hazard is present regarding past adaptation. However, there is a potential avenue after 2005 for insurance coverage to lower businesses' intentions to employ more adaptation measures after a flood. This has significant policy relevance such as opportunities for strengthening the link between insurance and risk reduction measures and boosting insurance coverage against flooding in general.

Keywords Flooding · Risk reduction · Private businesses · Insurance · Moral hazard · Company

1 Introduction

Flooding is a significant global problem (CRED-UNISDR 2015; CRED and UNDRR 2018). For example, flooding has caused a total loss of €162 billion across the European Environmental Agency members between 1980 and 2019, corresponding to 37% of total

✉ Paul Hudson
  paul.hudson@york.ac.uk

1 Department of Environment and Geography, University of York, York, UK

2 Institute of Environmental Science and Geography, University of Potsdam, Potsdam-Golm, Germany

 Springer

losses from natural hazards (European Environment Agency 2019). According to the IPCC AR6 WGII report there is growing confidence that the more extreme the temperature increase that humanity causes the more frequent and intense various types of flooding will become in Europe (IPCC 2021). Additionally, in Germany, the 2002 flood caused €11.6 billion in financial losses, four floods between 2005 and 2011 generating a loss of over €100 million each, while in 2013 major flooding again caused a financial loss of between €6–8 billion (Kienzler et al. 2015; Kuhlicke et al. 2020a, b). Only recently, i.e., in July 2021, past impacts were by far exceeded by devastating flash floods in Western Germany that caused more than 180 fatalities and around €30 billion of financial losses. Moreover, in several regions losses are projected to increase due to the combined effects of social-economic development and climate change increasing the scope and value of what can be lost during a flood (IPCC 2014, 2018). Therefore, research has been dedicated to under-standing and developing strategies for limiting flood impacts

This research strand is particularly important given the growing focus on risk govern-ance (Hartmann and Driessen 2017; Matczak and Hegger 2021) and integrated flood risk management (Bubeck et al. 2016) as part of a wider focus on human behavior in flood risk management (Aerts et al. 2018; Kuhlicke et al. 2020b). These approaches create frame-works that request each stakeholder at risk of flooding to undertake risk management activities in line with their capabilities (as is explicitly stated since 2005 in the German Federal Water Act). In flood-prone areas the most important stakeholders can be summa-rized as the public sector, private households, and private businesses. The role of the public sector in flood risk management has been long recognized (see White (1945) or Wiering et al. (2017)), as has private households (see Thieken et al. (2006), Johnson and Priest (2008), or Terpstra and Gutteling (2008)) and how the balance between stakeholders has been changing (Meijerink and Dicke 2008; Geaves and Penning-Rowsell 2016) through increased calls for multi-sector partnerships (Kunreuther 2015; Paudel et al. 2015; Hud-son et al. 2019; Otto et al. 2019). However, research on the role of private businesses in terms of their flood impacts or their adaptation strategies has been comparative neglected when compared to households, as commented in Kreibich et al. (2007), Sieg et al. (2017), Gayan and Bingunath (2012). This is despite the call in the Sendai Framework for Disas-ter Risk Reduction to more strongly include the private sector in risk management (Neise and Revilla-Diez 2018). Additionally, private businesses are important because they are critical to society in providing goods and services, generating employment opportunities, and contribute towards overall prosperity (Wedawatta and Ingirige 2012; Tyler and Sadiq 2019). Additionally, businesses play a major role in building capacity to mitigate, prepare, respond, and recover from disaster events (Tyler and Sadiq 2019). Therefore, it is crucial to understand business vulnerability to flooding through their adaptive behaviors, especially as they are important stakeholders in adaptation discourses.

For instance, Forino and von Meding (2021) investigate climate change adaptation (of which flood risk management is one element) across businesses in Australia. They find (much like households) a range of views on climate change influencing their actions. For-ino and von Meding (2021) also find that there are diverse interactions between businesses and other relevant stakeholders. In the case of Australia, Forino and von Meding (2021) state that higher government levels offer just vague and limited support to businesses, pri-vate businesses and city governments can be collaborative and fragmented, while some private businesses interact with local communities through information disclosure. While the literature on the role of private businesses in flood risk management is relatively lim-ited there is pre-existing work (Kreibich et al. 2011; Gayan and Bingunath 2012; Bhat-tacharya-Mis et al. 2018; Neise et al. 2018, 2019; Neise and Revilla-Diez 2019; Jehmlich

et al. 2020). Neise and Revilla-Diez (2018) study the role of small and medium enterprises (SMEs) in Jakarta, Indonesia. They explore how SMEs may be willing to contribute towards collective disaster risk adaptation and find that SMEs suffer from similar problems regarding the public good nature of collective flood defenses, similar to the discussion presented in Geaves and Penning-Rowsell (2016) for flood risk management in England. Moreover, Neise and Revilla-Diez (2018) also find that SMEs are also more likely to take part in risk reduction activities if they are more exposed to flooding and display the right risk attitudes. Again, this is potentially similar to previous findings concerning households (Zaalberg et al. 2009) and risk aversion (Petrolia et al. 2015) leads to a higher likelihood of employing adaptive behaviors. Finally, Neise and Revilla-Diez (2018) find some evidence that social interactions also factor into the chance of taking part in collective action, which could be argued to be similar to the role of social behaviour in household-level adaptation or risk reduction (Bubeck et al. 2013; Lo et al. 2015; Lo and Chan 2017).

Ingirige (2014) also study the uptake of measures against flooding by SMEs as a result of their risk perception and how this can be influenced by risk communication activities. Ingirige (2014) notes that the probabilities are often communicated as return periods (e.g., an area that has one in 75-year risk is prone to have a higher chance of flooding than an area whose risk is one in 100 years as shown in flood maps). This framing and the relative uncertainty of flood events affecting an area, most SMEs choose to "wait and see" rather than to act immediately (Ingirige 2014). This is similar to Neise et al. (2021) who find that Indonesian SMEs also mainly pursued a 'wait and see' approach. Neise et al. (2021) state that this is because the preferred adaptation measures of the studied SMEs were largely ineffective against the high inundation levels suffered in previous flood.

Wedawatta and Ingirige (2012) also study SMEs to undertake an investigation of adaptation to flooding. They study four SME case studies to identify their responses to flood risk and any proactive flood risk adaptation. Wedawatta and Ingirige (2012) find that their studied SMEs implemented different property-level protection measures and generic business continuity/risk management measures to achieve a desired level of protection. However, the desired level of protection may not be sufficient as they also argue that SMEs often tend to underestimate their degree of flood risk which has a correspondingly low priority in their agenda. In addition, Herbane (2015) study the flood adaptation decision-making process of SMEs in the UK through 215 interviews with owner-mangers. Herbane (2015) finds that the decision to adopt is influenced by flood experience, flood impacts, the likelihood of significant business interruption, and their perceived ability to employ measures to lower potential flood impacts. Their results highlight the importance of the private businesses age rather than size as a determinant of formalizing action in addition to recent experience and perceived ability to intervene.

Kreibich et al. (2007) study private businesses in the German federal state of Saxony after the major 2002 flood. Saxony was the most affected federal state during this severe flood event. Kreibich et al. (2007) studied 415 private businesses across a range of sectors and sizes to investigate potential deficits regarding their flood risk management approaches. They find at this time that the preparedness and precautionary activities of private businesses were low. Kreibich et al. (2007) note how due to the presence of a flawed early warning system only 55% of the private businesses received a flood warning rendering many private businesses being unable to perform emergency measures. Kreibich et al. (2007) found that within the 2002 flood the mean total damage to private businesses amounted to €1.1 million euros but recovered quickly because of relatively good compensation, e.g. insurance payments and governmental disaster assistance. Kreibich et al. (2007) note that like household's flood preparedness and precaution activities increased after experiencing

a flood. This finding was later repeated by Kuhlicke et al. (2020a, b) who studied 2,000 households and 300 private businesses who had been repeatedly flooded in Germany up to (and including) the year 2013, whereby actors displayed a learning effect after each flood reducing flood damage through increased adaptive behavior. Additionally, Kuhlicke et al. (2020a) find that private businesses' ability to recover from floods decreased after each repeated flood. This supports the argument that for private businesses, post-flood recovery is an iterative process, potentially across all actors in society (Marshall and Schrank 2014). However, when Kreibich et al. (2011) study the difference in overall preparedness in households and private businesses between the 2002 and 2006 floods in Germany, they note that by the 2006 floods only 10% of households were unprepared (from 30%), but private businesses only fell from 54 to 29%. Jehmlich, Hudson et al. (2020) conduct a pilot study of business-level responses to flooding from 64 businesses in a district of the city of Dresden, Germany that experienced major flooding in 2002 and 2013. Using a mixture of survey data and qualitative interviews, they indicate that a major driver of adaptive behavior is flood experience. Further, a lack of ownership might have hampered property-level adaptation. Jehmlich, Hudson et al. (2020) also find that risk perceptions may not be a strong predictor of adaptive behavior. Jehmlich, Hudson et al. (2020) further notes that additional research is needed to understand the role of insurance in the adaptation process of businesses. This is because Jehmlich et al. (2020) find that the financial assistance a firm received did not strongly impact adaptation decisions in the sense of statistical significance (due to a small sample) but indicated that insurance coverage might have a larger positive impact than government disaster aid.

Therefore, a highly policy-relevant adaptation or precautionary measure is insurance. Insurance is the archetypal recovery mechanism as in return for the premium, an insurer provides compensation after a flood occurs (Savitt 2017). Insurance offers a multi-faceted avenue for managing flood risk since good compensation systems can promote faster recovery after a flood if they are well designed and functioning as noted in Kreibich et al. (2007) and Poontirakul et al. (2017). Fast post-flood recovery is important because it limits indirect economic impacts by reducing the time private businesses are inactive or hindered in their business activities (Koks et al. 2016). Moreover, it is often argued that well-designed insurance schemes also promote additional precautionary behavior (Surminski 2014; Kunreuther 2015; Surminski et al. 2015; Hanger et al. 2018; Hudson et al. 2020).[1] The core of this link is that the insurance sector can act as an aggregator of knowledge and reward those who implement additional precautionary behaviour through more beneficial or generous insurance coverage terms (e.g., Kunreuther 2015 or Surminski & Thieken 2017). While insurance appears to offer a win–win mechanism for flood risk management it can fail if information asymmetries are systematically present.

Information asymmetries occur where information is not equally shared or available to both parties. With regard to flood insurance, the first information asymmetry is adverse selection, which is where the policyholder has more knowledge of their risk than the insurer. Within the flood risk management literature this is taken to mean that the insurance policies will be bought mainly by those at higher risk, limiting the diversification potential of insurers. This is further complicated by accumulated flood risk tends to be geographical clustered leading to demand being further clustered creating long-run sustainability issues (Charpentier 2008), because a sustainable insurance pool requires a mixture of higher and

---

[1] However, the empirical evidence for this in current practice is rather ambiguous Surminski and Thieken (2017).

lower risks. Moral hazard, on the other hand, is where the purchase of insurance causes a behavioral change in the policyholder, which leads to higher overall risk further threatening the sustainability of the insurance pool. Therefore, insurers have developed additional mechanisms to address these problems. For example, deductibles are often included in insurance contracts to prevent moral hazard in a range of industries (Wang et al. 2008; Einav et al. 2013; Winter 2013; Alessie et al. 2020). Research on these topics has indicated that the presence of adverse selection and moral hazard varies across insurance markets (Cohen and Siegelman 2010). To the best of our knowledge, there is not a substantial literature investigating natural hazard insurance market outcomes for private businesses.

This study seeks to contribute to this literature by presenting an initial investigation into the presence of moral hazard in German businesses that were surveyed between 2002 and 2013 in flood-prone areas across Germany after having experienced a damaging flood event, e.g., see Thieken, Kreibich et al. (2017). While there has not been a previous study concerning moral hazard and private businesses in Germany, there have been studies investigating moral hazard within private households. Hudson et al. (2017) study households in the same flood-prone areas that the affected businesses were sampled from. Hudson et al. (2017) find little evidence for moral hazard as insurance was not systematically associated with lower precautionary behaviour. Rather there was the potential for advantageous selection as those most proactive about protecting themselves against flooding were more likely to buy insurance. This can be interpreted in a way that insurance is not seen as an alternative to adaptive behavior but as a complementary safety strategy (Thieken 2018). However, they identify problems with adverse selection as private households with insurance tended to suffer more flood damage than private households without insurance coverage. Osberghaus (2015) use a nationally representative survey of German households to explore whether their perception of being insured is linked with precautionary or risk-reducing actions. Osberghaus (2015) also find the absence of the systematic presence of moral hazard.

Wider studies of moral hazard in regards to flood insurance for households can also be. Mol et al. (2020a; b) present findings in a lab experiment of over 2000 Dutch homeowners and did not find support for moral hazard but find many cautious people who invest both in private insurance as well as pro-active individual risk reduction measures. Similar findings were described for private households in Germany by Thieken et al. (2006) or Thieken (2018). Furthermore, Shao et al. (2019) apply Bayesian Network modeling to a survey dataset of households along the US Gulf Coast and find that the overall support for flood mitigation can be inferred from flood insurance purchase behavior. Therefore, Shao et al. (2019) find little evidence for the presence of moral hazards. Botzen et al. (2019) also investigate the complementary between flood insurance and property-level risk reduction in New York City using a sample of over 1000 homeowners impacted by Hurricane Sandy. In doing so they find that for precautionary measures the two are complementary (i.e., the opposite of moral hazard known as advantageous selection) while insurance coverage and emergency measures may be substitutes, revealing a moral hazard effect.

However, while the research on private households offers a useful start in researching moral hazard within businesses, different results can be expected due to different structures of decision making, risk preferences, and adaptive capacities. For instance, it is possible to anticipate a stronger potential for moral hazard in businesses as it can be argued they have a fiduciary responsibility to maximize profits or to protect their interests. We investigate if private businesses display the same systematic absence of moral hazard as was found for households in Germany (Osberghaus 2015; Hudson et al. 2017). Moreover, the current study extends upon the previous studies mentioned above by studying more

than one avenue for moral hazard to occur. For instance, Osberghaus (2015) and Hudson et al. (2017) do not study behavioral intentions or behavior during a flood. We achieve this outcome by analysing the linkages between insurance coverage and emergency measures performed during a flood, adaptation intentions after a flood, and precautionary activities already employed before a flood. The analyses benefit from a repeated cross-sectional design. This allows us to explore aspects of the temporal dimension of flood risk management. We focus on the following three hypotheses:

(1) Private businesses who were insured before the flood in question perform fewer emergency measures during the flood than those without insurance.
(2) Private businesses who were insured before the flood have in general employed fewer precautionary measures before the flood than those without insurance.
(3) Private businesses who were insured before the flood have lower intentions to employ additional flood risk-reducing measures after the flood than those without insurance.

These hypotheses are based on what we would expect if moral hazard were systematically present in German private businesses flood adaptation outcomes because then insurance coverage would lower the opportunity cost of not suitably preparing for a flood. Moreover, they are based on the assumption that there is not an active link between insurance and additional risk management by businesses. Ehrlich and Becker (1972) show that in the absence of a link between insurance policies and policyholder risk management, insurance coverage promotes moral hazard via fewer precautionary measures. It has been noted that across Europe this linkage is not strongly present (Surminski et al. 2015; Hudson et al. 2020). However, it must be noted that much of this research is focusedon household property insurance. The active linkage of policyholder flood risk management and insurance might not occur due to the presence of transaction costs of implementing and monitoring such a system. This might not be as relevant for businesses who are fewer in number compared to private households.

2 Data and methods

2.1 Data set description and collection

This paper uses survey data collected in the aftermath of large-scale floods which occurred across Germany in 2002 and 2013, as well as smaller flood events occurring in 2005, 2006, 2010, and 2011. Each survey was conducted as an independent effort with its own research objectives; however, each survey was based on a relatively standardized framework allowing them to be compared (see Thieken et al. 2017).

In all survey waves efforts were made to survey a wide geographical sample of the areas impacted by these floods. However, the surveys following 2002 and 2013 were by far the largest as these were the largest floods. These studies together contribute about 77% of the observations; the remaining 23% are from the smaller surveys following the smaller flood events. Furthermore, to collect an initial sample in each case addresses and contact numbers were identified from areas known to have been impacted by the floods in question. The surveys were conducted via telephone-aided computer surveys (CATI) and only contacted who declared that they were indeed impacted by a given flood were invited to take part in the survey (see Thieken et al. 2017 for more details).

The surveys are developed from a common core, but questions and wording slightly differed across individual surveys. However, a constant set of questions can be developed. Once the data across the various surveys is aggregated there are 1338 observations, of which about 74% of the sample is in the former German Democratic Republic (East Germany) in turn 73% of these respondents were in the Free State of Saxony, corresponding to about 54% of the entire sample.

In this sample, about 22% of the sample had pre-flood insurance coverage in 2002, which had grown to 35% in 2013. Similarly, pre-flood precaution increased from 26% in 2002 to 36% by 2013. In 2002 about 68% reported that they performed emergency measures during the flood, while in 2013 91% of businesses reported this. This indicates an overall increasing level of risk management behaviour over time that was already documented by Thieken et al. (2016), Kreibich et al. (2017), or Kuhlicke et al. (2020a, b).

While this study mainly focuses on the above data we also use, where suitable, information drawn from two sets of semi-structured interviews with representatives of German insurance industry which were both accompanied by a standardized survey among all insurers that offer flood insurance coverage to households and businesses in Germany. The first data set was collected early in 2003 after the 2002 floods consisting of an interview with a representative from the Association of German Insurers (GDV) and a survey among 110 insurers, from which just 14 responded (as partly described by Thieken et al. 2006). Nearly ten years later, i.e. between September 2012 and January 2013, i.e. a few months before the 2013 floods, semi-structured interviews were conducted with representatives from the GDV, one regional insurer and two reinsurance companies as well as the consumer protection to reflect upon conditions of the flood insurance market in Germany and changes since 2002. These interviews were followed by a standardized survey among 106 insurers to learn more about contract details, costs, incentives for further precaution and perspectives of insurers on flood risk management in Germany. 18 insurers responded in 2013. Many questions were phrased similarly to the survey in 2003. Due to the low response rates and the small sample sizes, these data are used as an additional source of qualitative information for the discussion of the analyses. See SI.1 for more details.

2.2 Methods

We use an approach based on a series of probit models linking insurance purchase and the employment of precautionary measures, emergency measures, and intentions for post-flood action. The dependent or explanatory variables are presented in panel A of Table 1, with a focus on which questions were sufficiently similar across all surveys and risk reduction measures. The independent variables are presented in panel B of Table 1. In each set of models, the set of independent variables is the same. The exception regards the performance of emergency measures during the flood which includes if the private business had received a flood early warning message. In these models, moral hazard is investigated through the coefficients of the insurance-related independent variables. An overall positive coefficient indicates advantageous selection as insurance purchase was positively associated with adaptive behavior. An overall negative coefficient indicates moral hazard as insurance purchase is negatively associated with adaptive behaviour. While an overall statistically insignificant coefficient implies no overall systematic relationship. This choice of methodological approach was made so that the results produced were conceptually comparable to those of previous studies of moral hazard in German private households

Table 1 Summary statistics the combined survey waves

Variable name	Variable description	Mean	Standard deviation	Observations (% of total sample respondents) (%)
Panel A—dependent variables				
Intentions				
	A binary variable taking the value of 1 if the business intended after the flood to implement 'stationary or mobile water barriers', and 0 otherwise. This is only applicable for business who did not state that it was impossible for them to employ the measure	0.24	0.43	83
	A binary variable taking the value of 1 if the business intended after the flood to implement 'adjusting the use of flood-prone areas to limit impacts', and 0 otherwise. This is only applicable for business who did not state that it was impossible for them to employ the measure	0.55	0.49	50
	A binary variable taking the value of 1 if the firm intended after the flood to implement 'places hazardous materials/chemicals in higher areas', and 0 otherwise. This is only applicable for firms who did not state that it was impossible for them to employ the measure	0.41	0.49	21
	A binary variable taking the value of 1 if the firm intended after the flood to implement 'flood-proofed air conditioning system', and 0 otherwise. This is only applicable for firms who did not state that it was impossible for them to employ the measure	0.26	0.44	20
	A binary variable taking the value of 1 if the firm intended after the flood to implement 'the flood protection of the building is improved', and 0 otherwise. This is only applicable for firms who did not state that it was impossible for them to employ the measure	0.31	0.46	44
Precautionary intentions	A binary variable taking the value of 1 if the firm intends to employ at least one of the risk reduction measures mentioned above in the near future and 0 otherwise	0.2	0.4	100
Pre-flood precaution				
	A binary variable taking the value of 1 if the firm implemented 'stationary or mobile water barriers' before the flood in question, and 0 otherwise. This is only applicable for firms who did not state that it was impossible for them to employ the measure	0.14	0.34	96
	A binary variable taking the value of 1 if the firm implemented 'adjusting the use of flood-prone areas to limit impacts' before the flood in question, and 0 otherwise. This is only applicable for firms who did not state that it was impossible for them to employ the measure	0.27	0.44	68
	A binary variable taking the value of 1 if the firm implemented 'placing sensitive/hazards devices/facilities into higher locations' before the flood in question, and 0 otherwise. This is only applicable for firms who did not state that it was impossible for them to employ the measure	0.24	0.43	67

Table 1 (continued)

Variable name	Variable description	Mean	Standard deviation	Observations (% of total sample respondents) (%)
	A binary variable taking the value of 1 if the firm implemented 'places hazardous materials/chemicals in higher areas' after the flood, and 0 otherwise. This is only applicable for firms who did not state that it was impossible for them to employ the measure	0.33	0.47	32
	A binary variable taking the value of 1 if the firm implemented 'flood-proofed air conditioning system' before the flood in question, and 0 otherwise. This is only applicable for firms who did not state that it was impossible for them to employ the measure	0.33	0.47	31
	A binary variable taking the value of 1 if the firm implemented 'the flood protection of the building is improved' before the flood in question, and 0 otherwise. This is only applicable for firms who did not state that it was impossible for them to employ the measure	0.13	0.33	63
Precautionary behaviour	A binary variable taking the value of 1 if the firm had employed at least one of the risk reduction measures mentioned above before the flood in question, and 0 otherwise	0.38	0.48	100
Emergency measures	A binary variable taking the value of 1 if the firm had performed emergency risk reduction measures during the flood in question and 0 otherwise	0.8	0.4	100
Panel B—independent variables				
SME	A binary variable taking the value of 1 if the private business is a Small or Medium Enterprise (i.e., less than 250 employees) and 0 otherwise. The definition of SME follows the suggested European Union definition (see: https://ec.europa.eu/eurostat/web/structural-business-statistics/structural-business-statistics/sme)	0.87	0.34	100
Previous experience	A binary variable taking the value of 1 if the firm had been flooded before the event under study, and 0 otherwise	0.52	0.5	93
Ownership	A binary variable taking the value of 1 if the firm owns the property in which it operates, and 0 otherwise (e.g. it is a renter)	0.54	0.49	99
Insured	A binary variable taking the value of 1 if the firm had flood insurance coverage before the flood, and 0 otherwise	0.27	0.44	95
Year post 2005	A binary variable taking the value of 1 if the respondent is in relation to a flood event post 2005, and 0 otherwise	0.57	0.5	100
Insured*year	An interaction term of the 'Insured' and 'Year post 2005' dummy variables	0.17	0.38	95

Table 1 (continued)

Variable name	Variable description	Mean	Standard deviation	Observations (% of total sample respondents) (%)
Perceived probability of future flooding	A binary variable taking the value of 1 if the respondent provided a value of 'Very likely' or 'likely' to be flooded again on a 6-point Likert scale and 0 otherwise	0.6	0.49	95
Warning Received	A binary variable taking the value of 1 if the respondent received an early warning that there was an oncoming flood, and 0 otherwise	0.69	0.46	100
Prepared emergency plan	A binary variable taking the value of 1 if the respondent has/practiced an emergency plan for what to do during a flood, and 0 otherwise	0.1	0.3	100
East	A binary variable taking the value of 1 if the respondent is in a federal state that was a part of the former Democratic Republic of Germany, and 0 otherwise	0.74	0.44	100
Tenure	A continuous variable indicating the number of years a private business has been located on the current location	31	41	93

Variables selected are based upon the following studies on a range of topics relating to flood risk and private businesses: (Kreibich et al. 2007; Herbane 2015; Marshall et al. 2015; Halkos and Skouloudis 2019); Percentage of observations reflects the share of businesses who could potentially employ this measure and did not provide a missing value

(Osberghaus 2015; Hudson et al. 2017) by using as similar a methodological approach as was possible given the change of focus from households to companies.

Our selection of control variables is drawn from our understanding of the wider scientific literature. However, much of the literature relevant for this study has evolved for private households rather than private businesses as outlined in the introduction. There is literature documenting business-level adaptation to flooding (e.g., Kreibich et al. 2007; Marshall et al. 2015; Halkos and Skouloudis 2019; Jehmlich et al. 2020). Additionally, as argued in Hudson et al. (2017), moral hazard is determined by factors which are not directly observable to the insurer providing flood insurance, e.g. the preferences of the policyholder (Ehrlich and Becker 1972; Mas-Colell 1995). Furthermore, it must be noted that overall, the surveys we use were designed to understand which adaptive actions have been taken to help explain the flood damage suffered by private businesses across floods, with minor differences in questions across surveys (Thieken et al. 2017).

Suitable proxy or related concepts must be used to measure subjective perceptions and capacity of private businesses. One element supposed to play an important role in how likely they perceive to be flooded again in the future. However, due to measuring this variable after the flood there are known problems with temporal feedback loops when using current values to explain past behavior (Bubeck et al. 2012; Siegrist 2013). Though this is a known problem, it is still a common choice due to the difficulties in developing suitable panel data within the flood risk research domain (Hudson et al. 2020). This issue is a larger problem in relation to hypotheses 1 and 2, rather than 3 due to its more forward-looking nature.

One question that was consistently asked across all the survey waves is if the private business in question had an emergency plan and has conducted emergency exercises in the past for what to do in the case of a flood. Similarly, a dummy variable for the degree of employed precautionary behavior before the flood has also been included. The responses to these questions can be understood as if the private business in question is taking a proactive stance towards adaptive behaviour against flooding.

We also assume that the presence of different risk cultures or environments plays a role in influencing the decisions of private businesses. We employ an east/west distinction as there was a tradition of a natural hazard bundle being included in insurance system in the German Democratic Republic (East Germany) for private households as compared the mostly voluntary approaches in Federal Republic of Germany (West Germany). Upon German reunification voluntary flood insurance has been available since 1991 (e.g., Thieken et al. 2006). This has been argued to create a different insurance/risk culture in eastern Germany as compared to Western Germany, which resulted in higher insurance coverage in eastern Germany during the time period studied (Hudson et al. 2017).

The post-2005-year dummy is considered because it is assumed to mark an implicit shift in German flood risk management. In this year, an extension of German law (Federal Water Act) was made to compel all residents within flood-prone areas to proactively adapt to flooding and limit their risk profile as much as possible (Thieken et al. 2016). This could have a knock-on effect on how businesses would approach flood risk management as well. Therefore, this variable is also interacted with the insurance variable, to indicate if a change in moral hazard occurred with this shift in risk management priorities. The post-2005-year dummy indicates if an observation relates to a flood event from 2006 and onwards, because the legislation came into effect in May 2005, but we cannot expect significant impacts on behaviour before the floods that occurred in July/August that year but impacts on behaviour could be plausible by Spring 2006 (when the next survey wave was

conducted).[2] The focus of this paper is not comparing different flood events per se, but rather the behaviour of companies at different points in time to potentially spot systematic differences in sample behaviour over time. The is primarily done using the post-2005 dummy variable and the interaction term consisting of the post-2005 dummy variable and having purchased insurance coverage before a given flood. The interaction term is what directly compares the relationship between insurance coverage and adaptive actions after 2005 with the relationship pre-2005.

A dummy variable is also included for early warning, i.e., if the affected private business received a warning that a flood was incoming in the immediate period before the flood occurred. This is particularly important for emergency measures, which would be employed directly before a flood to achieve their maximum effect. It is known that warnings can promote substantial risk reduction for private households (Kreibich et al. 2021). As noted above, this variable is only included for the emergency measure model, as it is otherwise not applicable.

In addition to these factors, the wider literature adds flood experience due to the increased tangibility that being flooded brings to the decision-making process, because flooding can be described as a high-impact/low-probability event which generates problems in understanding this threat until it has been experienced (Kunreuther and Michel-Kerjan 2009). A similar effect is argued in Jehmlich, Hudson et al. (2020) whereby the longer a firm is located in an area, the greater the perceived attachment to their location and the subjective impact of being flooded. Therefore, the tenure of a firm in its current location is.

Finally, certain variables from the literature are deemed to be important. For example, profitability or turnover is highlighted as important because it provides resources for adaptive action. However, the rate at which this question was answered is low. This indicates a potential sample selection issue. Therefore, it is not a suitable question to consider as it would further complicate the analysis as there may be factors, we are unaware of, driving the answers given.

3 Results

The results of the statistical analyses are presented in Table 2. In this table the raw coefficient estimates are presented to show the general statistical significance and direction of each variable. However, probit models are non-linear which means that the coefficients cannot be directly understood as changes in probability. To do so marginal effects (ME) must be calculated. A marginal effect is the first derivative of the estimated probit model with respect to the parameter of interest, evaluated at the sample mean value for each variable.

Turning to model 1 in Table 2, we see factors that are connected to the likelihood of performing emergency measures during a flood event. The statistically significant variables are employing at least one of the considered precautionary behaviour before the flood event (ME=9%), receiving a flood warning before the flood event (ME=14%), being affected after 2005 (ME=11%), the respondent being an SME (ME=17%), having experienced a

---

Table 2 Probit models of the overall linkage between insurance purchase and emergency behaviour, pre-employed precautionary behaviour, and precautionary behaviour intentions

Variables	(1) Emergency measures performed during a flood	(2) Employed at least 1 preparedness measure before the flood	(3) Intended to implement at least 1 preparedness measure after the flood
Employed at least 1 preparedness measure before the flood	0.43*** (0.11)		−0.49*** (0.09)
Prepared emergency plan	0.26 (0.20)	0.33** (0.13)	0.21 (0.13)
Warning Received	0.57*** (0.10)		
Perceived probability of future flooding	0.01 (0.11)	0.38*** (0.09)	0.17* (0.09)
Insured	−0.01 (0.15)	0.23 (0.15)	0.42*** (0.15)
Year post 2005	0.46*** (0.13)	0.07 (0.11)	−0.34*** (0.10)
Insured*Year post 2005	0.23 (0.23)	−0.17 (0.19)	−0.4** (0.19)
East	0.12 (0.12)	−0.27*** (0.1)	0.25*** (0.09)
Ownership	0.01 (0.10)	0.38*** (0.09)	0.38*** (0.08)
SME	0.62*** (0.15)	−0.67*** (0.13)	0.29** (0.13)
Previous experience	0.43*** (0.11)	0.32*** (0.09)	0.03 (0.09)
Tenure	0.003** (0.002)	0.001 (0.001)	0.002* (0.001)
Constant	−0.80*** (0.21)	−0.28* (0.17)	−0.47*** (0.17)

Table 2 (continued)

Variables	(1)	(2)	(3)
	Emergency measures performed during a flood	Employed at least 1 preparedness measure before the flood	Intended to implement at least 1 preparedness measure after the flood
Observations	1,124	1,126	1,126

Standard errors in parentheses; ***$p<0.01$, **$p<0.05$, *$p<0.1$

flood at its current location (ME = 10%), and the tenure of the firm in its current location (ME = 0.08% per additional year). These factors are positively associated with the performance of emergency measures. Interesting, the preparation of an emergency plan was positively but not significantly linked to performing emergency measures during a flood. This result is plausible because of the interconnection between planning for an emergency and having performed preparedness measures. We would argue that the actual implementation of precautionary behaviors represents a stronger indication of behaviour since it demands longer-term preparation or construction work at the building. It has been argued in previous research that people who are proactive in one area of risk management are so in others (Hudson et al. 2017).

Model 2 in Table 2 instead links precautionary behaviour to the explanatory factors. In this model the following factors were positively linked to undertaking precautionary behaviour before a flood event: having and practised an emergency plan (ME = 13%), perceiving a high likelihood of being flooded again (ME = 14%), owning the private business's building(s) (ME = 14%), and having previous flood experience (ME = 12%). On the other hand, being in the former East Germany (ME = −10%) and being an SME (ME = −26%) are negatively associated.

Model 3 in Table 2 links the intention to employ at least one new set of precautionary behaviours after a given flood to the selected explanatory factors. In this model the following factors were positively linked to undertaking precautionary behaviour after a flood event: perceiving a high likelihood of being flooded again (ME = 7%), having insurance before the flood (ME = 17%), owning the private business's building(s) (ME = 15%), being in the former East Germany (ME = 10%), and the tenure of the firm in its current location (ME = −0.07% per additional year), being an SME (ME = 12%). On the other hand, factors negatively associated were employing at least one set of precautionary behaviours before the flood event in question (ME = −19%), the interaction term of being insured before a flood after 2005 (ME = −16%), the private business was surveyed after 2005 (ME = −13%).

Overall, in both model 1 and model 2 the insurance variables are not statistically significant. This could be taken as an indication of the absence of moral hazard. However, the results of model 3 present a different outcome. Insurance coverage before 2005 was positively associated with the intention to employ at least one new set of precautionary behaviours (ME = 17%) but the after 2005 interaction term is negative (ME = −16%). A test of the combined coefficients (*value = 0.03, Chi²(1) = 0.05, p = 0.84*) indicates that this effect is statistically insignificantly different from zero, with a difference in marginal effects of less than 1%. This indicates a potential advantageous selection effect before 2005 (i.e., a positive relationship between insurance coverage and proactive adaptation), but a moral hazard impact after 2005 (i.e., a negative relationship between insurance coverage and proactive adaptation) as an incentive to be more prepared in the future is being eroded. This could be in line with the observation that private businesses displayed higher levels of preparedness after 2005, which reduces the incentive to further protect themselves.

4 Discussion

4.1 Presence of moral hazard

To investigate the presence of moral hazard in private businesses, we used a sample of over 1000 companies surveyed between 2003 and 2013 to see if their purchase of

insurance before a given flood was connected to their adaptive behaviour during, before, and after the flood representing three avenues for moral hazard to occur. In relation to hypothesis 1 where insured private businesses would have been more likely to perform emergency measures during the flood if moral hazard was present, we see no significant correlations between insurance and performing emergency measures. Therefore, we do not find strong evidence in favour of the presence of moral hazard through this avenue. Similarly, in relation to hypothesis 2 where insured private businesses would have employed fewer precautionary measures before the flood if moral hazard was present, we do not find strong evidence in favour of the presence of moral hazard. These results are like those found for German households possibly because 87% of the sample is comprised of SMEs, who may display similar decision-making processes to private households as compared to larger private businesses. While the primary focus is on the results from the quantitative dataset, we can support the argument that the behaviour of SME businesses (87% of respondents in the dataset) is like households through information from the interviews with representatives from the insurance industry (see Sect. 2.1 for a description). To triangulate our findings from the quantitative analysis presented and the interviews, we read through the two sets of interviews to spot common themes and patterns from the respondents that would offer insight into explaining the quantitative findings, such as how they perceive their business models or how their responses had changed from the previous interview. In these interviews, the insurance representatives acknowledged that flood insurance for businesses works like the insurance for households except for very big firms which are, however, not included in our data set. This means that flood insurance is primarily an add-on to the building/content insurance against fire, storm, and hail with a potential additional/separate insurance against business interruption. The insurance companies surveyed also mentioned that the criteria for being eligible for insurance coverage are similar to those used for the residential sector. This is a predominate focus on the hazard zone (called ZÜRS by the German insurers) followed by the number of previous claims. It was further explained in the interview that for the size of the contracts there is no on-site inspection because the transaction costs of such activities for many businesses would render the product line unprofitable. This is reinforced by the statements of the insurance companies that large or industrial businesses are treated separately, i.e., special contracts are negotiated (including the re-insurers). In these cases, an insurance might also cover damage from storm surges, which are usually excluded from the insurance against natural hazards in Germany. Additionally, from the interviews it appears that to the German insurance industry, the deductible included in the policy is be regarded as an important, and commonplace, measure against moral hazard. Therefore, it may be possible that such mechanisms may have played successfully and prevented the occurrence of moral hazard as indicated by our analyses. Though the results of Hudson et al. (2017) place caution on this avenue. This is because Hudson et al. (2017) argue that only very large deductibles may be effective at preventing moral hazard.

However, there was one avenue for moral hazard to occur, that was not explored in previous studies: the significant negative correlation between the intention to employ new precautionary behaviours after the flood and insurance coverage (hypothesis 3). The intentions and implementation of further employ risk reduction measures after a given flood were negatively correlated with insurance coverage, but at the same time, there was a higher overall level of preparedness post-2005 as compared to pre-2005. This finding is partly conflicting with the Federal Water Act that requires, since 2005, all flood-prone stakeholders to lower their risk. On the one hand, the higher level of precaution post-2005 matches

the aims of the Federal Water Act. However, on the other hand, the lower intention to adapt post-2005 might signal a saturation level has been reached among flood-prone businesses.

This implies that while a historical moral hazard effect might not have been detected, a 'future moral hazard' impact may be detectable in future studies studying moral hazard in Germany. A potential rationale for this moral hazard avenue can be drawn from Bubeck et al. (2020) who use panel data to study the dynamics of household adaptation against flooding between 2013 and 2017. The relevant aspect of Bubeck et al. (2020) is the investigation into which measures are most often implemented after a respondent states their intention. Bubeck et al. (2020) find that intentions to employ 'high-cost measures' are the most acted upon intentions (as compared to medium- or low-cost measures),[3] which most of the precautionary measures listed in Table 1 are. An additional consideration is that in 2002 26% of businesses had employed at least one of the considered measures before the flood-hit, while in 2013 this had grown to 36%. Taken together, we argue that this leads to a lower average effective intention to employ more measures. This then leads to a stronger disincentive to adapt from holding insurance. The disincentive is stronger because the recipient tends to act upon the intentions for 'high-cost' investments but sees relatively fewer benefits from lower-cost investments. A second potential rationale can be drawn from Mol et al. (2020a; b). Mol et al. (2020a; b) use an experimental economics approach to study moral hazard in private individuals. They find that moral hazard is found in the high-probability scenarios (15% occurrence probability), but not in the low-probability scenarios (3% occurrence probability). Mol et al. (2020a; b) suggest that moral hazard is less of an issue when flooding probabilities are low. Our survey data reports that in 2002 only 35% of the business respondents believed it was likely that they would be flooded again, while this increased to 72% by 2013. Likewise, in 2002 only 24% of the businesses responded that they were flooded before, while by 2013 this had grown to 63%. Assuming that protection standards have been maintained to meet a fixed flooding probability, this could explain why moral hazard occurred post 2005 as the subjective probability of flooding could be growing over time. This weakens the intention for future adaptation but is not strong enough to undo previously committed strategies. However, the confirmation of this avenue requires longitudinal data following specific businesses over time (i.e., panel data).

A further rationale could be as follows: moral hazard occurs when there are information asymmetries between the insurer and the policyholder (i.e., one knows more than the other). Information asymmetries can occur because of transaction costs which limit the attractiveness of monitoring the precautionary behaviour of policyholders (e.g., surveyors must be hired and sent into the field to check). This in turn limits the ability of insurers to reward and promote proactive behaviour, as the potential profitability of doing so shrinks. Therefore, while Ehrlich and Becker (1972) predict moral hazard should occur, Dionne and Eeckhoudt (1985) argue that this may not occur if policyholders are sufficiently risk-averse. While private businesses are often assumed to be risk neutral (i.e. more willing to accept risks than risk-averse households), the internal incentive structure of firms can create incentives for key decision-makers to act in a risk-averse manner (Borkan and Kunreuther 1979), Greenwald and Stiglitz (1990), Greenwald and Stiglitz (1993), Michel-Kerjan et al. (2015)). Moreover, smaller businesses may be more risk-averse as it is more

---

[3] Bubeck et al. (2020) based their classification on that presented in Rözer et al. (2016), who provide the following definitions of cost-categories low-cost are those such as acquiring information; medium-cost are those such changing the inferior use of flood-prone areas; high-cost, which require building-level structural changes.

intricately linked to the owner and their risk aversion as an individual. In terms of an active link between insurance and proactive policyholder adaptive behavior, similar issues may be faced with private households where there is perceived to be a weak systematic link between various insurance conditions and adaptive behaviour when insurance is considered overall (Surminski et al. 2015; Surminski and Thieken 2017; Hudson et al. 2020). However, it must be noted that there are fewer private businesses as compared to households in flood-prone areas. Therefore, the transaction costs of monitoring and personally dealing with private business insurance policies and behavior could be smaller allowing a stronger link between the premium charged and the precautionary behavior of households. Though given how the insurers interviewed stated how there are no on-site inspections for most of the business types in our sample before issuing a policy, it is not surprising how the insurers also affirmed that regarding precautionary measures on-site inspections only take place in special cases. An example of such a special case is premises in the high-hazard zone which are usually regarded as uninsurable. In these cases, the implementation of property-level measures is a condition to providing insurance coverage. In the survey of 2012/13, 12 to 13 of the surveyed insurers (depending on the type of insurance) stated that they do this, which is a large increase as in 2003 just 3 insurers (out of 13) did so. This follows on that in 2013 insurers greatly valued these measures as just 3 (out of 18) insurers confirmed that they did not value precautionary measures at all, while in 2003 no insurer valued voluntarily implemented measures. In the survey of 2013, just around 10% of the insurers (2 out of 17) stated that they do not inform their client about property-level adaptation measures. The others use the counselling interview or leaflets for this aspect. This adds further credence to the idea of a saturation point being reached in policyholder adaptive behaviours. The interviews indicate a large shift in the degree to which insurers attempt to promote adaptive behaviour. When this is combined with the observations of higher levels of overall preparedness and concern from private business respondents their may be less scope for increased action if their self-perceived capacity to act has been reached.

4.2 Limitations

Surveying flood-affected businesses are more challenging in comparison to flood-affected households as noted by Thieken et al. (2017). On the one hand, a questionnaire for businesses cannot cover as much as questions and details as a comparable household survey since entrepreneurs are often unwilling to answer long surveys. On the other hand, flood-affected businesses are much more heterogeneous than households, e.g., there are businesses in (small) rented stores on a building's ground level as well as industrial premises with several buildings on a large site. The challenge is to create a questionnaire that captures all business settings while limiting the duration of the survey. Consequently, the information collected about flood-affected businesses tends to be less detailed in comparison to information about private households (Thieken et al., 2017), which is reflected in a lower data quality as compared to similar surveys conducted for private households.

A general consideration to be made is that the surveys used in this study were developed between 2002 and 2013. At first, these surveys were more focused on studying the physical damaging processes and influencing factors (Kreibich et al. 2007; Sieg et al. 2017). However, much like with households there has been a growing focus on understanding behaviour and subjective perceptions (Hudson et al. 2020). This trend should also further extend into business owners and other stakeholders because the incentive structure is different from private households, as well as the potential decision-making process and

criteria. This is important because the survey design was overall based on theories and experiences developed for private households rather than for private businesses. Therefore, future research can work on better adapting behavioural theories of household-level action to private businesses. However, despite this limitation we were able to exploit the dataset's feature as a repeated cross-section to gain a sense of the stability of moral hazard over time as a greater focus on individual behaviour is being promoted in flood risk management (see Kuhlicke et al. 2020b, for a discussion). A repeated cross-sectional approach only allows for the detection of systematic changes in population outcomes, rather than individual behaviours.

Even if the most recent data is already nearly 8 years old at the time of writing, using data that stretches from 2002 to 2013 offers valuable insights into flood risk management that has undergone substantial changes in Germany since the 1990s towards a risk-based approach (Bubeck et al. 2017). The first is that there is a dearth of studies exploring longitudinal relationships in disaster risk management (Siegrist 2014; Hudson et al. 2020; Mondino et al. 2020). Therefore, a body of literature needs to be developed to act as a suitable basis for future longitudinal research. We explore if the overall population-level relationships have remained constant or not overtime. In doing so we find that the core relation studied has not been completely stable over time. The interplay between behavioural intentions and insurance coverage has changed as the overall risk management environment has also changed. This indicates a dynamic relationship that can be potentially manipulated and altered by changing policy and social contexts to create the incentives for 'good' behaviour. Therefore, if future research can specifically isolate why the moral hazard relationship has (not) changed between 2002 and 2013, or potentially changed again afterwards, this information can be useful in creating a more proactive risk management environment. The creation of a proactive risk management environment is becoming a key corner stone of how society will be required to manage climatic threats as climate change worsens disaster profiles (see, IPCC 2021). However, to truly expand research in this direction, a greater emphasis must be placed on longitudinal data studies across the field, not just for private households but for all stakeholder groups, such as businesses.

4.3 Policy implications

One policy implication emanates from the observation that we do not find strong evidence for the presence of moral hazard, actively lowering the preparedness actions of private businesses. Insurance, or similar risk transfer mechanisms, are an important part of risk management strategies because their ability to aid by providing a rapid recovery process. However, if moral hazard were detectably present then expanding insurance coverage would result in a reduction of adaptive behaviours, which in the end would result in larger (expected) flood damage. The results presented in Table 2 do not present systematic evidence for moral hazard in terms of implemented measures. Therefore, when these results are combined with the findings for private households across Germany (see Osberghaus (2015), Hudson et al. (2017) for example), it appears we may not suffer from this classical insurance problem. However, assuming households and SMEs share aspects of their decision process, there is a potential concern for moral hazard regarding future adaptation intentions. This was the only avenue detected for a potential moral hazard impact after 2005. Possible reasons could be a higher overall level of adaptation, higher perceptions of flood probabilities, and non-systematic presence of active rewards for policyholder risk

reduction. Without an increasingly active link, it could be that this one avenue for moral hazard is strengthened lowering the future adaptation potential.

There is another avenue to consider: charity hazard. Charity hazard is where an actor expects to receive post-flood compensation from the government and therefore does not buy insurance (Raschky and Weck-Hannemann 2007). Andor et al. (2020) indicate for German households a substantial charity hazard being present in flood-prone households. This is supported by the modelling study of Tesselaar et al. (2022) who find a similar potential across Europe. Hudson et al. (2021) find few systematic differences between how the Protection Motivation Theory (PMT) explains adaptive behaviour across households and SMEs. Therefore, it is plausible that this finding on charity hazard is transferable to that of the SMEs presented here (as the data used in Hudson et al. (2021) is the same as the 2013 data used in this study) and helps to explain why insurance coverage is relatively low, especially as efforts to increase insurance coverage in recent years have been focused on private households. This could also be expected to display a similar effect to moral hazard, though more research on this avenue will be required.

4.4 Research implications

The theoretical baseline that guided the empirical assessment was drawn, primarily, from the literature seeking to document/explain the damage of flood-affected private businesses suffered of which their adaptive behaviour was deemed to be an explanatory variable. However, the study of moral hazard within the flood risk research domain has focused upon the decision process of individual people rather than an organisational unit. Therefore, there is research in understanding the overlap between these two directions moral hazard research can travel in. The implicit assumption in the survey was that by asking questions to the individual most knowledgeable about the flood risk domain the overall behaviour and experience of the firm can be understood. However, there are also power dynamics and relationships within private businesses that may create complex interactions within the decision processes that go beyond a single responsible actor. The resulting implication is that in addition to the nature of the firm, etc., efforts should be made to understand the decision process of the manager, or responsible individual(s) as well. This is because a manager's personal experience maybe transferable as a vicarious experience. For example, a consistent finding is that experiencing a flood at the private business location promotes additional precautionary behaviour (e.g., Kreibich et al. 2011). Moreover, this potential avenue for vicarious experiences could be especially present in SMEs as they are more likely to have managers, employees, etc. who are more attached/committed to traditions and communities in the flood-prone areas. In future research, there should be a stronger attempt to link these areas together.

Additionally, research into both flood risk management has become more behaviourally focused (Kuhlicke et al. 2020b) as have recent developments in research on insurance (Corcos et al. 2020). There can be greater scope for combing these developments together to better understand through which mechanisms moral hazard may or may not occur. This is especially relevant as there is a long-term understanding that aspects of the expected utility theory-based economic thinking used to develop theories of moral hazard is largely insufficient in relation to natural hazards like flooding (Kunreuther and Michel-Kerjan 2009). Therefore, a deeper exploration of how behavioural experiments such as those in Mol et al. (2020a; b), or Osberghaus and Reif (2021), and behavioural theories overall could be better applied to uncover this information.

5 Conclusion

Considering the trend of increasing flood risk due to a combination of socio-economic development and climate change there is a growing focus in flood risk management to involve all stakeholders within integrated risk management approaches. Currently, much of the research on involving stakeholders in this process has focused on private households even though businesses are also located in flood-prone areas and suffer from a large share of damage. To fully understand the consequences of this trend, we need to study the behaviour of all stakeholders in flood-prone areas. Our study seeks to contribute towards this by studying the flood risk adaptation actions of private businesses located in flood-prone areas as linked to their pre-flood insurance coverage. Moreover, as compared to previous studies on moral hazard in Germany, this study uses a repeated cross-sectional dataset to explore three different channels through which moral hazard could occur: the performance of emergency measures during a flood; the employment of precautionary measures before a flood; and alterations in the intentions to employ further precautionary measures after a flood. The presence of a strong moral hazard effect would create conflicting interactions between the ways in which flood-prone actors are expected to behave.

To investigate this, our study employed a dataset of 1338 observations to explore if a signal regarding the systematic presence of moral hazard through three channels could be detected. In doing so, we do not find a strong signal for moral hazard in terms of lowering the degree of pre-flood preparedness or emergency measures employed during the flood. This finding repeats what was known for German households. However, there is a potential avenue for moral hazard to appear in terms of the preparedness intentions post-2005: the intentions to and employment of further employ risk reduction measures after a given flood were lowered, but at the same time there was a higher overall level of preparedness post-2005 as compared to pre-2005. This finding is partly conflicting with the Federal Water Act. The Federal Water Act has required since 2005 all flood-prone stakeholders to lower their risk. On the one hand, the higher level of precaution post-2005 matches well with the aims of the Federal Water Act. However, on the other hand, the lower intention to adapt post-2005 might signal that a saturation level of private adaptation has already been reached among flood-prone businesses. Therefore, a greater emphasis on developing effective incentivisation mechanisms maybe required to off-set this issue moving forwards.

Overall, our findings indicate mostly positive implications for risk management across Germany because the general increase in flood insurance coverage over time has not been associated with a strong decrease in risk-reducing behaviour resulting in a worsening of flood damage. However, unlike with previous studies on households we cannot determine if this is because of the intrinsic motivation of private business-leaders or changing perceptions on the impacts of flooding or the nature of the German insurance market. Additional research can be conducted on understanding the source of outcome by more directly focusing on these concepts as specially adapted for businesses rather than being directly transferred from research on households. However, in the absence of more detailed information, we suppose that the outcome of this study is due to the intrinsic motivation of business leaders. We draw this conclusion as around 87% of the sample consists of SMEs and as such are likely to be led by residents directly. Residents were found previously to have this outcome-driven by their intrinsic motivations. However, additional research is needed to further explore this, using the current study as the initial foray into this area. One avenue for future research is to explore the decision processes of companies employing flood risk adaptation measures more deeply (consider, e.g., the potential influence of smaller market

shares, business priorities or different internal incentives, profitability concerns, etc.). This would help establish how suitable concepts and methods developed for private households can be transferred to other stakeholder groups, such as business, and what adaptations are required.

References

Aerts JCJH, Botzen W, Clarke KC, Cutter SL, Hall JW, Merz B, Michel-Kerjan E, Mysiak J, Surminski S, Kunreuther H (2018) Integrating human behaviour dynamics into flood disaster risk assessment. Nat Clim Chang 8:193–199

Alessie RJM, Angelini V, Mierau JO, Viluma L (2020) Moral hazard and selection for voluntary deductibles. Health Econ 29(10):1251–1269

Andor MA, Osberghaus D, Simora M (2020) Natural disasters and governmental aid: Is there a charity hazard? Ecol Econ 169:106534

Bhattacharya-Mis N, Lamond J, Montz B, Kreibich H, Wilkinson S, Chan F, Proverbs D (2018) Flood risk to commercial property: training and education needs of built environment professionals. Int J Disaster Resil Built Environ 9(4/5):385–401

Borkan B, Kunreuther H (1979) Contingency planning against low probability events. Best's Rev 80(S24):106–112

Botzen WJW, Kunreuther H, Michel-Kerjan E (2019) Protecting against disaster risks: why insurance and prevention may be complements. J Risk Uncertain 59(2):151–169

Bubeck P, Aerts JCJH, de Moel H, Kreibich H (2016) Preface: flood-risk analysis and integrated management. Nat Hazards Earth Syst Sci 16:1005–1010

Bubeck P, Berghäuser L, Hudson P and Thieken AH (2020) Using panel data to understand the dynamics of human behavior in response to flooding. Risk Analysis n/a(n/a)

Bubeck P, Botzen WJW, Aerts JCJH (2012) A review of risk perceptions and other factors that influence flood mitigation behavior. Risk Anal 32(9):1481–1495

Bubeck P, Botzen WJW, Kreibich H, Aerts JCJH (2013) Detailed insights into the influence of flood-coping appraisals on mitigation behaviour. Glob Environ Chang 23(5):1327–1338

Bubeck P, Kreibich H, Penning-Rowsell EC, Botzen WJW, Moel H, Klijn F (2017) Explaining differences in flood management approaches in Europe and in the USA–a comparative analysis. J Flood Risk Manag. https://doi.org/10.1111/jfr3.12151

Charpentier A (2008) Insurability of climate risks. The Geneva Pap 33:91–109

Cohen A, Siegelman P (2010) Testing for adverse selection in insurance markets. J Risk Insur 77(1):39–84

Corcos A, Montmarquette C, Pannequin F (2020) How the demand for insurance became behavioral. J Econ Behav Organ 180:590–595

CRED-UNISDR (2015) The human cost of weather related disasters, 1995–2015, Centre for research on the epidemiology of disasters and United Nations office for disaster risk reduction

CRED and UNDRR (2018) Economic losses, poverty, & diasters: 1998–2017

Dionne G, Eeckhoudt L (1985) Self-insurance, self-protection, and increased risk aversion. Econ Lett 17(1–2):39–42

Ehrlich I, Becker GS (1972) Market insruance, self-selection, and self-protection. J Polit Econ 80(4):623–648

Einav L, Finkelstein A, Ryan SP, Schrimpf P, Cullen MR (2013) Selection on moral hazard in health insurance. Am Econ Rev 103(1):178–219

European Environment Agency (2019) Economic losses from climate-related extremes. European Environment Agency, Copenhagen

Forino G and von Meding J (2021) Climate change adaptation across businesses in Australia: interpretations, implementations, and interactions. Environment, Development and Sustainability

Gayan W, Bingunath I (2012) Resilience and adaptation of small and medium-sized enterprises to flood risk. Disaster Prev Manag an Int J 21(4):474–488

Geaves LH, Penning-Rowsell EC (2016) Flood Risk Management as a public or a private good, and the implications for stakeholder engagement. Environ Sci Policy 55:281–291

Greenwald BC, Stiglitz JE (1990) Asymmetric information and the new theory of the firm: financial constraints and risk behavior. Am Econ Rev 80(2):160–165

Greenwald BC, Stiglitz JE (1993) Financial market imperfections and business cycles*. Q J Econ 108(1):77–114

Halkos G and Skouloudis A (2019) Investigating resilience barriers of small and medium-sized enterprises to flash floods: a quantile regression of determining factors. Climate and Development 1–10

Hanger S, Linnerooth-Bayer J, Surminski S, Nenciu-Posner C, Lorant A, Ionescu R, Patt A (2018) Insurance, public assistance, and household flood risk reduction: a comparative Study of Austria, England, and Romania. Risk Anal 38(4):680–693

Hartmann T, Driessen P (2017) The flood risk management plan: towards spatial water governance. J Flood Risk Manag 10(2):145–154

Herbane B (2015) Threat orientation in small and medium-sized enterprises. Disaster Prev Manag 24(5):583–595

Hudson, Thieken AH and Bubeck P (2020) The challenges of longitudinal surveys in the flood risk domain. J Risk Res 23(5): 642–663

Hudson P, Botzen WJW, Aerts JCJH (2019) Flood insurance arrangements in the European Union for future flood risk under climate and socioeconomic change. Glob Environ Change 58:101966

Hudson P, Botzen WJW, Czajkowski J, Kreibich H (2017) Risk selection and moral hazard in natural disaster insurance markets: empirical evidence from Germany and the United States. Land Econ 93(2):179–208

Hudson P, Bubeck P, Thieken AH (2021) A comparison of flood-protective decision-making between German households and businesses. Mitig Adapt Strat Glob Change 27(1):5

Hudson P, de Ruig L, de Ruiter M, Kuik O, Botzen W, le Den X, Persson M, Benoist A, Nielsen C (2020) Best practices of extreme weather insurance in Europe and directions for a more resilient society. Environ Hazards 19(3):301–321

Ingirige B (2014) Putting policy initiatives into practice: adopting an "honest broker" approach to adapting small businesses against flooding. Struct Surv 32(2):123–139

IPCC (2014) Climate Change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change. Geneva, Switzerland, IPCC

IPCC (2018) Global Warming of 1.5C. Switzerland, IPCC

IPCC (2021) The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change In Press, Cambridge University Press

Jehmlich C, Hudson P and Thieken AH (2020) Short contribution on adaptive behaviour of flood-prone companies: a pilot study of Dresden-Laubegast, Germany. J Flood Risk Manage n/a(n/a): e12653

Johnson CL, Priest SJ (2008) Flood risk management in England: A changing landscape of risk responsibility? Int J Water Resour Dev 24(4):513–525

Kienzler S, Pech I, Kreibich H, Müller M, Thieken AH (2015) After the extreme flood in 2002: changes in preparedness, response and recovery of flood-affected residents in Germany between 2005 and 2011. Nat Hazard 15:505–526

Koks E, Carrera L, Jonkeren O, Aerts JCJH, Husby TG, Thissen M, Standardi G, Mysiak J (2016) Regional disaster impact analysis: comparing input–output and computable general equilibrium models. Nat Hazards Earth Schemes Sci 16:1911–1924

Kreibich H, Hudson P and Merz B (2021) Knowing what to do substantially improves the effectiveness of flood early warning. Bulletin of the American Meteorological Society

Kreibich H, Müller M, Schröter K, Thieken AH (2017) New insights into flood warning reception and emergency response by affected parties. Nat Hazard 17:2075–2092

Kreibich H, Müller M, Thieken AH and Merz B (2007) Flood precaution of companies and their ability to cope with the flood in August 2002 in Saxony, Germany. Water Resour Res 43(3)

Kreibich H, Seifert I, Thieken AH, Lindquist E, Wagner K, Merz B (2011) Recent changes in flood preparedness of private households and businesses in Germany. Reg Environ Change 11(1):59–71

Kuhlicke C, Masson T, Kienzler S, Sieg T, Thieken AH, Kreibich H (2020a) Multiple flood experiences and social resilience: findings from three surveys on households and companies exposed to the 2013 flood in Germany. Weather Clim Soc 12(1):63–88

Kuhlicke C, Seebauer S, Hudson P, Begg C, Bubeck P, Dittmer C, Grothmann T, Heidenreich A, Kreibich H, Lorenz D, Masson T, Reiter J, Thaler T, Thieken AH and Bamberg S (2020) The behavioural turn in flood disaster risk management and its implication for future research and policy. WIREs Water e1418

Kunreuther H (2015) The role of insurance in reducing losses from extreme events: the need for public-private partnerships. The Geneva Pap Risk Insur Issues Pract 40(4):741–762

Kunreuther H, Michel-Kerjan E (2009) At war with the weather: managing large scale risks in a new era of catastrophes. MA, MIT Press, Cambridge

Lo AY, Chan F (2017) Preparing for flooding in England and Wales: the role of risk perception and the social context in driving individual action. Nat Hazards 88:367

Lo AY, Xu B, Chan FKS, Su R (2015) Social capital and community preparation for urban flooding in China. Appl Geogr 64:1–11

Marshall MI, Niehm LS, Sydnor SB, Schrank HL (2015) Predicting small business demise after a natural disaster: an analysis of pre-existing conditions. Nat Hazards 79(1):331–354

Marshall MI, Schrank HL (2014) Small business disaster recovery: a research framework. Nat Hazards 72(2):597–616

Mas-Colell A (1995) Microeconomic theory. Oxford University Press, New York

Matczak P, Hegger D (2021) Improving flood resilience through governance strategies: gauging the state of the art. Wires Water 8(4):e1532

Meijerink S, Dicke W (2008) Shifts in the public-private divide in flood management. Int J Water Resour Dev 24(4):499–512

Michel-Kerjan E, Raschky P, Kunreuther H (2015) Corporate demand for insurance: new evidence From the U.S. terrorism and property markets. J Risk Insur 82(3):505–530

Mol JM, Botzen WJW, Blasch JE (2020a) Behavioral motivations for self-insurance under different disaster risk insurance schemes. J Econ Behav Org 84:101500

Mol JM, Botzen WJW, Blasch JE (2020b) Risk reduction in compulsory disaster insurance: experimental evidence on moral hazard and financial incentives. J Behav Exp Econ 84:101500

Mondino E, Scolobig A, Borga M, Albrecht F, Mård J, Weyrich P, Di Baldassarre G (2020) Exploring changes in hydrogeological risk awareness and preparedness over time: a case study in northeastern Italy. Hydrol Sci J 65(7):1049–1059

Neise T, Garschagen M and Revilla Diez J (2021) Engagement of small and medium-sized manufacturing enterprises in individual flood adaptation in Indonesian coastal cities—implications for flood governance. Climate change research, policy and actions in indonesia: science, adaptation and mitigation. Djalante R, Jupesta J and Aldrian E. Cham, Springer International Publishing: 99–120

Neise T, Revilla-Diez J (2018) Firms' contribution to flood risk reduction – scenario-based experiments from Jakarta and Semarang, Indonesia. Procedia Eng 212:567–574

Neise T, Revilla-Diez J (2019) Adapt, move or surrender? Manufacturing firms' routines and dynamic capabilities on flood risk reduction in coastal cities of Indonesia. Int J Disaster Risk Reduct 33:332–342

Neise T, Revilla-Diez J, Garschagen M (2018) Firms as drivers of integrative adaptive regional development in the context of environmental hazards in developing countries and emerging economies – a conceptual framework. Environ Plan c Pol Space 36(8):1522–1541

Neise T, Sambodo MT and Revilla-Diez J (2019) Are Micro-, small- and medium-sized enterprises willing to contribute to collective flood risk reduction? Scenario-based field experiments from Jakarta and Semarang, Indonesia. Organization & Environment: 1086026619875435

Osberghaus D (2015) The determinants of private flood mitigation measures in Germany — evidence from a nationwide survey. Ecol Econ 110:36–50

Osberghaus D, Reif C (2021) How do different compensation schemes and loss experience affect insurance decisions? Experimental evidence from two independent and heterogeneous samples. Ecol Econ 187:107087

Otto A, Kellermann P, Thieken AH, Máñez Costa M, Carmona M, Bubeck P (2019) Risk reduction partnerships in railway transport infrastructure in an alpine environment. Int J Disaster Risk Reduct 33:385–397

Paudel Y, Botzen WJW, Aerts JCJH, Dijkstra T (2015) Risk allocation in a public-private catastrophe insurance system: an actuarial analysis of deductibles; stop-loss; and premium. J Flood Risk Manag 8(2):116–134

Petrolia DR, Hwang J, Laundry CE, Coble KH (2015) Wind insurance and mitigation in the coastal zone. Land Econ 91(2):272–295

Poontirakul P, Brown C, Seville E, Vargo J, Noy I (2017) Insurance as a double-edged sword: quantitative evidence from the 2011 Christchurch earthquake. The Geneva Pap Risk Insur Issues Pract 42(4):609–632

Raschky PA, Weck-Hannemann H (2007) Charity hazard—a real hazard to natural disaster insurance? Environ Hazards 7(4):321–329

Rözer V, Müller M, Bubeck P, Kienzler S, Thieken A, Pech I, Schröter K, Buchholz O, Kreibich H (2016) Coping with pluvial floods by private households. Water 8:304. https://doi.org/10.3390/w8070304

Savitt A (2017) Insurance as a tool for hazard risk management? An evaluation of the literature. Nat Hazards 86(2):583–599

Shao W, Feng K, Lin N (2019) Predicting support for flood mitigation based on flood insurance purchase behavior. Environ Res Lett 14(5):054014

Sieg T, Vogel K, Merz B, Kreibich H (2017) Tree-based flood damage modeling of companies: damage processes and model performance. Water Resour Res 53(7):6050–6068

Siegrist M (2013) The necessity for longitudinal studies in risk perception research. Risk Anal 33(1):50–51

Siegrist M (2014) Longitudinal studies on risk research. Risk Anal 34(8):1376

Surminski S (2014) The role of insurance in reducing disaster risk - the case of flood insurance. Int Rev Environ Resour Econ 7:241–278

Surminski S, Aerts JCJH, Botzen WJW, Hudson P, Mysiak J, Pérez-Blanco CD (2015) Reflection on the current debate on how to link flood insurance and disaster risk reduction in the European Union. Nat Hazards 79(3):1451–1479

Surminski S, Thieken A (2017) Promoting flood risk reduction: the role of insurance in Germany and England. Earth's Future 5:979–1001

Terpstra T, Gutteling JM (2008) Households' perceived responsibilities in flood risk management in The Netherlands. Int J Water Resour Dev 24(4):555–565

Tesselaar M, Botzen WJW, Robinson PJ, Aerts JCJH, Zhou F (2022) Charity hazard and the flood insurance protection gap: an EU scale assessment under climate change. Ecol Econ 193:107289

Thieken A, Kreibich H, Müller M and Lamond J (2017) Data collection for a better understanding of what causes flood damage–experiences with telephone surveys. Flood Damage Surv Assess 95–106

Thieken AH (2018) Contributions of Flood Insurance to Enhance Resilience-Findings from Germany. In: Fekete A, Fiedrich F (eds) Urban disaster resilience and security: addressing risks in societies. Publishing, Cham, Springer International, pp 129–144

Thieken AH, Kienzler S, Kreibich H, Kuhlicke C, Kunz M, Mühr B, Müller M, Otto A, Petrow T, Pisi S, Schröter K (2016) Review of the flood risk management system in Germany after the major flood in 2013. Ecol Soc 21(2):51

Thieken AH, Petrow T, Kreibich H, Merz B (2006) Insurability and mitigation of flood losses in private households in Germany. Risk Anal 26(2):383–395

Tyler J, Sadiq A-A (2019) Business continuity and disaster recovery in the aftermath of Hurricane Irma: exploring whether community-level mitigation activities make a difference. Nat Hazard Rev 20(1):04018026

Wang JL, Chung C-F, Tzeng LY (2008) An empirical analysis of the effects of increasing deductibles on moral hazard. J Risk Insur 75(3):551–566

Wedawatta G, Ingirige B (2012) Resilience and adaptation of small and medium-sized enterprises to flood risk. Disaster Prev Manag an Int J 21(4):474–488

White GF (1945) Human adjustment to floods: a geographical approach to the flood problem in the United States. , University of Chicago

Wiering M, Kaufmann M, Mees H, Schellenberger T, Ganzevoort W, Hegger DLT, Larrue C, Matczak P (2017) Varieties of flood risk governance in Europe: How do countries respond to driving forces and what explains institutional change? Glob Environ Chang 44:15–26

Winter RA (2013) Optimal insurance contracts under moral hazard. Handbook of Insurance. Dionne G. New York, NY, Springer New York: 205–230

Zaalberg R, Midden C, Meijnders A, McCalley T (2009) Prevention, adaptation, and threat denial: flooding experiences in the Netherlands. Risk Anal 29(12):1759–1778