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Rent capitalisation patterns of extreme weather hazards – Evidence from Switzerland

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Highlights

Natural hazard risk is not only reflected in house prices, as shown in previous studies, but also in residential rents.
When dealing with natural hazards, property investors should not only look at potential asset devaluations due to physical damage, but also take into account lower rent cashflows.

Flooding and surface runoff hazards are associated with 1.4% and 3.5% lower rents in Switzerland, respectively, but only outside cities.
It might be that the comparably higher dwelling demand in cities wipes out natural hazard effects on rents. Further research is needed to explain these findings.

MINERGIE®-rated buildings are positively linked to rents, but only for buildings of medium building standard. The premium is estimated to be 4.1% for such a property on average.
Obtaining MINERGIE certification for medium-standard buildings might be relevant for cashflow optimisation purposes.

No single hazard discount (max. 4.1%) exceeds the premium for a MINERGIE-rated medium standard building (4.1%).
Labelling certain types of buildings with environmental standards might be a way for property investors to hedge against rent losses caused by natural hazard risks.

Abstract

Natural hazards pose a vital threat to both buildings and people. The lower equilibrium price of exposed properties, as confirmed by extant empirical studies, reflects both of these dimensions. Using rental rates rather than sales transaction prices or capital values, may provide a key for disentangling the two effects as tenants incur all negative effects of a natural hazard apart from the damage to the building which costs are borne by the owner. Our study of a sample of 18,339 dwellings in Switzerland finds that hillslope debris flow and storm hazard are associated with a significant rental discount across the country. Flooding and surface runoff hazard are associated with significant discounts outside of urban areas, but results are inconsistent within urban areas. Results on the effect of avalanches, debris flow, landslides, hail, and rockfall on rents are inconclusive. Heat-exposure does not appear to be associated with lower rents in Switzerland. Additionally, we find that environmental building certificates are associated with a premium depending on the standard of the building.

1. Introduction

Asset managers are future-proofing their portfolios in the face of climate change. Both the increased risks from natural hazards as well as the transition towards net-zero affect the returns on property. This paper studies the effect of natural hazards and environmental standards on net residential rents in Switzerland. We look primarily at flooding and the MINERGIE®-rating for environmental performance, but also include most other natural hazards that affect properties and persons in Switzerland: surface runoff, debris flow, hillslope debris flow, landslides, rockfall, avalanches, hail, storm, and heat.

While it is comparatively easy to insure against structural damage to buildings as a result of an extreme weather event, any reductions in cashflows from reduced rental income are harder to quantify for investors. Tenants face a risk that is different from owner-occupiers, whom have been the subject of most previous studies on natural hazard risks to properties. The total risk of natural hazards to a tenant consists of their risk of death or injury, any disruption suffered in the aftermath of the disaster and damage to the contents of the home. Damages to the building structure, on the other hand, are excluded as these are borne by the owner instead.

The rent a tenant is willing to pay for a property should in theory be equal to the rent in the absence of any natural hazard risk, minus the expected costs to the tenant of all disasters. This means that we expect rent paid on properties seriously at risk from natural hazards to be lower than the rent on comparable unaffected properties in a competitive market. From the perspective of the property asset manager, any such rental discounts come on top of the (insurable) risk of a one-time event of property damage which may or may not occur. Similarly, we expect the benefits of environmental building standards in the form of reduced heating costs, increased thermal comfort and a smaller ecological footprint to be reflected in higher rents.

The relationship between flood risk and house prices has been extensively studied in the past. While a few authors find insignificant discounts or even premiums (Bin & Kruse, 2006), most authors find that houses in floodplains sell for less than comparable properties not at risk from flooding. A meta-analysis by Beltrán, Maddison, and Elliott (2018) found a discount of 4.6% for properties located in a 100-year floodplain. Some authors also found an additional discount in the first couple of years following a major flood (Atreya, Ferreira, & Kriesel, 2013; Bin & Landry, 2013). Previous research using rent as the dependent variable has been very limited so far. The only previous attempt in Europe was by Hirsch and Hahn (2018), who found that flood-hazard (100-year floodplain) is associated with 1.8% lower rents in Regensburg (DE).

Natural hazards other than flooding have rarely been studied. A single paper on landslide hazards found up to 11.3% lower transaction prices for affected properties in South Korea (Kim, Park, Yoon, & Cho, 2017). For heat, Livy (2019) found that heatwaves with degree days 15% above the mean are associated with a 4.2% reduction in transaction prices in Ohio (US). Borzino, Chng, Mughal, and Schubert (2020) surveyed Singaporeans who indicated that they are willing to pay 0.43% of their income on average to mitigate the Urban Heat Island effect. Cross-sectional estimates of property prices or rents do not yet exist for heat as a hazard, nor are there any estimates for other climate-related natural hazards.

Energy efficiency/environmental ratings and residential rents have previously been studied in the case of Switzerland:[1] Feige, McAllister, and Wallbaum (2013) find a 2.9% discount in rent/m^2 per unit increase in 'Energy efficiency' (a composite indicator), which they ascribe to the use of gross rents (including services) in their study. Previously, Salvi, Horehájová, and Müri (2008) estimated that MINERGIE-certification is associated with 3.5–7% higher *transaction prices* for residential buildings in

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[1] *For studies on other countries, see Fuerst, McAllister, Nanda, and Wyatt (2016); Kholodilin, Mense, and Michelsen (2016).*

the canton of Zurich. The main requirements for this certification include a well-insulated building envelope, controlled air ventilation system and an efficient and renewable energy supply, with final energy consumption being the main indicator (MINERGIE, 2022).[2]

We synthesise both research strands and assess the effects of natural hazards as well as environmental certification on rents in Switzerland. The results can help property owners make their portfolio more resilient: First, do tenants care about the impact of the environment on themselves, i.e., are they willing to pay more to reduce their exposure to natural hazards? Second, do they care about their impact on the environment, i.e., are they willing to pay more for environmentally certified houses? Assessing those questions can guide property owners on what possibilities exist to hedge against financial losses caused by climate change, i.e., can certification premiums compensate discounts due to natural hazards? Is the impact on rent cashflows from green premiums greater, or from reducing natural hazard exposure?

2. Natural hazards in Switzerland

Natural hazards in Switzerland can be divided into four categories: geological hazards, hydrological hazards, gravitational hazards, and meteorological hazards. Major earthquakes are extremely uncommon in Switzerland and this geographical hazard is therefore not included (Swiss Seismological Service, 2022). As Switzerland is landlocked, flooding can only result from rivers and lakes overflowing, which we simply call “flooding” in the remainder of this paper. Inundation can also result directly[3] from rainfall, which we call “surface runoff”. Included gravitational hazards are debris flow, hillslope debris flow, landslides, rockfall, and avalanches. Debris flow, hillslope debris flow and landslides can appear to be quite similar, but they are distinct phenomena: Hillslope debris flow contains much more water than a landslide and usually starts higher up on steeper slopes. Debris flow emerges in streambeds, while hillslope debris flow does not. Storm, hail and heat are classified as meteorological hazards here.

Table 1: Annual impact of natural hazards in Switzerland

Natural Hazard	Mean annual damage. Mio. CHF (buildings)*	Mean annual deaths	Of which inside buildings	Source (Deaths)
Flooding	96.2	1.6	0.2	WSL (2022)/Andres et al. (2017)
Avalanches	8.7	5.5	2.8	SLF (2022)/Andres et al. (2017)
Landslides	2.4	0.7	0.6	WSL (2022)/Andres et al. (2017)
Rockfall		1.3	0.1	WSL (2022)/Andres et al. (2017)
Debris Flow	n/a	0.3	0.1	WSL (2022)/Andres et al. (2017)
Storm	49.3	1.5**		Andres et al. (2017)
Hail	115.3	n/a	n/a	–
Period	2002–2021	1946–2021	1946–2015	

*Source: Vereinigung Kantonaler Gebäudeversicherungen (2022). *19 cantons only. **1946 – 2015 period*

In terms of physical damage, flooding and hail are the costliest natural hazards (see Table 1). According to data from the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) and the Institute for Snow and Avalanche Research (SLF), avalanches stand out as particularly deadly. Following a series of severe disasters following extreme weather events in 1999, the Swiss government set out to map the intensity of various natural hazards across Switzerland in a systemic way (Bründl,

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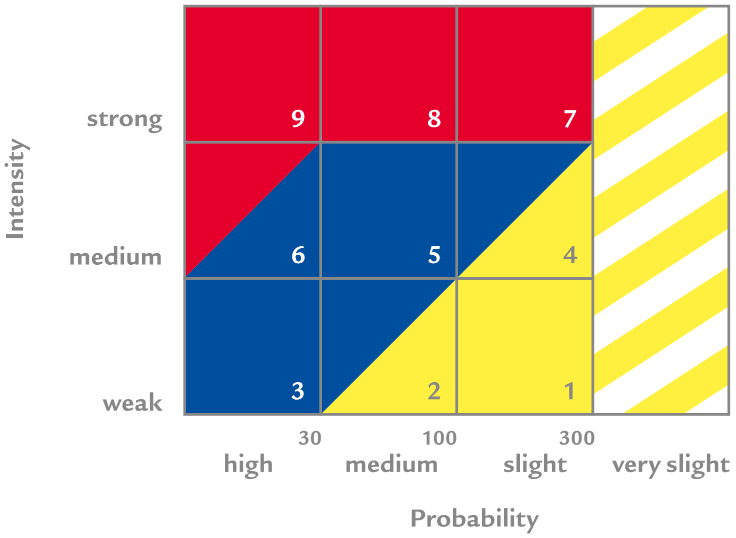
[2] *Newly built MINERGIE-certified homes have a maximum annual energy consumption of 55 kWh/m^2, but standards depend on the year of certification, presence of solar panels and are different for renovated buildings*

[3] *Flooding is usually also the result of precipitation, but surface runoff is caused directly by rain or melting snow when the soil (or sewage system) cannot absorb the water quickly enough.*

Romang, Bischof, & Rheinberger, 2009). Terrain analysis, topographic and geological maps, aerial photographs and satellite images as well as event inventories and historical chronicles inform the hazard analysis. The physical impacts of the hazards are derived from a process analysis and enhanced by physical modelling where relevant. Intensity is expressed in terms of expected physical impact (pressure, velocity, inundation depth, etc.) during a reference period, and is a combination of both probability and expected impact. Figure 1 shows how probability (in events per time period) and intensity combine into the five hazard levels shown in Table 2.

Although an effort has been made to make the hazard levels comparable across natural hazards (the same levels and definitions are used), they are not strictly comparable because different hazards are modelled in different ways. A general description of the modelling of all hazards can be found in reports by the Federal Office for Spatial Development (2005) and the *Bundesamt für Umwelt* (BAFU, 1999).[4] The hazard maps are published by the individual cantons.

Figure 1: Hazard levels as a function of probability and intensity.



Source: Federal Office for Spatial Development (2005)

As Table 2 shows, only the two highest hazard levels are associated with risks to persons. Given that only risks borne by occupants should be reflected in rents, we expect only to see a significant discount for hazard levels 4 and 5 relative to the three lower levels, with a larger discount for level 5. Significant differences in rent between levels 1, 2 and 3 are consequently not expected, but any such differences would be best ascribable to disruption suffered by residents and/or damaged contents.

Table 2: Hazard levels defined

Level	Definition	Description[5]	Corresponding colours
5	Substantial hazard	Sudden destruction of buildings is possible. Residents are at risk inside and outside buildings.	Red
4	Moderate hazard	Significant damage to buildings is possible but sudden destruction is very unlikely. Persons are at risk outside buildings.	Blue
3	Small hazard	No risk to persons. Minor damage to buildings possible.	Yellow
2	Residual hazard	No risk to persons. Minor damage to buildings can't be excluded completely.	White-yellow striped
1	No hazard	No risk to persons or structures	White (not shown)

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[4] *Avalanche hazard levels are defined in more detail in BFF/EISLF (1984) other gravitational hazards in (BUWAL/BWW/BRP, 1997), and hydrological hazards in (BWW/BRP/BUWAL, 1997).*

[5] *Descriptions translated to English from BAFU (2015).*

In addition to the categorized hazards described above, this paper also includes the continuous variable heat days; indicating how many days per year with a maximum temperature of over 30 degrees Celsius can be expected to occur at the location of the property. Following high mortality during ever more frequent heat waves (Thommen, 2005), heat-resilient building techniques such as green roofs, shades and high-albedo materials have become popular recently (Attia et al., 2021), but there has been no previous research on whether people are willing to pay to reduce exposure to heat.

3. Data

We use a dataset of 19,486 Swiss rental contracts. These are combined with natural-hazard data retrieved from each of the Swiss cantons. The combined dataset is prepared by Wüest Partner AG (WP), a consultancy providing digital solutions and real estate consulting in Switzerland, Germany and France. Structural characteristics of the properties are based on the judgements of different valuers. Locational attributes (including natural hazards) are assigned by WP using the coordinates of the properties.[6] Please see Appendix A for a description of all included variables and Appendix B for descriptive statistics.

We use the current annual rent of active (as of 2022) rental contracts throughout Switzerland. The rent is exclusive of service charges and/or utilities. Except for the south-western cantons of Geneva and Vaud,[7] there are no restrictions on rents in Switzerland at the time when the contract is agreed. Once the contract is signed, however, tenants enjoy protection against evictions and rent increases. Rents are not allowed to rise by more than a nationally set reference rate, 40% of the inflation-rate or 0.5% annually (Mieterverband, 2022). Exceptions apply for renovations. This means that rents for older contracts are generally lower than for more recently signed contracts. All contracts with a start date prior to 2021[8] are therefore excluded from the sample, as it is impossible to accurately infer the rent as agreed upon at the contract start-date from the currently paid rent. To clarify, it might be that some rents were increased with an amount less than the reference rate, while others were increased by the full amount (we have no way of knowing).

3.1. Natural hazards

After cleaning the data, the first thing we notice is that, apart from flood, runoff, and hail, exposure to high hazard levels is uncommon in the sample (see Table 3). The distribution of the latter is very different from other hazards, with all properties falling into the top three categories of hail hazards. Given that there is relatively little spatial difference in exposure to hail, and hail is the costliest of the included hazards in terms of damage to buildings (see Table 1), this is not surprising. Since we want to account for all natural hazards, the missing observations for runoff force us to reduce our sample to 18 385.

Table 3: Observations by hazard level and type

Level	Flooding	Runoff	Debris flow	Hillslope debris	Landslide	Rockfall	Avalanche	Hail	Storm
5	1 353	316	0	0	12	17	0	4 584	2
4	2 497	1 048	344	514	85	0	33	14 533	116
3	3 127	5 345	0	17	80	0	0	369	1 819
2	1 459	0	29	0	31	15	0	0	14 694
1	11 050	11 676	19 113	18 955	19 278	19 454	19 453	0	2 855
Total	**19 486**	**18 385**	**19 486**	**19 486**	**19 486**	**19 486**	**19 486**	**19 486**	**19 486**

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[6] *For heat, gridded (2 by 2 km) maps from the Swiss meteorological agency (MeteoSwiss) are used.*

[7] *Geneva has rent control; Vaud limits the increase in rent after renovations. Both cantons are excluded.*

[8] *There have been no changes in the reference rate since the first quarter of 2021.*

Low numbers of observations for higher hazard levels make it difficult to draw reliable conclusions, so we focus our analysis on those hazards that have sufficient variance in terms of hazard levels: flooding, surface runoff, debris flow, hillslope debris flow, hail and storm. Landslides, rockfall, and avalanches are not excluded, exposure to these hazards might still be an important factor for valuation, but accurate estimation of the magnitude of the discount will be impossible.

3.2. Building Standards

Next, we look at two measures of building standard: the standard as reported by valuators and the MINERGIE standard (see Table 4). Note that the 'standard' is the quality of the building assessed by experts and reflects the materials used and the finishes. This is distinct from the 'state' of the building which reflects how well the building has been maintained.

Table 4: Joint frequencies of general building standard and MINERGIE certification

		Standard					
		1	2	3	4	5	Total
MINERGIE	No	0	237	8 145	7 030	240	15 652
	Yes	0	0	299	2 328	60	2 687
	Total	**0**	**237**	**8 444**	**9 358**	**300**	**18 399**

We observe that the two standards are related (Cramér's V = 0.2996), with the high-standard buildings significantly more likely to have a MINERGIE rating. As opposed to most previous studies, we examine the premium for MINERGIE in excess of the premium associated with the building standard. This way, we account for the possibility that higher standard buildings are already better insulated and have other characteristics that command a higher rent, and that the added value of a MINERGIE rating is consequently likely to be smaller, while the costs of converting a high-standard building to MINERGIE standard is probably lower.

3.3. Recent disasters

As previous studies have shown increased discounts in the wake of disasters (Atreya et al., 2013; Bin & Landry, 2013), we include recent disaster-data to check whether this pattern holds for Swiss tenants as well. A database of disasters per municipality is maintained by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) since 1972. Using news reports, flooding events, debris flows, landslides, and rockfall events are recorded and classified according to total damage in three categories: Small (below 400 000 CHF), medium (400 000–2 000 000 CHF) and big (>2 000 000 and/or fatality). For each property, we take the time in years between the last disaster (medium or worse) in each category and the start date of the rental contract. Unlike previous authors, we do not look at the time since a single extreme event like Hurricane Katrina, but we use all recorded events to see if the pattern holds more generally. Table 5 shows how recent various disasters are in our sample.

Table 5: Included properties by time since last disaster in community

Time since last disaster (years)	Disaster type			
	flood	rockfall	landslide	debris flow
0–2	3 001	24	864	4
2–5	2 266	23	151	33
5–10	4 298	29	287	3
>10	9 942	19 431	18 205	19 467
Total	**19 507**	**19 507**	**19 507**	**19 507**

Given that the number of properties in areas with recent disasters of types other than flood is very small, we only consider flooding in our further analysis.

4. Research Strategy

The general hedonic equation (Rosen, 1974) used to estimate marginal willingness to pay (WTP) for various hazard levels, heat days and MINERGIE-standard is as follows:

$$ln(Rent)_{ij} = \beta_0 + \beta_1\ \mathbf{hazards}_i + \beta_2\ heat\ days_i + \beta_3\ MINERGIE_i \times \mathbf{standard}_i + \beta_4 \mathbf{Z}_{ij} + \Psi + \varepsilon_i$$

where $ln(Rent)_{ij}$ is the natural logarithm of total (net) annual rent paid for dwelling i in municipality j, $\mathbf{hazards}_i$ is a vector of natural hazard ratings, heat days is the number of annual heat days at the location of the property, $MINERGIE_i$ is a binary variable that takes the value 1 if the dwelling is built to MINERGIE-standard, $\mathbf{standard}_i$ is a categorical variable in five levels indicating the building standard of property i, $\mathbf{Z}_{ij}$ is a vector of controls at the property and municipality level and Ψ is a series of month × year indicating when the rental contract went into force. ε_i is an error term (robust standard errors are used).

Apart from general controls like dwelling size, age, location etc., we include some variables to control for any factors (positive or negative) that are related to hazard exposure. We include distance to lakes and rivers to control for the benefits of living close to water by including distance to lake, distance to river and lakeview. Water-related hazards are further expected to affect ground floor residents more than others, as higher floors are very unlikely to flood, so we interact groundfloor with flooding and runoff.

Gravitational hazards are associated with living on or at the bottom of a hill slope. To control for any amenities associated with living on a hillslope, we account for the incline of the slope, the orientation of the plot, elevation relative to the community and view of mountains and lakes.

To control for the positive amenities associated with warm weather, we account for mean temperature in winter and summer as well as *HDD* (heating degree days). Comparing rents across different (macro-) climates is difficult as we would be comparing the rents of properties in completely different places. We therefore compare top floor apartments with other dwellings instead. Heat affects those living directly under the roof more than others (Taylor et al., 2015; Vandentorren et al., 2006), so we estimate whether *HDD* is valued differently depending on floor level.

MINERGIE is interacted with **standard** to measure the WTP in excess of the WTP for a certain building-standard. The coefficient β_3 therefore indicates the marginal WTP (in percent). *MINERGIE* also acts as a control for heat, as well-insulated buildings are associated with increased thermal comfort (and heat in turn acts as a control for *MINERGIE*)

5. Results

The results for all of Switzerland are shown in Table 6. Only the most relevant control variables are shown. Appendix C contains the full estimation results. Hazard level 1 (no hazard) is the base level and therefore omitted, except in the case of hail where level 3 (small hazard) is the base level. As landslide, rockfall, and avalanche have an insufficient number of observations (see Table 3) to produce meaningful statistical estimates, we do not discuss the interpretation of these estimates. The log-linear specification allows us to interpret the coefficients as fractional and percentage changes.

Table 6: Baseline model

Variable		ln(rent)	
flooding	substantial	0.00772	(0.0047)
	moderate	−0.0129***	(0.0035)
	small	0.0340***	(0.0034)
	residual	0.0286***	(0.0041)
	none	base level	
runoff	substantial	0.00103	(0.00888)
	moderate	−0.00178	(0.00514)
	small	0.00689**	(0.00254)
	none	base level	
debris flow	moderate	−0.00581	(0.00708)
	residual	0.0102	(0.0297)
	none	base level	
hillslope debris	moderate	−0.0326***	(0.00718)
	none	base level	
landslide	substantial	0.126***	(0.0224)
	moderate	0.0596***	(0.0166)
	small	0.0119	(0.0142)
	residual	0.0888***	(0.0243)
	none	base level	
rockfall	moderate	−0.0803	(0.0457)
	residual	−0.0711*	(0.0333)
	none	base level	
avalanche	moderate	0.0914*	(0.0360)
	none	base level	
hail	substantial	0.0493***	(0.0128)
	moderate	0.0606***	(0.0123)
	small	base level	
storm	substantial	−0.0120	(0.0321)
	moderate	0.0545**	(0.0189)
	small	−0.0412***	(0.00544)
	residual	−0.0152***	(0.00332)
	none	base level	
heat days		0.00412***	(0.000484)

Variable		ln(rent)	
distance to lake	<250	0.0765***	(0.0115)
	<500	0.0919***	(0.00790)
	<1000	0.0376***	(0.00591)
	<1500	0.0000714	(0.00410)
	>1500	base level	
distance to river	<250	0.0398***	(0.00374)
	<500	0.0329***	(0.00385)
	<1000	0.0209***	(0.00320)
	<1500	−0.0178***	(0.00395)
	>1500	base level	
non-alpine		0.0270***	(0.00496)
rel. elevation		0.000206***	(0.0000587)
lakeview		0.00000972*	(0.00000410)
mountainview		0.00209***	(0.000127)
summer temp.		0.0336***	(0.00690)
winter temp.		−0.0355***	(0.00762)
standard = 2		base level	
MINERGIE × standard = 2		no observations	
standard = 3		0.0528***	(0.0117)
MINERGIE × standard = 3		0.0997***	(0.0143)
standard = 4		0.0803***	(0.0120)
MINERGIE × standard = 4		0.0733***	(0.0123)
standard = 5		0.170***	(0.0157)
MINERGIE × standard = 5		0.151***	(0.0257)
property-level controls		Included	
plot orientation and slope		Included	
area-level controls		Included	
socio-economic controls		Included	
year × month FE		Included	
R^2		0.855	
degr. freedom		18 222	
BIC		−18 426.6	
N		18 339	

*Robust Standard Error in parentheses. *p 0.05; **p 0.01; ***p 0.001. Complete list of controls in Appendix C*

Although moderate flood hazard is associated with a significant discount of around 1.3%, substantial hazard does not return a significant effect, which is surprising. The significantly positive estimates for small and residual hazard levels relative to no hazard are similarly surprising as we expected no or small negative estimates. We see a similar pattern for surface runoff, albeit less starkly.

Hillslope debris flow (moderate) shows a significantly negative estimate of −3.3%, while the negative estimate for debris flow does not differ significantly from zero at the 5% significance level. This probably has to do with the fact that the number of moderate hazard-observations is relatively small (for residual hazard it is even smaller).

For hail, we find that substantial hazard is significantly lower than moderate hazard (p = 0.000; Wald test). The discount is given by the difference between the estimates: (0.0606–0.0493) × 100% = 1.1%. Small hazard (the reference level) is associated with a lower estimate, but it should be noted that this category contains relatively few, geographically concentrated, observations. In the case of storm, we find increasing discounts for residual hazard at –1.5% and small hazard at –4.1%, but positive estimates for the moderate and substantial hazard levels. Again, this probably has to do with the small number of observations in the two latter categories. The discounts for small and residual storm hazard are unexpectedly large, as we expected something close to zero.

MINERGIE is associated with 4.1% higher rents at building standard 3 (medium), which is statistically significant (p = 0.000; Wald test).[9] For standard 4 and 5 we actually find slightly higher rents for uncertified buildings, with the difference for highest building standard level 5 being insignificant (p = 0.4594; Wald test) and the test result for level 4 being around the 95%-confidence level (p = 0.0499; Wald test). The estimate associated with MINERGIE at standard 4 is –0.7%.[10]

Heat days are positively valued on a national level, which is unsurprising given that people generally prefer to live in areas with warmer climates. In Section 5.2. we investigate whether this heat, which is a preferable thing as an environmental amenity, is valued less if occupants are more exposed to it when they are inside their home. Estimates for control variables are all as expected; distance to lakes and rivers being valued positively, as are views of mountains and living on hillsides (slope; relative elevations).

5.1 Flooding and runoff in urban versus non-urban areas

While for some hazards unexpected results may be attributable to the small number of observations, this is not a valid explanation for common hazards such as flooding or runoff. On closer inspection, we find that the counterintuitive pattern of high rents in high-hazard areas exists only in cities. When interacting with the dummy-variable *urban*,[11] we find that the pattern is driven by observations in cities, and that estimates for other types of communities are perfectly in line with expectations of a discount to exposed properties (see Table 7). Now, we find small, insignificant discounts for small and moderate hazards and a significant negative one for substantial hazard at –1.4%. A similar pattern emerges for runoff risk: substantial hazard has an estimate of –3.5% while the estimates for other hazard levels do not differ significantly from zero. There are no substantial differences for hail, storm, or hillslope debris, except that estimates associated with hail are not significant in urban subsample. This suggests that hydrological hazards are unique in being valued differently according to community type.

We tried interacting hazard risk with multiple variables associated with cities (age, distance to city centre, size, standard, dwelling type) to explain the remaining puzzling results for urban property, but found no factor that explains the difference between the two areas better than the variable urban, or a variable that explained the pattern within cities.

5.2 Vulnerability

Next, we investigate if there is a differential impact of heat days for rental units that are located on the ground floor compared to the top floor (Table 8). We find that the estimate for the interaction between heat days and (presumably more vulnerable) top floor apartments is not significantly different from the estimate for heat days interacted with other housing types (p = 0.2817; Wald test) We further tested whether hotter dwellings are rented out for less in the warmer summer months, again differentiating between top floor and other dwellings but no relationship between rent and month of contract signing in combination with top floor, or month and heat days, was found (estimates not shown).

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[9] *(0.0997–0.528) × 100% = 4.1%*

[10] *(0.0733–0.0803) × 100% = –0.7%*

[11] *Urban takes the value 1 if the community type is big city, medium-sized city or small city.*

5.3 Recent disasters

Previous research has generally found increased discounts for flooding in the wake of disasters caused by natural hazards. We interact flooding with the inverse of time[12] in years since the last flood, meaning that flooding risk is weighted more heavily if the community has recently been struck by a disaster (see Appendix C on the right). The interaction term between flooding and urban area location accounts for the difference in flood-pricing between types of communities (see Section 5.1.). Negative estimates for flooding interacted with the inverse of time since flood would imply that recent flooding events are associated with lower rents; we would expect this for higher hazard levels only (or at least more so than for less affected properties). Yet, the estimates of this term are inconsistent; we find both significant positive and negative estimates and observe no clear relationship with hazard level or community type.

Table 7: Urban vs non-urban

Variable		All	Urban	Non-urban	N	N (urban)	N (non-urban)
flooding	substantial	0.00772	0.0300***	−0.0137*	1204	508	696
	moderate	−0.0129***	−0.0150**	−0.00936	2175	1142	1033
	small	0.0340***	0.0727***	−0.000600	2789	1355	1434
	residual	0.0286***	0.0566***	0.000700	1397	765	632
	none	base level	base level	base level	10774	5501	5273
runoff	substantial	0.00103	0.0277*	−0.0347**	315	201	114
	moderate	−0.00178	0.00702	−0.00943	1047	591	456
	small	0.00689**	0.0169***	0.00466	5346	3025	2321
	none	base level	base level	base level	11631	5454	6177
debris flow	moderate	−0.00581	−0.0553**	0.0227**	344	87	257
	residual	0.0102	0.0198	no observations	29	29	0
	none	base level	base level	base level	17966	9155	8811
hillslope debris flow	moderate	−0.0326***	−0.0476***	−0.0326*	509	359	150
	none	base level	base level	base level	17830	8912	8918
landslide	substantial	0.126***	0.118***	no observations	12	12	0
	moderate	0.0596***	−0.000546	0.0652***	85	18	67
	small	0.0119	0.0000809	0.0310	80	48	32
	residual	0.0888***	−0.00822	0.205***	31	22	9
	none	base level	base level	base level	18131	9171	8960
rockfall	moderate	−0.0803	0.122	0.0869	17	12	5
	residual	−0.0711*	no observations	−0.0578	15	0	15
	none	base level	base level	base level	18307	9259	9048
avalanche	moderate	0.0914*	−0.327**	0.150***	33	10	23
	none	base level	base level	base level	2159	1409	750
hail	substantial	0.0493***	0.0175	0.105***	3868	1697	2171
	moderate	0.0606***	0.0273	0.120***	14102	7270	6832
	small	base level	base level	base level	396	304	92
storm	substantial	−0.0120	−0.0350	no observations	2	2	0
	moderate	0.0545**	0.104***	−0.0710*	116	102	14
	small	−0.0412***	−0.0365***	−0.0438***	1575	850	725
	residual	−0.0152***	−0.0168**	−0.0134***	13819	7455	6364
	none	base level	base level	base level	2827	862	1965

**p 0.05; **p 0.01; ***p 0.001. Complete list of controls in Appendix C*

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[12] *The variable takes the value 1 if the disaster occurred in the previous year, 0.5 if it happened 2 years ago etc. The value of the variable halves as the time doubles.*

Table 8: Vulnerability

Variable	ln(rent)	
flooding = substantial × groundfloor = 0	0.0109*	(0.00489)
flooding = substantial × groundfloor = 1	0.0312	(0.0278)
flooding = moderate × groundfloor = 0	−0.0155***	(0.00381)
flooding = moderate × groundfloor = 1	0.0355	(0.0260)
flooding = small × groundfloor = 0	0.0357***	(0.00360)
flooding = small × groundfloor = 1	0.0653*	(0.0262)
flooding = residual × groundfloor = 0	0.0331***	(0.00422)
flooding = residual × groundfloor = 1	0.0401	(0.0277)
flooding = none × groundfloor = 0	base level	base level
flooding = none × groundfloor = 1	0.0371	(0.0251)
runoff = substantial × groundfloor = 0	0.00178	(0.00893)
runoff = substantial × groundfloor = 1	−0.00163	(0.0363)
runoff = moderate × groundfloor = 0	0.0000933	(0.00549)
runoff = moderate × groundfloor = 1	−0.0154	(0.0125)
runoff = small × groundfloor = 0	0.00716**	(0.00271)
runoff = small × groundfloor = 1	0.00413	(0.00625)
runoff = none × groundfloor = 0	base level	
runoff = none × groundfloor = 1	no observations	
top floor=0 × heat days	0.00403***	(0.000498)
top floor=1 × heat days	0.00487***	(0.000820)
R^2	0.855	
degr. freedom	18 212	
BIC	−18 367.0	
N	18 339	

*Robust Standard Error in parentheses. *p 0.05; **p 0.01; ***p 0.001. Complete list of controls in Appendix C*

6. Conclusions

This study examined the relationship between residential rents and ten prevalent natural hazards (flooding, surface runoff, debris flow, hillslope debris flow, landslides, rockfall, avalanches, hail, storm, & heat) as well as the MINERGIE environmental label in Switzerland. It provides guidance to residential property investors on whether they can expect lower cash flows from properties that are exposed to one or multiple natural hazards on top of any insurable material damage, and on how such discounts compare to rent premiums on environmental certification.

For hillslope debris flow and storm, we find significant rent discounts, which means that tenants tend to pay less for properties exposed to these two hazards. Insignificant estimates are found for debris flow-hazard, while substantial hail hazard is associated with lower rents than moderate hazard even if for both, rents are higher than for small hazard. For the hazards avalanche, rockfall and landslide, we were unable to produce reliable estimates due to an insufficient number of observed properties exposed to these hazards. These findings mean that tenants are not indifferent to natural hazard risks, and that they are willing to pay less in some cases. Why they care about some hazards but not others, is for further research to establish. Possible explanations include the degree to which tenants are affected, awareness of the different hazards, or differences in the definitions of hazard levels. While hazard levels are designed to be comparable across hazards, hazards inevitable manifest themselves in different ways and carry quite different threats in terms of the financial and human threat.

The pricing of the most prevalent natural hazards, flooding and surface runoff, appears to be different for urban and non-urban areas. Outside urban areas, we estimate that exposure to substantial flooding hazard, the highest possible hazard level, is associated with a rental discount of 1.4%. This estimate is broadly in line with Hirsch and Hahn (2018), the only other rental study of natural hazards from non-coastal Europe.[13] Residual, small and moderate hazard levels are not associated with a significant discount. In urban areas, we find inconsistent result, possibly reflecting the more complex small-scale spatial and pricing patterns within densely built-up areas. For surface runoff (non-urban) the discounts for substantial hazard is 3.5%, while within urban areas the estimates are again inconsistent.

One possible explanation is that as buildings in cities tend to carry higher economic and, in some cases, also higher cultural value, more resources may be deployed to protect them from flood damage compared to their rural counterparts. The hypothesis that a greater value at risk leads to better adaptation and therefore lower vulnerability, however, does not explain the premium associated with natural hazard levels of 2 and 3 for flooding. Alternatively, the signal might get drowned out in tight urban markets with low vacancy rates where tenants have less market power. Where this is the case, the observable price signals of property characteristics such as long-term flood risk may be distorted. This is something for further research to establish.

We find that exposure to heat in the form of living on the top floor of a building is not associated with lower rents, this can mean that heat is not considered a disutility or that living on the top floor does not make heat harder to mitigate (using air-conditioning or ventilation). The main caveat here is that the heat map resolution (2 km grid) is too low to capture the full intensity of the Urban Heat Island effect at the scale of individual neighbourhoods. Similarly, we do not find any evidence that increased exposure to flooding and runoff hazard by living on the flood-prone ground floor is reflected in lower rents in Switzerland above and beyond any overall rental discounts.

Lastly, we find that the MINERGIE environmental standard is not associated with a significant rent premium in the case of high-quality buildings. The premium is substantial only in the case of buildings built to a medium standard (4.1%), for higher standards we find no premium or even a small negative estimate (–0.7% at level 4). This suggests that the construction standards of high-quality buildings are already so high that the MINERGIE-standard does not add any further price premium. The premium associated with MINERGIE at medium standard is similar in magnitude to the biggest discounts associated with any single hazard (4.1% for storm (small) and 3.5% for substantial runoff hazard outside of urban areas).

The results in this study can have several implications for property investors. First, property investors should account for longer-term reductions in rental cash flows in their investment appraisals, in addition to pricing the risk of structural damage to assets and disrupted rental income during the repair and recovery phase. This applies to flooding, surface runoff, storm, and hillslope debris flow and, possibly to a lesser extent, to other natural hazards. As investment appraisals are inherently forward-looking, investors may also take a view on whether the risk of a given hazard in a given area may be higher in the future or not. Second, while climate-resilient building has garnered considerable attention in recent years, our results suggest that investments that reduce the impact of (urban) heat stress (shades, high-albedo materials) are unlikely to generate higher rent cashflows in Switzerland. Third, certifying buildings to the MINERGIE standard might not be reasonable in view of hedging natural hazard discounts if the building standard is rather low or high. We find a MINERGIE rent premium only for buildings of medium standards, suggesting that for those buildings, certifying energy efficiency retrofits investments might be worthwhile, depending on the cost of conversion. Finally, given that the estimated rent premium for a MINERGIE-certified average-sized building of medium standard is equal to or exceeds the discounts of any single natural hazard, labelling such buildings with environmental standards might be a way for property investors to hedge against rent losses caused by natural hazard risks.

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[13] *They found 1.8% for location in a 100-year floodplain, with additional discount for increased expected inundation depth except for the very greatest depths.*

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Appendix A: Variable descriptions

Label	Measurement level	Description
rent	dwelling	rent per year
community type	municipality	12 different community types as defined by BFS
standard	building	Grade for the standard (building quality) of building in general 1 = worst, 5 is best
state	building	Structural state of the building. 1 = worst, 5 is best
MINERGIE	building	MINERGIE-Standard
parking	building	Garage: does property have a garage or not
hillslope debris	building	hillslope debris *(Hangmur)* hazard rating
avalanche	building	Avalanche *(Lawine)* hazard rating
debris flow	building	debris flow *(Murgang)* hazard rating
landslide	building	landslide *(Erdrutsch)* hazard rating
rockfall	building	rockfall *(Strurzprozesse)* hazard rating
flooding	building	flooding *(Hochwasser)* hazard rating
runoff	building	surface runoff (Oberflächenabfluss) hazard rating
hail	building	hail *(Hagel)* hazard rating
storm	building	storm *(Sturm)* hazard rating
size	dwelling	size in sqm of the dwelling
dwelling type	dwelling	dwelling type
floor	dwelling	floor level
top floor	dwelling	takes the value 1 if the dwelling is on top floor
rooms	dwelling	number of rooms of dwelling
age	building	age of building
dist. center	building	distance in meters to center
dist. shop	building	distance in meters to shop
dist. transport	building	distance in meters to transport
dist. lake	building	distance in meters to a lake
dist. river	building	distance in meters to a river
dist. nature	building	distance in meters to nature
lakeview	building	theoretical view of lakes from a vantage height of 2 m, which could potentially prevail at this location.
mountainview	building	theoretical view of the most dominant and renowned peaks of the Swiss mountain landscape, which could potentially prevail at this location.
pop. density	building	pop density in a radius of 1000 m
heat days	building	Heat days per year in 2020. 2 by 2 km grid (BFS)
income diversity	building	Income diversity in a radius of 1000 m
tax rate	building	Marginal income tax rate for a two-person household (married, tenants, no children) earning 120 000 CHF per year
HDD	municipality	average heating degree days for period 1980–2010. Municipal level.
canton	canton	Canton ID
unemployment rate	canton	unemployment rate at the municipal level
urban	building	takes the value 1 if community type is big city, medium-sized city or small city
year	dwelling	start year of rental contract.
month	dwelling	start month of rental contract.
elevation	building	meters above sea level
rel. elevation	building	elevation building minus elevation municipality
slope	building	incline of the plot upon which the building stands
exposition	building	exposition of the plot upon which the building stands
alpine	municipality	1 if in the mountains (according to BFS)
summer temp.	building	mean temperature in summer. 10 by 10 km grid (E-OBS)
winter temp.	building	mean temperature in winter. 10 by 10 km grid (E-OBS)
summer	dwelling	takes the value 1 if the contract started in June, July or August
inv. time since flood	municipality	1 divided by the time in years (rounded up) since the last flood with more than 400 000 CHF in damage

Appendix B: Descriptive statistics (N=18 339)

Variable	Mean	Std. Dev.	Min	Max
ln(rent)	9.741	0.3727	7.352	1.191
flooding	4.001	categorical	1	5
runoff	4.177	categorical	1	5
hillslope debris	4.917	categorical	1	4
avalanche	5.875	categorical	1	6
debris flow	4.942	categorical	1	4
landslide	4.973	categorical	1	5
rockfall	4.996	categorical	1	4
hail	1.809	categorical	3	5
storm	4.055	categorical	1	5
heat days	11.350	4.134	0	28.566
HDD	3417.266	284.952	2373	6756
floor	2.341	1.945	0	8
top floor	0.154	0.361	0	1
rooms	3.180	1.087	1	7
age	34.112	29.972	0	122
Age^2	2061.925	2953.722	0	14884
standard	3.530	categorical	2	5
MINERGIE	0.147	.3536348	0	1
size	76.553	28.172	9	430
state	4.0714	categorical	2	5
parking	0.878	0.327	0	1
Size^2	6653.941	5151.651	81	184 900
dist. lake	1798.231	categorical	250	2000
dist. river	1134.304	categorical	250	2000
inv. dist. nature	0.00017	0.0011	1.22 × 10^7	0.01
inv. dist. transport	0.00011	0.00025	8.73 × 10^7	0.003
inv. dist. centre	0.00076	0.0025	1.57 × 10^8	0.01
lakeview	121.607	403.565	0	3948
mountainview	9.326	10.391	0	57
slope	2.617	3.095	0.012	30.025
exposition	7.735	2.347	1	9
rel. elevation	8.390	26.971	–144.177	224.103
alpine	0.120	0.324	0	1
summer temp.	17.303	1.082	7.592	20.495
winter temp.	2.838	1.032	–6.469	5.763
tax rate	0.1075	0.021	0.035	0.155
pop. density	4833.223	27.859	20.456	16360.09
pop. Density^2	3.11 × 10^7	3.77 × 10^7	418.447	2.68 × 10^8
income diversity	2.416	0.397	1.335	3.511
unemployment	0.023	0.0048	0.004	0.039
year	2021.052	categorical	2021	2022
month	5.544	categorical	1	12

Appendix C: Full regression results

Variable	Baseline		Urban		Vulnerability		Recent Disaster	
standard = 2 × MINERGIE = 0	base level		base level		base level		base level	
standard = 2 × MINERGIE = 1	–		–		–		–	
standard = 3 × MINERGIE = 0	0.0528***	(0.0117)	0.0505***	(0.0116)	0.0532***	(0.0116)	0.0467***	(0.0115)
standard = 3 × MINERGIE = 1	0.0997***	(0.0143)	0.100***	(0.0142)	0.101***	(0.0142)	0.100***	(0.0142)
standard = 4 × MINERGIE = 0	0.0803***	(0.0120)	0.0777***	(0.0119)	0.0813***	(0.0120)	0.0738***	(0.0119)
standard = 4 × MINERGIE = 1	0.0733***	(0.0123)	0.0702***	(0.0122)	0.0745***	(0.0123)	0.0691***	(0.0122)
standard = 5 × MINERGIE = 0	0.170***	(0.0157)	0.175***	(0.0157)	0.171***	(0.0156)	0.165***	(0.0155)
standard = 5 × MINERGIE = 1	0.151***	(0.0257)	0.142***	(0.0247)	0.153***	(0.0257)	0.143***	(0.0247)
flooding = 5	0.00772	(0.00471)						
flooding = 4	–0.0129***	(0.00352)						
flooding = 3	0.0340***	(0.00342)						
flooding = 2	0.0286***	(0.00406)						
flooding = 1	base level							
runoff = 5	0.00103	(0.00888)					–0.00546	(0.00887)
runoff = 4	–0.00178	(0.00514)					–0.00257	(0.00512)
runoff = 3	0.00689**	(0.00254)					0.00608*	(0.00253)
runoff = 1	base level						base level	
hillslope debris = 4	–0.0326***	(0.00718)			–0.0321***	(0.00715)	–0.0394***	(0.00739)
hillslope debris = 1	base level				base level		base level	
avalanche = 4	0.0914*	(0.0360)			0.0918*	(0.0364)	0.0945**	(0.0364)
avalanche = 1	base level				base level		base level	
debris flow = 4	–0.00581	(0.00708)			–0.00553	(0.00713)	0.000869	(0.00718)
debris flow = 2	0.0102	(0.0297)			0.00919	(0.0296)	–0.0256	(0.0284)
debris flow = 1	base level				base level		base level	
landslide = 5	0.126***	(0.0224)			0.126***	(0.0226)	0.127***	(0.0227)
landslide = 4	0.0596***	(0.0166)			0.0606***	(0.0165)	0.0624***	(0.0166)
landslide = 3	0.0119	(0.0142)			0.0139	(0.0141)	0.0104	(0.0141)
landslide = 2	0.0888***	(0.0243)			0.0893***	(0.0246)	0.0749**	(0.0249)
landslide = 1	base level				base level		base level	
rockfall = 4	–0.0803	(0.0457)			–0.0810	(0.0458)	–0.0836*	(0.0419)
rockfall = 2	–0.0711*	(0.0333)			–0.0701*	(0.0328)	–0.0624	(0.0334)
rockfall = 1	base level				base level		base level	
hail = 5	0.0493***	(0.0128)			0.0509***	(0.0128)	0.0441***	(0.0131)
hail = 4	0.0606***	(0.0123)			0.0623***	(0.0123)	0.0585***	(0.0126)
hail = 3	base level				base level		base level	
storm = 5	–0.0120	(0.0321)			–0.0145	(0.0358)	–0.0424	(0.0316)
storm = 4	0.0545**	(0.0189)			0.0545**	(0.0189)	0.0664***	(0.0190)
storm = 3	–0.0412***	(0.00544)			–0.0407***	(0.00545)	–0.0362***	(0.00553)
storm = 2	–0.0152***	(0.00332)			–0.0154***	(0.00332)	–0.0153***	(0.00338)
storm = 1	base level				base level		base level	
heat days	0.00412***	–0.000484					0.00363***	(0.000497)
HDD	0.0000360***	(0.00000932)	0.0000387***	(0.00000947)	0.0000364***	(0.00000931)	0.0000287**	–0.00000916
urban = 0 × flooding = 5			–0.0137*	(0.00584)			–0.0336***	(0.00696)
urban = 0 × flooding = 4			–0.00936	(0.00478)			–0.0132**	(0.00510)
urban = 0 × flooding = 3			–0.000600	(0.00406)			–0.0158**	(0.00486)
urban = 0 × flooding = 2			0.000700	(0.00576)			0.00810	(0.00687)
urban = 0 × flooding = 1			base level				base level	
urban = 1 × flooding = 5			0.0300***	(0.00761)			0.0456***	(0.0100)
urban = 1 × flooding = 4			–0.0150**	(0.00529)			–0.00740	(0.00688)
urban = 1 × flooding = 3			0.0727***	(0.00530)			0.0903***	(0.00695)

Variable	Baseline		Urban		Vulnerability		Recent Disaster	
urban = 1 × flooding = 2			0.0566***	(0.00580)			0.0475***	(0.00790)
urban = 1 × flooding = 1			base level				base level	
urban = 0 × runoff = 5			−0.0347**	(0.0113)				
urban = 0 × runoff = 4			−0.00943	(0.00698)				
urban = 0 × runoff = 3			0.00466	(0.00333)				
urban = 0 × runoff = 1			base level					
urban = 1 × runoff = 5			0.0277*	(0.0122)				
urban = 1 × runoff = 4			0.00702	(0.00728)				
urban = 1 × runoff = 3			0.0169***	(0.00376)				
urban = 1 × runoff = 1			base level					
urban = 0 × hillslope debris = 4			−0.0326*	(0.0131)				
urban = 0 × hillslope debris = 1			base level					
urban = 1 × hillslope debris = 4			−0.0476***	(0.00900)				
urban = 1 × hillslope debris = 1			base level					
urban = 0 × avalanche = 4			0.150***	(0.0276)				
urban = 0 × avalanche = 1			base level					
urban = 0 × non-alpine			−0.00536	(0.00746)				
urban = 1 × avalanche = 4			−0.327**	(0.112)				
urban = 1 × avalanche = 1			−0.0470***	(0.00670)				
urban = 1 × non-alpine			base level					
urban = 0 × debris flow = 4			0.0227**	(0.00794)				
urban = 0 × debris flow = 2			–					
urban = 0 × debris flow = 1			base level					
urban = 1 × debris flow = 4			−0.0553**	(0.0171)				
urban = 1 × debris flow = 2			0.0198	(0.0294)				
urban = 1 × debris flow = 1			base level					
urban = 0 × landslide = 5			–					
urban = 0 × landslide = 4			0.0652***	(0.0185)				
urban = 0 × landslide = 3			0.0310	(0.0247)				
urban = 0 × landslide = 2			0.205***	(0.0285)				
urban = 0 × landslide = 1			base level					
urban = 1 × landslide = 5			0.118***	(0.0237)				
urban = 1 × landslide = 4			−0.000546	(0.0335)				
urban = 1 × landslide = 3			0.0000809	(0.0171)				
urban = 1 × landslide = 2			−0.00822	(0.0320)				
urban = 1 × landslide = 1			base level					
urban = 0 × rockfall = 4			0.0869	(0.0869)				
urban = 0 × rockfall = 2			−0.0578	(0.0324)				
urban = 0 × rockfall = 1			base level					
urban = 1 × rockfall = 4			0.122	(0.0942)				
urban = 1 × rockfall = 2			–					
urban = 1 × rockfall = 1			base level					
urban = 0 × hail = 5			0.105***	(0.0208)				
urban = 0 × hail = 4			0.120***	(0.0205)				
urban = 0 × hail = 3			base level					
urban = 1 × hail = 5			0.0175	(0.0142)				
urban = 1 × hail = 4			0.0273	(0.0140)				
urban = 1 × hail = 3			base level					
urban = 0 × storm = 5			–					
urban = 0 × storm = 4			−0.0710*	(0.0360)				
urban = 0 × storm = 3			−0.0438***	(0.00766)				

Variable	Baseline		Urban		Vulnerability		Recent Disaster	
urban = 0 × storm = 2			−0.0134***	(0.00394)				
urban = 0 × storm = 1			base level					
urban = 1 × storm = 5			−0.0350	(0.0324)				
urban = 1 × storm = 4			0.104***	(0.0219)				
urban = 1 × storm = 3			−0.0365***	(0.00845)				
urban = 1 × storm = 2			−0.0168**	(0.00652)				
urban = 1 × storm = 1			base level					
urban = 0 × heat days			0.00653***	(0.000650)				
urban = 1 × heat days			0.00256***	(0.000540)				
flooding = 5 × groundfloor = 0					0.0109*	(0.00489)		
flooding = 5 × groundfloor = 1					0.0312	(0.0278)		
flooding = 4 × groundfloor = 0					−0.0155***	(0.00381)		
flooding = 4 × groundfloor = 1					0.0355	(0.0260)		
flooding = 3 × groundfloor = 0					0.0357***	(0.00360)		
flooding = 3 × groundfloor = 1					0.0653*	(0.0262)		
flooding = 2 × groundfloor = 0					0.0331***	(0.00422)		
flooding = 2 × groundfloor = 1					0.0401	(0.0277)		
flooding = 1 × groundfloor = 0					base level			
flooding = 1 × groundfloor = 1					0.0371	(0.0251)		
runoff = 5 × groundfloor = 0					0.00178	(0.00893)		
runoff = 5 × groundfloor = 1					−0.00163	(0.0363)		
runoff = 4 × groundfloor = 0					0.0000933	(0.00549)		
runoff = 4 × groundfloor = 1					−0.0154	(0.0125)		
runoff = 3 × groundfloor =0					0.00716**	(0.00271)		
runoff = 3 × groundfloor = 1					0.00413	(0.00625)		
runoff = 1 × groundfloor = 0					base level			
runoff = 1 × groundfloor = 1					–			
top floor = 0 × heat days					0.00403***	(0.000498)		
top floor = 1 × heat days					0.00487***	(0.000820)		
urban = 0 × flooding = 5 × inv. time since flood							0.149***	(0.0305)
urban = 0 × flooding = 4 × inv. time since flood							−0.0430*	(0.0211)
urban = 0 × flooding = 3 × inv. time since flood							0.0877**	(0.0268)
urban = 0 × flooding = 2 × inv. time since flood							−0.0828***	(0.0223)
urban = 0 × flooding = 1 × inv. time since flood							−0.0332**	(0.0113)
urban = 1 × flooding = 5 × inv. time since flood							−0.0238	(0.0237)
urban = 1 × flooding = 4 × inv. time since flood							0.0142	(0.0131)
urban = 1 × flooding = 3 × inv. time since flood							−0.0150	(0.0153)
urban = 1 × flooding = 2 × inv. time since flood							0.0512***	(0.0117)
urban = 1 × flooding = 1 × inv. time since flood							0.0416***	(0.00635)
urban			0.438***	−0.0311			0.281***	(0.0215)
top floor					0.00646	(0.00997)		
groundfloor	base level		base level		base level		base level	
floor = 1	0.00105	(0.00349)	0.000713	(0.00346)	0.0331	(0.0249)	0.000660	(0.00345)
floor = 2	0.000355	(0.00361)	0.000811	(0.00359)	0.0303	(0.0249)	0.000202	(0.00358)

Variable	Baseline		Urban		Vulnerability		Recent Disaster	
floor = 3	0.0172***	(0.00400)	0.0168***	(0.00397)	0.0457	(0.0249)	0.0171***	(0.00398)
floor = 4	0.0205***	(0.00492)	0.0201***	(0.00487)	0.0485	(0.0251)	0.0199***	(0.00488)
floor = 5	0.0339***	(0.00627)	0.0343***	(0.00627)	0.0608*	(0.0254)	0.0339***	(0.00626)
floor = 6	0.0462***	(0.00661)	0.0454***	(0.00655)	0.0730**	(0.0254)	0.0444***	(0.00660)
floor = 7	0.0669***	(0.00964)	0.0641***	(0.00950)	0.0941***	(0.0264)	0.0653***	(0.00949)
floor > 7	0.0747***	(0.00742)	0.0744***	(0.00733)	0.103***	(0.0255)	0.0746***	(0.00730)
rooms	0.0353***	(0.00316)	0.0358***	(0.00313)	0.0353***	(0.00316)	0.0352***	(0.00313)
age	–0.00421***	(0.000146)	–0.00423***	(0.000147)	–0.00421***	(0.000146)	–0.00421***	(0.000146)
age^2	0.0000355***	(0.00000141)	0.0000354***	(0.00000140)	0.0000355***	(0.00000141)	0.0000355***	(0.00000141)
state = 2 × size	base level		base level		base level		base level	
state = 3 × size	0.0625***	(0.00901)	0.0639***	(0.00896)	0.0622***	(0.00900)	0.0646***	(0.00889)
state = 4 × size	0.138***	(0.00921)	0.141***	(0.00913)	0.138***	(0.00919)	0.141***	(0.00906)
state = 5 × size	0.198***	(0.00951)	0.198***	(0.00945)	0.198***	(0.00950)	0.197***	(0.00939)
parking	–0.0170**	(0.00529)	–0.0154**	(0.00528)	–0.0164**	(0.00527)	–0.0163**	(0.00530)
size	0.0121***	(0.000849)	0.0121***	(0.000836)	0.0121***	(0.000848)	0.0121***	(0.000840)
size^2	–0.0000251***	(0.00000478)	–0.0000251***	(0.00000471)	–0.0000251***	(0.00000478)	–0.0000251***	(0.00000473)
apartment	base level		base level		base level		base level	
detached house	0.163***	(0.0285)	0.164***	(0.0322)	0.167***	(0.0305)	0.157***	(0.0302)
duplex	0.0115	(0.0109)	0.0148	(0.0109)	0.00567	(0.0109)	0.0118	(0.0109)
garden apartment	0.0128	(0.0197)	0.0159	(0.0197)	0.0116	(0.0201)	0.0115	(0.0190)
loft	–0.0208	(0.0223)	–0.0228	(0.0219)	–0.0207	(0.0224)	–0.0190	(0.0219)
penthouse	–0.00377	(0.0108)	0.000197	(0.0107)	–0.0157	(0.0112)	–0.00294	(0.0107)
rooftop apartment	0.112***	(0.00731)	0.112***	(0.00722)	0.0994***	(0.00791)	0.112***	(0.00728)
single room	–0.448***	(0.0316)	–0.440***	(0.0316)	–0.447***	(0.0316)	–0.442***	(0.0317)
studio	–0.0666*	(0.0276)	–0.0585*	(0.0276)	–0.0688*	(0.0278)	–0.0598*	(0.0277)
terraced house	0.0390	(0.0517)	0.0521	(0.0463)	0.0350	(0.0510)	0.0486	(0.0454)
terrace apartment	0.0887***	(0.0199)	0.0689***	(0.0200)	0.0927***	(0.0200)	0.0883***	(0.0197)
unknown dwelling type	0.0305***	(0.00469)	0.0304***	(0.00474)	0.0331***	(0.00469)	0.0313***	(0.00467)
income diversity	0.110***	(0.00376)	0.108***	(0.00378)	0.109***	(0.00377)	0.109***	(0.00374)
unemployment rate	–8.619***	(0.321)	–8.206***	(0.330)	–8.557***	(0.322)	–7.979***	(0.333)
dist. lake <250	0.0765***	(0.0115)	0.0762***	(0.0115)	0.0755***	(0.0115)	0.0830***	(0.0113)
dist. lake <500	0.0919***	(0.00790)	0.0936***	(0.00798)	0.0921***	(0.00793)	0.0938***	(0.00794)
dist. lake <1000	0.0376***	(0.00591)	0.0457***	(0.00612)	0.0380***	(0.00591)	0.0422***	(0.00594)
dist. lake <1500	0.0000714	(0.00410)	0.000209	(0.00422)	0.000257	(0.00410)	0.000672	(0.00415)
dist. lake >1500	base level		base level		base level		base level	
dist. river <250	0.0398***	(0.00374)	0.0394***	(0.00383)	0.0395***	(0.00374)	0.0418***	(0.00372)
dist. river <500	0.0329***	(0.00385)	0.0324***	(0.00389)	0.0334***	(0.00385)	0.0349***	(0.00381)
dist. river <1000	0.0209***	(0.00320)	0.0222***	(0.00325)	0.0209***	(0.00320)	0.0236***	(0.00318)
dist. river <1500	–0.0178***	(0.00395)	–0.0165***	(0.00397)	–0.0174***	(0.00394)	–0.0168***	(0.00393)
dist. river >1500	base level		base level		base level		base level	
inv. dist. nature	–1.409	(0.955)	0.0529	(1.004)	–1.363	(0.953)	–0.0701	(0.962)
inv. dist. transport	7.175	(4.720)	8.649	(4.587)	7.635	(4.716)	9.226*	(4.561)
inv. dist. centre	1.274*	(0.599)	1.082	(0.596)	1.296*	(0.599)	1.088	(0.601)
lakeview	0.00000972*	(0.00000410)	0.0000117**	(0.00000404)	0.00000976*	(0.00000410)	0.00000696	(0.00000403)
mountainview	0.00209***	(0.000127)	0.00187***	(0.000128)	0.00209***	(0.000127)	0.00194***	(0.000127)
slope	0.00282***	(0.000663)	0.00323***	(0.000683)	0.00292***	(0.000659)	0.00290***	(0.000664)
exposition = 1	base level		base level		base level		base level	
exposition = 2	0.0356***	(0.00874)	0.0282**	(0.00887)	0.0352***	(0.00873)	0.0367***	(0.00874)
exposition = 3	0.0183*	(0.00875)	0.0154	(0.00890)	0.0186*	(0.00875)	0.0199*	(0.00877)
exposition = 4	0.0700***	(0.00876)	0.0611***	(0.00890)	0.0700***	(0.00876)	0.0679***	(0.00865)
exposition = 5	0.0338***	(0.00933)	0.0277**	(0.00944)	0.0334***	(0.00933)	0.0274**	(0.00941)
exposition = 6	0.0484***	(0.00878)	0.0428***	(0.00894)	0.0488***	(0.00872)	0.0470***	(0.00874)

Variable	Baseline		Urban		Vulnerability		Recent Disaster	
exposition = 7	0.0617***	(0.00858)	0.0585***	(0.00869)	0.0608***	(0.00860)	0.0574***	(0.00853)
exposition = 8	0.0701***	(0.00889)	0.0600***	(0.00915)	0.0705***	(0.00886)	0.0662***	(0.00897)
exposition = 9	0.0443***	(0.00720)	0.0422***	(0.00733)	0.0447***	(0.00720)	0.0446***	(0.00725)
tax rate	–2.933***	(0.0742)	–2.876***	(0.0744)	–2.937***	(0.0743)	–2.822***	(0.0749)
pop. density	0.0000290***	(0.00000162)	0.0000296***	(0.00000161)	0.0000293***	(0.00000162)	0.0000306***	(0.00000161)
pop. density^2	–1.04e-09***	(1.22e-10)	–1.08e-09***	(1.22e-10)	–1.05e-09***	(1.22e-10)	–1.13e-09***	(1.22e-10)
rel. elevation	0.000206***	(0.0000587)	0.000285***	(0.0000593)	0.000208***	(0.0000588)	0.000233***	(0.0000582)
summer temp.	0.0336***	(0.00690)	0.0325***	(0.00710)	0.0338***	(0.00691)	0.0242***	(0.00708)
winter temp.	–0.0355***	(0.00762)	–0.0358***	(0.00780)	–0.0360***	(0.00763)	–0.0281***	(0.00776)
non-alpine	0.0270***	(0.00496)	–		0.0273***	(0.00495)	0.0344***	(0.00524)
Big cities	base level		base level		base level		base level	
Medium-sized cities	–0.253***	(0.00542)	–0.254***	(0.00559)	–0.253***	(0.00542)	–0.252***	(0.00547)
Small cities	–0.294***	(0.00601)	–0.297***	(0.00630)	–0.295***	(0.00602)	–0.291***	(0.00618)
Rich communities	–0.127***	(0.00941)	0.192***	(0.0214)	–0.127***	(0.00939)	0.193***	(0.0221)
Touristic municipalities	–0.229***	(0.0167)	0.0737**	(0.0249)	–0.231***	(0.0166)	0.0928***	(0.0251)
Inner suburbs big cities	–0.174***	(0.00503)	0.143***	(0.0199)	–0.175***	(0.00504)	0.145***	(0.0207)
Outer suburbs big cities	–0.244***	(0.00753)	0.0807***	(0.0200)	–0.245***	(0.00754)	0.0832***	(0.0208)
Inner suburbs medium-sized cities	–0.295***	(0.00600)	0.0205	(0.0197)	–0.296***	(0.00601)	0.0237	(0.0205)
Outer suburbs medium-sized cities	–0.300***	(0.00807)	0.00984	(0.0202)	–0.301***	(0.00808)	0.0206	(0.0211)
Dormitory towns (outside agglomeration)	–0.288***	(0.0109)	0.0274	(0.0213)	–0.290***	(0.0109)	0.0371	(0.0219)
Industrial communities	–0.255***	(0.00850)	0.0591**	(0.0202)	–0.257***	(0.00853)	0.0673**	(0.0211)
Rural communities	–0.317***	(0.0207)	–		–0.320***	(0.0207)	–	
2021–1	base level		base level		base level		base level	
2021–2	0.00933	(0.00577)	0.00780	(0.00572)	0.00939	(0.00577)	0.0127*	(0.00572)
2021–3	0.0209***	(0.00577)	0.0180**	(0.00570)	0.0208***	(0.00577)	0.0242***	(0.00572)
2021–4	0.0226***	(0.00580)	0.0215***	(0.00572)	0.0225***	(0.00580)	0.0271***	(0.00575)
2021–5	0.0307***	(0.00584)	0.0285***	(0.00576)	0.0308***	(0.00584)	0.0349***	(0.00581)
2021–6	0.00761	(0.00585)	0.00593	(0.00582)	0.00774	(0.00586)	0.0110	(0.00583)
2021–7	0.0177**	(0.00560)	0.0164**	(0.00552)	0.0178**	(0.00560)	0.0198***	(0.00555)
2021–8	0.00667	(0.00601)	0.00636	(0.00594)	0.00676	(0.00602)	0.00480	(0.00604)
2021–9	0.0123*	(0.00600)	0.0103	(0.00598)	0.0127*	(0.00600)	0.0101	(0.00608)
2021–10	0.0212***	(0.00628)	0.0195**	(0.00621)	0.0212***	(0.00629)	0.0199**	(0.00629)
2021–11	0.0295***	(0.00775)	0.0276***	(0.00770)	0.0293***	(0.00775)	0.0276***	(0.00771)
2021–12	0.0197*	(0.00799)	0.0168*	(0.00796)	0.0196*	(0.00802)	0.0189*	(0.00797)
2022–1	0.0192*	(0.00854)	0.0158	(0.00857)	0.0197*	(0.00856)	0.0162	(0.00861)
2022–2	–0.0372***	(0.0102)	–0.0395***	(0.0104)	–0.0366***	(0.0102)	–0.0389***	(0.0104)
2022–3	0.0448*	(0.0218)	0.0455*	(0.0215)	0.0438*	(0.0216)	0.0499*	(0.0216)
2022–4	–0.00651	(0.0171)	–0.00803	(0.0168)	–0.00665	(0.0172)	–0.00333	(0.0174)
constant	8.230***	(0.108)	7.860***	(0.110)	8.192***	–0.111	8.067***	(0.113)
R^2	0.855		0.858		0.855		0.857	
degr. freedom	18 222		18 201		18 212		18 201	
BIC	–18 426.6		–18 589.0		–18 367.0		–18 592.7	
Mean VIF	4.26		7.92		5.66		5.39	
N	18 339		18 339		18 339		18 332	

*Robust Standard Error in parentheses. *p 0.05; **p 0.01; ***p 0.001. ‘base level’ indicates base level.*