Loss Prevention Technologies' Effect on Property Damage Cost and Financial Savings: Evidence from Danish Municipalities

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Received: October 12, 2022
Revised: May 25, 2023
Accepted: May 26, 2023

Abstract

This paper presents an analysis of loss prevention technology investments across more than 4,000 buildings owned by Danish municipalities to estimate the financial returns from such investments. The study finds that while these technologies significantly reduce the cost of damage, the expected savings are insufficient to finance the investment or operation costs. Therefore, it is important to consider non-property or non-physical damage, such as business interruptions, when making investment decisions to determine if the full gains from the investments exceed the cost.

Keywords: Effect of Loss Prevention, Self-Protection, Property Risk Management, Loss Prevention Technologies, Fire Suppression Systems, Sprinkler System, Automatic Fire Alarm System, Automatic Water Leak Detection Systems, Burglar Alarm, Access Control System, Closed-Circuit TeleVision (CCTV), Building Management System

1 Introduction

One tends to believe that loss prevention efforts can control risks and that these efforts will have a positive economic net benefit. Accordingly, the expectation of reducing property damages drives investments in loss prevention technologies in buildings. Evidence of these savings is however mixed. Some technologies show expected savings that counter property risks under most circumstances, while others have less clear accounting, with benefits dependent on situational conditions (Soelvsten, 2022). In this paper, we use a new dataset that combines loss prevention technology investments and claims histories for Danish municipality buildings to examine the effect these multifaceted loss prevention technologies have on property damages and whether they are a financially solid investment.

To understand our interpretation of property risk, we focus on the following four main categories of property risk: fire, crime, technical building installations, and natural catastrophes. The limited knowledge about the effects of loss prevention technologies and their economic net benefits in regard to mitigating any of these multi-faced hazards has been summarized in a comprehensive literature review (Sølvsten (2022)). The review concludes that multiple co-existing risks are rarely studied together and rarely studied in the economics literature, so that higher level assessment of societal net benefits remains an open question. Restricted access to proprietary data appears to limit the scale and interest of potential research. This paper surmounts this hurdle with a partnership between industry, government and academia.

Best studied are crime loss prevention technologies. Little, however, is known about whether private investors would benefit financially from investing in crime loss prevention technologies. Evans, Tseloni, Farrell, Thompson, and Tilley (2017) and Welsh and Farrington (2003) agree that there is a need to increase the use of economic tools in future research to understand economic net benefits better when investing in loss prevention technologies.

Sølvsten and Kaiser (2022) begin to address societal gains and losses by investigating the effect of loss prevention technologies on policy premiums. They find that policy premiums are often unresponsive to investments in loss prevention technologies and the technologies can shift potential gains away from technology-adopting policy holders to their insurers. Still, the question of overall net benefits remains.

This article uses data combining known loss prevention technology installations with claims history to address this question. We estimate the impact of commonly used loss prevention technologies (*automatic fire alarm system (abbreviated fire alarm in this article), sprinklers, burglar alarms, access control systems, CCTV systems, water leak detection systems and building management systems*) on property damages accrued to Danish municipal buildings and then use these results to estimate the joint financial benefits to policy holders and insurers of investing in such technologies.

We proceed with the task in steps: (1) we calculate the effects of loss prevention technologies on the probabilities of adverse events occurring to a range of municipal buildings, (2) we estimate the effects of these technologies on the severity of damages experienced in the claims history, (3) we extrapolate the potential technology benefits to buildings without loss prevention technologies, and (4) we use these findings to calculate the potential financial savings from reduced property risks to Danish municipal buildings. We conclude with lessons and caveats for expanding to other situations.

2 Background and data

We surmount the challenge of obtaining empirical data on building characteristics, historical use of loss prevention measures, and building damage (Frank, Gravestock, Spearpoint, and Fleischmann (2013); Tilley, Thompson, Farrell, Grove, and Tseloni (2015)) through an iterative data collection process between the authors and Danish municipalities. The final dataset includes comprehensive panel data from 23 municipalities, covering more than 4,000 buildings with 6,068,900 m^2, categorised in 10 types of buildings, per year for the years 2014-2018. The 10 building types included in the study are School (452 addresses, 2,259,981 m^2), Daycare (833 addresses, 555,931 m^2), Nursing home (214 addresses,547,735 m^2), Administration (213 addresses,456,653 m^2), Sports venue (151 addresses, 431,408 m^2), Community Centre (356 addresses, 338,294 m^2), Residential (345 addresses, 329,059 m^2), Entertainment (121 addresses, 147,158 m^2), Workshop (110 addresses, 98,434 m^2), and Other (1269 addresses, 904,237 m^2). There were minimal changes in the municipal building portfolios during this five-year period.

Danish municipalities use nine different primary technologies to address the sub-risks of fire, crime, and building installations; the data do not give any indication of loss prevention directly related to natural catastrophes. The nine technologies can be grouped into three categories based on the specific sub-risk they target. Technologies for addressing the sub-risk of fire include Fire alarms and Sprinklers, while Burglar Alarms, Access Control, and CCTV technologies address the risk of crime. Water leak detection systems (with and without automatic stop valves) and Building Management Systems (BMS) address the risk from building installations. An overview of the use and stability of loss prevention technologies in the dataset over time is shown in Table 1. As only a small number of buildings had water leak detection systems without automatic stop valves and transient overvoltage protection systems, these technologies were not included in further analysis.

Table 1: Loss prevention overview

		Fire risk		Crime risk			Building installation risk			
Year	All units	Fire Alarm	Sprinkler	Burglar Alarm	Access control	CCTV	Water Leak, stop	Water Leak, detection	BMS	Transient
2014	4062	706	72	1376	283	362	202	11	211	2
2015	4050	715	75	1375	289	375	202	11	211	2
2016	4033	741	74	1370	294	378	236	11	209	2
2017	4024	754	74	1373	302	380	247	11	209	2
2018	4013	788	76	1379	333	383	264	11	209	2

Table 2 provides a summary of the use of loss prevention measures by unique units, total observations (unique units multiplied by the number of observed years), and recorded risk-related damages when the technology was in use. The technologies used are likely to have a complementary effect on property risk, and property owners often invest in multiple technologies. For example, municipalities use automatic fire alarm systems and sprinkler systems together to mitigate the risk of fire. Over the five-year period, there were 3350 observations of fire alarm systems used as a standalone system in 670 unique buildings. However, there were only 17 observations of 3 buildings with standalone sprinkler systems, while there were 354 observations of 72 buildings where both sprinkler and fire alarm systems were used together.

Similarly, for crime prevention, access control or video surveillance systems are rarely present without burglar alarms, though the reverse is not true. For technologies related to the risk from building installations, the majority have either water leak detection systems with automatic stop valves or building management systems, as standalone systems, with only 14 percent of buildings or observations having both systems installed. Information on the usage of building automation systems was not available for 1844 out of 4065 buildings; these observations are dropped in some regression analyses. This lack of recording could be due to variations in how building automation systems are perceived, as they are primarily used for controlling heating, ventilation, and air conditioning (HVAC) and may not be considered in the context of loss prevention.

In addition to data on building characteristics and the use of loss prevention technology, the municipalities provided a comprehensive list of all recorded building and inventory damages that occurred at each address during the five-year period. The submitted lists of building damages were thoroughly compared with the building portfolios to confirm accurate matching between the damages and the specific buildings.

Table 2 presents an overview of damages with the technologies we investigate empirically. Each category of technology is mutually exclusive and only includes the technologies specified.

Table 2: Loss prevention technologies by units and risk-focused damage

Technology	Unique units	Unique units over time, total	Cases of Damages
Fire alarms	670	3350	162
Fire Alarm and Sprinkler	72	354	13
Burglar alarms	654	3260	458
Burglar alarms and CCTV	47	226	17
Burglar alarms and Access control	149	746	133
Burglar alarms, CCTV and Access control	162	805	125
Burglar alarms, CCTV and Access control	89	458	65
Water leak, stop	122	598	28
BMS	164	816	77
Water leak - stop and BMS	47	233	31

3 Quality assurance of data

The individual municipalities confirmed all data by written consent and stated that the data give an accurate and fair view of the period. The municipalities that have contributed data all have a central administration for the payment of building damage.

This system can be interpreted as equivalent to an insurance company, internally handled through the municipality's own organization. Reporting of damages is thorough, with limited exclusion of minor damages under the municipality's internal deductible or damages that are not covered by the municipality's internal insurance program. 15 municipalities reported that all damages are registered centrally. Four municipalities reported that all damages above DKK 5,000 are registered. Two municipalities reported that all damages above DKK 10,000 are registered, and two municipalities reported that damages above DKK 50,000 are registered.

Table 3: All damages

Damage	Count	% of total cases	Mean, damage	Max, damage	Min, damage	Median, damage	Sum, damage	% of total damages
Sanitation	**1,858**	**39,9%**	**5,758**	**79,739**	**147**	**4,319**	**10,701,412**	**4.47%**
Burglary	**1,243**	**22.0%**	**24,745**	**467,233**	**211**	**10,755**	**30,748,072**	**12.86%**
W / burglar alarm	312	5.5%	22,563	195,900	312	11,398	7,039,709	2.94%
W / access control	12	0.2%	12,590	33,244	2,939	2,939	151,089	0.06%
W / CCTV	5	0.1%	22,389	87,864	1,922	7,423	111,947	0.05%
W / burglar alarm & CCTV	99	1.8%	44,812	467,233	1,634	14,614	4,436,495	1.85%
W / burglar alarm & access control	86	1.5%	22,849	143,618	829	11,091	1,965,030	0.82%
W / burglar alarm, CCTV & access control	59	1.0%	50,984	326,025	305	20,597	3,008,068	1.26%
Other	**671**	**11.9%**	**17,479**	**466,412**	**51**	**6,842**	**11,728,406**	**4.90%**
Vandalism	**460**	**8.2%**	**12,593**	**190,746**	**396**	**6,282**	**5,792,851**	**2.42%**
W / burglar alarm	146	2.6%	11,824	114,831	396	7,872	1,726,379	0.72%
W / access control	5	0.1%	20,786	83,155	2,082	5,206	103,930	0.04%
W / CCTV	0	0%	0	0	0	0	0	0%
W / burglar alarm & CCTV	34	0.6%	11,003	57,175	484	5,715	374,133	0.16%
W / burglar alarm & access control	39	0.7%	6,908	30,263	549	4,908	269,447	0.11%
W / burglar alarm, CCTV & access control	6	0.1%	38,409	190,746	1,873	9,138	230,458	0.10%
Fire	**410**	**7.3%**	**264,838**	**32,511,178**	**155**	**23,865**	**108,583,520**	**45.40%**
W / Fire alarm	162	2.8%	177,924	13,253,860	462	21,232	28,823,654	12.05%
W / Sprinkler	0	0%	0	0	0	0	0	0%
W / Fire alarm & Sprinkler	13	0.2%	2,742,069	32,511,178	30,397	249,288	35,646,896	14.90%
Water Damage, Other	**317**	**5.6%**	**107,358**	**4,367,630**	**911**	**30,879**	**34,032,416**	**14.23%**
W / Water leak - Stop valve	14	0.2%	115,358	972,060	6,733	39,524	1,615,016	0.68%
W / Water leak detection	2	0.0%	10,912	20,824	1,017	10,921	21,842	0.01%
BMS	36	0.6%	127,471	1,008,772	911	37,227	4,588,989	1.92%
W / Water leak - stop valve & BMS	18	0.3%	201,432	3,041,997	1,175	14,821	3,625,786	1.52%
Water Damage, pipe leakage	**250**	**4.4%**	**64,052**	**3,458,630**	**686**	**20,398**	**16,013,090**	**6.70%**
W / Water leak - Stop valve	14	0.2%	30,721	78,789	4,182	21,585	430,104	0.18%
W / Water leak detection	1	0.0%	16,014	16,014	16,014	16,014	16,014	0.01%
BMS	41	0.7%	28,941	267,339	686	11,869	1,186,618	0.50%
W / Water leak - stop valve & BMS	13	0.2%	56,523	286,988	3,415	29,966	734,805	0.31%
Storm	**208**	**3.7%**	**35,586**	**937,407**	**1,121**	**11,021**	**7,401,874**	**3.09%**
Cloudburst	**65**	**1.2%**	**114,350**	**994,800**	**253**	**29,327**	**7,436,859**	**3.11%**
Glass	**52**	**0.9%**	**4,788**	**34,177**	**518**	**3,115**	**248,971**	**0.10%**
Lightning	**44**	**0.8%**	**76,535**	**1,062,585**	**907**	**21,513**	**3,367,526**	**1.41%**
W / Transient	0	0%	0	0	0	0	0	0%
Hit by car	**25**	**0.4%**	**11,423**	**58,282**	**489**	**7,394**	**285,567**	**0.12%**
Snow load	**21**	**0.4%**	**94,569**	**425,895**	**54,252**	**61,705**	**1,985,958**	**0.83%**
Flooding	**14**	**0.2%**	**57,109**	**255,991**	**5,175**	**31,903**	**799,523**	**0.33%**
Insects & fungus	**1**	**0.0%**	**49,324**	**49,324**	**49,324**	**49,324**	**49,324**	**0.02%**
TOTAL	**5,639**	**100%**	**42,415**	**32,511,178**	**51**	**7,270**	**239,175,376**	**100%**

4 Quantifying the effect of loss prevention

As shown in Table 3, the mean and maximum damages tend to be reduced by loss prevention investments. In the case of fire alarms, for example, the mean damages fall by half and the maximum is only a third of that for claims with no alarms. At the same time, loss prevention technologies do not appear to be applied evenly across the distribution of the risk. Though the technologies tend to lower the mean and maximum damages within categories, for the costliest damages overall, loss prevention technology is frequently present. As the influence loss prevention might have on risk is not yet conclusive in the literature, two scenarios for investing in loss prevention are assumed. In the first scenario, it is expected that investments in loss prevention technologies are made to decrease the probability of experiencing any loss, i.e., dampening the distribution. In the second scenario, it is assumed that investments are made to limit costs in a damage event, i.e., shifting the distribution to the left. The difference becomes particularly meaningful as shifting the distribution to the left shifts the incidence of claims from the insurers back to the insureds through fixed deductible thresholds if the risk is insured.

4.1 Technologies' influence on the probability of an event

The technologies' influence on the probability of an adverse event is estimated econometrically as a function of building characteristics and loss prevention technologies. Results are presented as marginal effects in Table 4. The binary dependent variable *claim* describes whether or not damage with a financial cost above zero has been registered internally by the municipality for a given building. The analysis thus includes all the 4,000+ building units across the municipalities. The explanatory variables are building characteristics, e.g., the age of the building, the building size in square metres, the use of the buildings, and other variables that parsimoniously describe conditions around the building. These latter variables are population density and crime level per citizen in the municipality. Population density is measured at the municipality level and included in the model to reflect expected regional differences, including variation between city and rural municipalities, rather than detailed density differences for neighborhoods. The crime level per citizen in the municipality is included as it has been convincingly shown to influence the probability of being a victim of crime (Tilley, Tseloni, and Farrell (2011)).

The building size measured in square metres reflects the expected influence of building size on the probability of a damage event. The use of the building is expected to influence the risk for damage, and thus dummy variables are used to take the various building types into account when understanding a technology's influence on the probability. The ageing of installations is known to influence the risk of water damage in buildings (Cheng (2001); Loganathan and Lee (2005)) and is included and expressed in five categorical dummy variables for construction age in the intervals 0 - 30, 31 - 60, 61-90, above 91, and a variable for unknown building age. The interval of 30 years is set with the expectation that the probability for leaks will significantly increase after the first 30 year interval, as described by Park and Loganathan (2002a, 2002b). The interval 0-30 is the omitted category, so results can be interpreted relative to the newest buildings.

To measure the effect of the technology, dummy variables are introduced for each type. The 0-1 dummy variable indicates whether the technology has been installed in the property.

Recall fire damages are expected to be influenced by both fire alarms and sprinklers; the limited use of sprinkler systems as a stand-alone technology, however, causes us to restrict the model to address fire alarms' and fire alarms combined with sprinklers' influences on the probability. Similarly, for the sub-risk of crime, burglar alarms are the primary technology used to mitigate crime risk, and the burglar alarm is often supplemented with either access control or CCTV, or supplemented with both systems at the same time. The models are restricted to include these four variables describing the variation of the technology in use. For loss prevention related to building installations, more precise water-bearing installations are water leakage detection systems and building management systems used as both stand-alone systems and in combination; thus, three dummy variables are used.

The probability of damage is expressed as a function of the technologies present and the other explanatory variables (Equation 1).

$$Pr(claim = 1) = P = \frac{exp(\beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{j=1}^{m} \gamma_j Y_j + \sum_{k=1}^{q} \delta k Z_s) + \epsilon}{1 + exp(\beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{j=1}^{m} \gamma_j Y_j + \sum_{k=1}^{q} \delta k Z_k) + \epsilon} \tag{1}$$

where, X = Building characteristics, Y = Loss prevention technologies, Z = Building types, indexed with i, j, and k respectively

As loss prevention investments focus on a certain sub-risk, the empirical effect of a technology on damages can be clarified by concentrating on the targeted risk. Thus, the data are split up and run for each sub-risk independently to understand how technology affects the probability of the expected targeted sub-risk.

4.2 Pooled results: Technology and the probability of an event

The results shown in Table 4 indicate that only the combined use of burglar alarms, access control and CCTV is linked to a significant decrease in probability for damage. The variables Fire alarm, Fire alarm combined with Sprinkler, Burglar alarm, Burglar alarm combined with Access control, Burglar alarm combined with CCTV and Water detection system with automatic stop valve combined with Building management systems appear to be associated with a significant increase in probability of damage. Water detection system with automatic stop valve and Building management systems as stand-alone systems do not significantly influence the probability. Additionally, crime rates, the age of the building, and the use and size of the building all have significant positive relationships to the probability of an event.

We find that all building types have a significant yet smaller probability for damage relative to the category School. The influence building types have on the probability of damage makes it reasonable to expect that the effect of loss prevention is dependent on the use of the building. To investigate this, interaction terms for building type were added to the model; the results are also presented in Table 4. The results indicate that the non-school group has a significantly smaller probability of damage relative to the school group. While the combination of Burglar alarm, Access control and CCTV is the only loss prevention technology that decreases the probability for schools, it was found that for non-schools burglar alarms as stand-alone systems also decreased risk. The risk of damage is seen to be significantly higher for schools with burglar alarms. The remaining technologies continue to be linked to higher probabilities, although to a lesser degree for non-schools than schools.

4.3 Single risk results: technology and the probability of an event

While the results indicate the relationship between technology and loss prevention for all types of damages, it could be reasonable to expect greater ability to identify individual technology effects when the probability of damage is measured by the expected targeted damages that come as a result of technology. A similar trend is seen when the models are fitted to the risk-related damages and adjusted to the risk-related explanatory variables. The marginal effects are provided on the left-hand side of Table 4.

When interacted terms for building type are included, Burglar alarm combined with Access control and CCTV are still the only loss prevention technologies that are linked to a significantly lower probability. Burglar alarm as a stand-alone system and burglar alarm combined with CCTV, fire systems, and water leak detection systems remain counter-intuitively linked to a significantly higher probability or exhibit no statistically significant relationship.

The size of the building has a significant influence on risk, and thus larger buildings have a significantly higher probability for damage than smaller buildings in all three sub-risk groups. In order to control for the role of building types, the technologies are interacted with the building category Not-school.

After adding interaction terms, we find that for all three sub-risk models, schools continued to have a higher probability of experiencing damage than non-schools. Burglar alarms continue to be linked with a significantly higher probability even though the effect is smaller for non-schools. Burglar alarm combined with CCTV at schools is still linked to a significantly higher probability although the non-interacted coefficient is insignificant. Burglar alarm combined with Access control at schools is linked to an increase in probability although this appears to be insignificant for non-schools. Burglar alarm combined with Access control and CCTV is linked to a significantly lower risk for schools; however, it is also linked to a significantly higher probability for non-schools.

The crime rate in the surrounding environment has a significant positive association to risk when interaction terms are added to the model. Specifically, higher crime rates seem to increase the probability for crime-related damages.

Fire alarms continue to be linked to a significantly higher risk of fire. Water leakage detection technologies show mixed associations with probabilities of events. Water leak stop technology is associated with lower probability of events at schools while Building Monitoring Systems are associated with higher probability. The relationships are reversed for non-school buildings. The results suggest that the effect of technologies on the probability of an adverse event cannot yet be causally estimated even with a relatively large sample of almost 14,000 building damages. It is not possible to establish a meaningful causation between the identified increase in risk that can be explained by increased use of loss prevention from the data. Independent of whether the subset of data — including all damages in a single combined model or data and fitted models limited to risk-related damages - is used, the probability of damage is empirically associated with a significantly higher probability of an event.

While there is no definitive explanation as to why the probability tends to be generally higher when loss prevention technologies are in use, one likely explanation is that building portfolio owners might be more willing to invest in loss prevention in buildings where the probability of damage is deemed highest. Thus, it might not be the technologies that cause the risk to increase, but rather the risk profile of the building itself. Crime-related loss prevention research is the only research known by the authors to have tried to directly address this complication (Lawson, Rogerson, and Barnacle (2018); Tseloni, Thompson, Grove, Tilley, and Farrell (2017)). This research has been inconclusive regarding the influence of loss prevention on risk. As the probability is dependent on the environment, the needed variables to model the true effect are often not available.

Burglar alarm, access control, and CCTV are also all known to be linked to surveillance technology that monitors human behaviour and are at the same time the technologies that are found in this study to have the most consistently negative relationship to probability (independent of model). While the data do not show why the combination of crime loss prevention technologies is often found to significantly reduce the risk in the analysis, one explanation could be that surveillance technologies might positively influence behaviour of both criminals and people with a legitimate reason for being in the building. Whether this is a result of increased awareness of surveillance is not identifiable from the data. Although conflicting results are known to occur in the literature (Piza, Caplan, and Kennedy (2014)), related research focused on CCTV supports the argument of a lower probability for a criminal event (Piza, Welsh, Farrington, and Thomas (2019)). At the same time, others have found that crime loss prevention technologies often have a complementary effect on crime-related risk (Farrell (2013); Farrell, Tilley, and Tseloni (2014); Tilley et al. (2015); Tseloni, Farrell, Thompson, Evans, and Tilley (2017); Tseloni, Thompson, et al. (2017)). Thus it is likely that related crime loss prevention technologies complement burglar alarms.

The primary result of the sub-risk analysis confirms that the probability of experiencing damage is highest where building owners have invested more in damage prevention. The results also provoke some new insight. When technologies monitor human behaviour, the probability of damage is likely to be reduced. If the reduction in probability is a result of changed human behaviour, it would be reasonable to connect the result to the Routine activity theory, where the technologies can substitute the influence from capable guardians (Cohen and Felson (2010)). While this theory has long been applied to the understanding of criminal activity, it is the link to altered human behaviour amongst people with no criminal intent that is new. Further research is needed before it can be concluded whether surveillance technologies as a stand-alone system or in combination with other technologies alter human behaviour.

5 Technologies' influence on damage cost per square meter

As stated earlier, technology's role may also lower expected damages. This would be conditional on the event. While we see the probability of events being mostly higher with technology — although we do not claim causality — we also see that the damages per square metre are dampened at their maxima. We estimate the effects of technology on the damage cost per square metre to better understand how loss prevention technologies might affect the marginal change in cost per square metre. To further model the effect of neighbourhood conditions, the average response time for the fire rescue to arrive on scene in the municipality has been added.

It would be a natural choice to use either the log-normal or gamma distribution to analyze the loss severity of adverse events (Gschlößl and Czado (2007)). We know that if the analyzed data are heavily skewed, the log-normal would likely be the best fit, and if the analyzed data are positively skewed and the tail is considered light, then the Gamma distribution would likely be the better option (Gençtürk and Yiğiter (2016)). The choice between the two depends then on the nature of the data. We find that losses related to crime and building damages are positively skewed and with a tail that can be considered light, whereas the distribution of fire losses has more a heavily skewed tail.

We thus use the gamma distribution to look over the claim severity and rely on its flexibility and applicability to insurance data in general (Omari, Nyambura, and Mwangi (2018)). We test both distributions on the dataset and find the gamma distribution to be the best fit. The choice of distribution does not affect the result of the analysis for damage prevention related to fire damage, thus we maintain the gamma distribution for the entire analysis.

$$log(C_{ijs}|C_{ijs} => 0) = exp(\beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{j=1}^{m} \gamma_j Y_j + \sum_{s=1}^{q} \delta_s Z_s) + \epsilon_{ijs} \quad (2)$$

$$\epsilon \sim gamma(k, \theta)$$

where, X=Building characteristics, Y=Loss prevention technologies, Z=Building types

Recall that it is expected that building types might influence the effect of loss prevention, and thus interaction terms for building types and technologies are again added to a secondary model.

The two models are first tested with cost related to all 15 damage types, and then tested with a limited subset of the data which only includes risk related damages.

6 Pooled risk results: Technology and damage costs

To understand how loss prevention technologies might affect the cost of damages, all technologies and associated explanatory variables in a single pooled model will be tested to see how to influence the cost per square metre of all damages. The marginal results are presented on the right-hand side of Table 4.

While fire alarms are associated with lower damage, costs of fire alarm combined with sprinklers are significantly associated with increased costs per square metre.

Use of burglar alarms combined with access control and CCTV is linked to a significantly higher damage cost per square metre. In contrast, Burglar alarm, Burglar alarm combined with Access control and Burglar alarm combined with CCTV are linked to an insignificant reduction in cost per square metre.

The use of water damage technologies indicates either lower damages per square metre or an insignificant relationship.

The per capita crime rate and the mean fire response time both have a significant negative and thus unexpected relationship to cost. Building types still have a significant influence on the cost and, relative to schools, all other types have a higher cost per square metre. Schools are usually larger buildings, which will reduce the cost per square metre.

Fire alarm presence decreases the cost for both schools and non-schools. On the other hand, Fire alarm combined with Sprinkler systems is linked with a significant increase in cost for schools and a significant decrease in cost for non-schools.

Burglar alarm presence decreases the cost for both schools and non-schools. The effect of burglar alarms combined with access control is linked to a significant decrease in cost for schools although it significantly increases the cost for non-schools. Burglar alarm combined with CCTV significantly reduces cost for schools. This relationship is, however, insignificant for non-schools. We find no significant overall effect of Burglar alarm combined with Access control and CCTV; however, there is a significant increase in effect for non-schools.

Building management system presence is linked to a decrease in cost per square metre. While the main effect from the presence of water leakage detection with automatic stop valve on cost per square metre is an insignificant decrease in cost, the effect for non-schools is seen to significantly increase the cost relative to the main effect.

7 Single risk results: technology and damage costs

While some technologies are associated with significantly higher costs per square meter for all damage types, it is reasonable to expect that building owners target specific sub-risks when investing in loss prevention technologies. Thus, the technologies' influence on damage cost should likely be understood by sub-risk where the effect is likely better understood when isolated to the targeted risk.

For costs related to the sub-risk fire, we find that fire alarm presence significantly reduces the cost at the 90% confidence level. Fire alarm combined with Sprinkler has an insignificant yet increasing influence on the cost. This is likely explained by a low number of observations, as only 13 observed fire damages have been recorded with the combination of Fire alarm and Sprinkler. Likewise, building types influence the cost per square meter with a significant increase in cost relative to schools for residential, other, entertainment, community centre, daycare and sports venue types. No significant influence is found for building types administration, workshops or nursing homes.

For the sub-risk category crime, it is found that Burglar alarm combined with Access control and Burglar alarm combined with CCTV significantly reduce cost. Burglar alarm as stand-alone and Burglar alarm combined with Access control and CCTV have insignificant decreasing effects on the cost of damage. The building types again influence the cost with a significant increase in cost per square meter relative to schools for the building types other, workshop, community centre, daycare, and sports venue. No significant influence is found for the building types residential, entertainment, or nursing homes.

For the last sub-category, building installation, no significant influence was found regarding the loss prevention technologies.

When interaction terms are added to the models, non-schools are found to have a significantly higher cost per square meter for included risk related damages. The effect from the fire loss prevention technologies for fire damages is insignificant for both Fire alarm and Fire alarm combined with Sprinkler presence. This might be a result of too few observations and lacking degrees of freedom as the magnitude and direction of the effect continues to be similar to the model without interaction terms.

When interaction terms are added to the model related to crime to separate the effect for schools and non-schools, respectively, stand-alone burglar alarms do not have a significant influence on the cost for schools; however, the effect from Burglar alarm combined with Access control, Burglar alarm combined with CCTV and Burglar alarm combined with Access control and CCTV all significantly reduce the cost for schools. No crime loss prevention technology was found to significantly influence the cost per square metre for non-schools.

Table 4: Loss prevention technologies' effect on target risk, probability, claim = 1

	Scenario 1				Scenario 2					
	No interaction						With Interaction $NotSchool = 0$		$Notschool = 1$	
Cost/m2	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	dy/dx	p-value
FireAlarm	0.562***	0.000	0.0107	0.000	0.448**	0.016	0.0174	0.026		
	(0.121)		(0.00237)		(0.186)		(0.00784)			
FireAlarm −NotSchool					0.440*	0.052			0.0178	0.000
					(0.226)				(0.00345)	
FireAlarm & Sprinkler	0.215	0.498	0.00412	0.498	0.584	0.210	0.0260	0.319		
	(0.316)		(0.00608)		(0.466)		(0.0261)			
FireAlarm & Sprinkler −NotSchool					−0.462	0.451			0.00208	0.781
					(0.614)				(.00746)	
Building size in m^2	0.000118***	0.000	2.26e−06	0.000	0.000122***	0.000	4.22e−06	0.000	1.97e−06	0.000
	(1.29e−05)		(2.62e−07)		(1.23e−05)		(4.22e−07)		(2.47e−07)	
PopulationDensity	8.65e−06	0.154	1.66e−07	0.155	7.06e−06	0.242	2.44e−07	0.238	1.14e−07	0.243
	(6.07e−06)		(1.17e−07)		(6.03e−06)		(2.07e−07)		(9.78e−08)	
Number of obs	20,192		20,192		20,192		20,192		20,192	
Deviance	3628.52				3661.49					
AIC	0.181				0.182					
BurglarAlarm	0.337***	0.000	0.0225***	0.000	0.962***	0.000	0.137***	0.000		
	(0.0668)		(0.00446)		(0.117)		(0.0176)			
BurglarAlarm −NotSchool					−0.791***	0.000			0.0105*	0.063
					(0.147)				(0.00563)	
BurglarAlarm & AccessControl	0.190	0.103	0.0127	0.103	0.462***	0.004	0.0613***	0.008		
	(0.117)		(0.00777)		(0.159)		(0.0229)			
BurglarAlarm & AccessControl − NotSchool					−0.137	0.563			0.0214	0.105
					(0.237)				(0.0132)	
BurglarAlarm & CCTV	0.257**	0.025	0.0172**	0.025	0.0832	0.626	0.00994	0.632		
	(0.115)		(0.00764)		(0.171)		(0.0208)			
BurglarAlarm & CCTV − NotSchool					0.611***	0.006			0.0526***	0.000
					(0.221)				(0.0135)	
BurglarAlarm & CCTV & AccessControl	−0.298**	0.050	−0.0199**	0.050	−0.800***	0.001	−0.0729***	0.000		
	(0.152)		(0.0101)		(0.233)		(0.0170)			
BurglarAlarm & CCTV & AccessControl − NotSchool					1.428***	0.000			0.0468***	0.006
					(0.294)				(0.0168)	
Building size in m^2	0.000138***	0.000	9.18e−06***	0.000	0.000140***	0.000	0.0000163***	0.000	8.19e−06***	0.000
	(7.49e−06)		(4.93e−07)		(7.20e−06)		(8.14e−07)		(4.86e−07)	
Crime/population	3.063	0.147	0.204	0.147	4.508**	0.032	0.526**	0.032	0.265**	0.032
	(2.112)		(0.140)		(2.102)		(0.245)		(0.123)	
PopulationDensity	−2.14e−05***	0.000	−1.42e−06***	0.000	−2.43e−05***	0.000	−2.83e−06***	0.000	−1.43e−06***	0.000
	(4.50e−06)		(3.01e−07)		(4.57e−06)		(5.54e−07)		(2.69e−07)	
Number of obs	20,800		20,800		20,800		20,800		20,800	
Deviance	10227.85				10293.02					
AIC	0.493				0.496					
WaterLeak, Stop	−0.217	0.312	−0.00757	0.312	−0.949**	0.022	−0.0515***	0.002		
	(0.214)		(0.00749)		(0.413)		(0.0163)			
WaterLeak, Stop −NotSchool					1.473***	0.002			0.0176*	0.072
					(0.474)				(0.00977)	
BMS	0.311*	0.0558	0.0109*	0.056	0.530***	0.007	0.0475**	0.015		
	(0.163)		(0.00569)		(0.197)		(0.0195)			
BMS −NotSchool					−0.654*	0.065			−0.00322	0.671
					(0.354)				(0.00756)	
BMS & WaterLeak, Stop	0.830***	0.000288	0.0290***	0.000	0.707**	0.035	0.0695*	0.088		
	(0.229)		(0.00803)		(0.336)		(0.0407)			
BMS & WaterLeak, Stop −NotSchool					0.439	0.312			0.0520***	0.009
					(0.434)				(0.0199)	
Age31 − 60	0.352*	0.0864	0.0123*	0.087	0.310	0.129	0.0234	0.126	0.00842	0.132
	(0.205)		(0.00718)		(0.204)		(0.0153)		(0.00559)	
Age61 − 90	0.611***	0.00695	0.0214***	0.007	0.543**	0.016	0.0411**	0.016	0.0148**	0.018
	(0.226)		(0.00794)		(0.225)		(0.0170)		(0.00623)	
Age91 − x	0.887***	0.000136	0.0310***	0.000	0.726***	0.001	0.0549***	0.002	0.0197***	0.002
	(0.233)		(0.00819)		(0.226)		(0.0174)		(0.00629)	
AgeNA	0.288	0.141	0.0101	0.141	0.223	0.250	0.0169	0.247	0.00607	0.253
	(0.195)		0.00684		(0.194)		(0.0146)		(0.00531)	
Building size in m^2	0.000109***	0.000	3.80e−06***	0.000	0.000112***	0.000	8.44e−06***	0.000	3.03e−06***	0.000
	(1.35e−05)		(4.83e−07)		(1.26e−05)		(8.68e−07)		(4.08e−07)	
PopulationDensity	−5.17e−06	0.506	−1.81e−07	0.506	−6.66e−06	0.372	−5.03e−07	0.372	−1.81e−07	0.373
	(7.78e−06)		(2.72e−07)		(7.45e−06)		(5.64e−07)		(2.03e−07)	
Number of obs	11,094		11,094		11,094		11,094		11,094	
Deviance	3183.44				3251.48					
AIC	0.290				0.296					

Nota: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 5: Loss prevention technologies' effect on target risk, cost

	Scenario 1				Scenario 2					
	No interaction						With Interaction			
							$NotSchool = 0$		$Notschool = 1$	
Cost/m2	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	dy/dx	p-value
FireAlarm	−0.731* (0.392)	0.062	−222.90 (150.54)	0.139	−0.452 (0.739)	0.540	−19.254 (31.508)	0.541		
FireAlarm −NotSchool					−1.305 (0.950)	0.169			−509.14** (229.45)	0.026
FireAlarm & Sprinkler	1.391 (0.957)	0.146	424.31 (350.06)	0.225	2.267 (1.685)	0.179	327.25 (604.33)	0.588		
FireAlarm & Sprinkler −NotSchool					−2.490 (2.256)	0.270			−79.267 (484.04)	0.870
FireResponse	−0.244* (0.130)	0.061	−74.456 (55.111)	0.177	−0.169 (0.147)	0.250	−7.740 (8.140)	0.342	−66.364 (66.985)	0.322
PopulationDensity	7.50e−05** (3.37e−05)	0.026	0.0229 (0.0157)	0.146	8.04e−05** (3.63e−05)	0.027	0.00368 (0.00266)	0.167	0.0315 (0.0211)	0.134
Number of obs	403		403		403		403		403	
Deviance	1635.40				1835.56					
AIC	11.325				11.793					
BurglarAlarm	−0.000882 (0.219)	0.997	−.0402 (9.954)	0.997	0.262 (0.327)	0.424	4.846 (6.042)	0.423		
BurglarAlarm −NotSchool					−0.613 (0.445)	0.169			−19.097 (14.571)	0.190
BurglarAlarm & AccessControl	−1.426*** (0.361)	0.000	−64.939*** (18.679)	0.001	−2.054*** (0.450)	0.000	−16.584*** (3.549)	0.000		
BurglarAlarm & AccessControl − NotSchool					0.722 (0.735)	0.326			46.140*** (11.820)	0.000
BurglarAlarm & CCTV	−1.247*** (0.329)	0.000	−56.754*** (17.057)	0.001	−1.430*** (0.480)	0.003	−14.391*** (4.0130)	0.000		
BurglarAlarm & CCTV − NotSchool					0.138 (0.667)	0.836	−12.849***	0.010	−45.575*** (10.416)	0.000
BurglarAlarm & CCTV & AccessControl	−0.265 (0.441)	0.548	−12.064 (20.260)	0.552	−1.213* (0.706)	0.086	(4.974)			
BurglarAlarm & CCTV & AccessControl − NotSchool					1.136 (0.912)	0.213			−4.368 (31.748)	0.891
Crime/population	−1.967 (8.371)	0.814	−89.570 (381.68)	0.814	−5.069 (8.812)	0.565	−90.008 (156.10)	0.564	−297.13 (519.31)	0.567
PopulationDensity	−2.66e−05 (1.71e−05)	0.121	−.00121 (.000811)	0.135	−1.69e−05 (1.85e−05)	0.361	−0.000299 (0.000325)	0.356	−0.000988 (00111)	0.374
Number of obs	1,663		1,663		1,663		1,663		1,663	
Deviance	5275.24				5628.32					
AIC	8.810				9.0174					
WaterLeak, Stop	0.0584 (0.459)	0.899	6.530 (51.393)	0.899	−0.748 (0.974)	0.443	−7.321 (6.904)	0.289		
WaterLeak, Stop −NotSchool					0.952 (1.142)	0.404			34.981 (114.64)	0.760
BMS	−0.410 (0.359)	0.25	−45.908 (41.770)	0.272	−0.0135 (0.521)	0.979	−0.181 (6.980)	0.979		
BMS −NotSchool					−0.540 (0.890)	0.544			−71.704 (76.629)	0.349
BMS & WaterLeak, Stop	0.176 (0.440)	0.689	19.722 (49.578)	0.691	0.928 (0.699)	0.184	18.833 (20.639)	0.362		
BMS & WaterLeak, Stop −NotSchool					−1.970* (1.011)	0.051			−105.75** (49.357)	0.032
Age31 − 60	0.619 (0.434)	0.154	69.227 (51.724)	0.181	−0.212 (0.558)	0.704	−2.872 (7.730)	0.710	−33.230 (87.301)	0.703
Age61 − 90	0.466 (0.534)	0.383	52.092 (62.329)	0.403	−0.246 (0.672)	0.714	−3.332 (9.335)	0.721	−38.558 (104.01)	0.711
Age91 − x	0.0951 (0.506)	0.851	10.642 (56.678)	0.851	−0.499 (0.577)	0.387	−6.746 (8.261)	0.414	−78.063 (91.554)	0.394
AgeNA	0.370 (0.440)	0.400	41.369 (50.890)	0.851	−0.0900 (0.540)	0.868	−1.217 (7.387)	0.869	−14.082 (84.413)	0.868
PopulationDensity	−1.29e−05 (1.88e−05)	0.492	−0.00144 (0.00210)	0.493	−3.54e−05* (2.13e−05)	0.097	−0.000479 (0.000325)	0.141	−0.00554 (0.00344)	0.108
Number of obs	433		433		433		433		433	
Deviance	1036.61				1250.44					
AIC	9.621				10.093					

Nota: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

When adding interaction terms to the model related to building installation, water leak detection systems with automatic stop valve combined with the building management system reduces the cost of water damage significantly at the 90% confidence level. The remaining technologies continue to have an insignificant influence on cost.

There is inconsistency in the results of the pooled analysis including all damage types versus those for the individual sub-risk groups with data constrained to risk-related damages only. Investments in loss prevention are expected to target a certain risk where the expected benefits are perceived to be highest. Recall that all technologies, when targeting the expected risk, were found to significantly reduce costs. To sum up the effect of the technologies on the targeted risk, Table 4 and 5 provide a summary of results and the marginal effects on the probability and cost per square metre, respectively. Additional detailed results are available in the appendix.

8 Estimated financial savings

The predicted probabilities of a damage event for each building from equation 1 are stored and used to calculate a predicted claim size for each building per square meter as a function of the probability of an event as well as the building's characteristics and technologies.

The overall savings from technology adoptions can then be estimated as the change in expected claims from a change in technologies applied, which is conditional on the building characteristics. This change is found by calculating the difference between total predicted claims with no technology and total predicted claims given the current technology levels. The estimated savings from investing in the various loss prevention technologies is thus estimated by:

$$\hat{S}_1 = \hat{P}_{t_0}\hat{C}_{t_0} - \hat{P}_{t_1}\hat{C}_{t_1} \tag{3}$$

where, $\hat{P}_{t_0}$ *= Predicted mean probability without loss prevention,* $\hat{C}_{t_0}$ *= Predicted mean cost without loss prevention,* $\hat{P}_{t_1}$ *= Predicted mean probability with loss prevention, and* $\hat{C}_{t_1}$ *= Predicted mean cost with loss prevention*

With the exception of those related to crime risk, most loss prevention technologies are not known or expected to influence the probability for damage, and a second estimation of financial savings is calculated. In the second estimation, the predicted mean probability is no longer dependent on the presence of loss prevention technology and is thus equal to the predicted mean for all buildings with and without loss prevention. This adjusts the estimation for potential bias if buildings owners are systematically choosing to install loss prevention technologies in buildings with higher risk. Therefore, the second estimation is stated as:

$$\hat{S}_2 = \hat{P}\hat{C}_{t_0} - \hat{P}\hat{C}_{t_1} \tag{4}$$

where, $\hat{P}$ = *Predicted mean probability,* $\hat{C}_{t_0}$ = *Predicted mean cost without loss prevention, and* $\hat{C}_{t_1}$ = *Predicted mean cost with loss prevention*

While technologies' influence on the probability is uncertain, the calculation provides an understanding of the positive correlation between reduction in damage cost and the use of loss prevention technologies. Based on these results, it is possible to predict the expected savings per year that result from investing in loss prevention technologies, based on the predicted means from the five-year period.

The mean size of all buildings is 1,495 m2, the mean size school is 4,996 m2 and the mean size of a non-school building is 1,054 m2. The biggest savings for the mean size building when no interaction terms are added are gained by investing in fire alarms (significant effect at the 95% confidence level). This gives a total savings of DKK 10.53 per square metre, which is equal to a yearly savings of DKK 15,733.07 for the mean size building over the five years. The second highest savings can be gained from Burglar alarm combined with Access control (significant effect at the 99% confidence level) with a savings of DKK 2.86 per square meter, which is equal to a yearly saving of DKK 4,270.91 for the mean size building. Burglar alarm combined with CCTV has a significant influence on the cost at the 99% confidence level, with an annual savings of DKK 2.14 per square meter or DKK 3,199.15 for the mean size building.

If a technology's effect is estimated to be dependent on building type and with the introduction of interaction terms, as Fire alarm is no longer significant, savings cannot be estimated. Nonetheless, while the technologies related to crime risk are only significant for the main effect, schools — and insignificantly for non-schools, the presence of Burglar alarm combined with Access control provides a DKK 3.36 per square metre yearly savings, equal to DKK 16,778.44 for a mean size school. By investing in burglar alarms combined with CCTV, DKK 2.83 savings per square meter, or DKK 14,141.22 for a mean size school, are realized. By investing in a burglar alarm combined with access control and CCTV, DKK 2.49 per square metre, or 12,441.33 for a mean size school, can be saved (90% confidence level). The only technology related to building installations that significantly influences the cost is Building management systems combined with water leakage detection with stop valves for non-schools, at the 90% confidence level. The mean saving per square meter is estimated at DKK 3.97, or DKK 4,188.85 for a mean size non-school building. An overview of the estimated savings per technology can be found in Table 6.

Despite these estimates of positive financial savings for the technologies, the magnitude of the savings can hardly be expected to finance installation or even operating costs of the systems from an individual building approach. Only physical building damage is included in these estimated savings, however. The data show that a stumbling block for loss prevention technology adoption is that even if it is extremely effective, is not seen as worth it for the building owner because the expected saving per building is low. True savings might be higher if non-property or non-physical damage in the form of business interruptions and other non-quantifiable damages are included in the valuation.

Table 6: Financial savings in a five-year period - target risk

Technology	Financial savings per m2 (Mean probability)			Financial savings mean size building (Mean probability)		
		With interaction			With interaction	
	No interaction	School *(Main effect)*	Non-School *(Difference from main effect)*	No interaction	School **6,747.95** m^2 ***(Main effect)***	Non-School **1,189.44** m^2 ***(Difference from main effect)***
Fire alarm	10.53**	1.84	6.07	15,733.07**	9,170.23	6,402.22
Fire alarm and Sprinkler	-2.33	-13.67	2.76	-3481.28	-68,283.3	2,909.13
Burglar alarm	0.94	-2.48	1.12	1,406.12	-12,382.1	1,183.83
Burglar alarm and Access control	2.86***	3.36***	2.75	4,270.91***	16,778.44***	2,899.96
Burglar alarm and CCTV	2.14***	2.83***	2.68	3,199.15***	14,141.22***	2,823.55
Burglar alarm, Access control and CCTV	2.89	2.49*	-0.24	4,312.35	12,441.33*	-250.03
Water Leak, stop	1.84	0.89	-0.70	2,746.68	4,463.59	-735.67
BMS	2.63	0.96	1.81	3,937.50	4,811.03	1,909.78
Water Leak, stop and BMS	0.80	-2.18	3.97*	1,197.26	-10,913.82	4,188.85*

*** $p<.01$, ** $p<.05$, * $p<.1$

Full results including building type coefficients are available upon request to the author.

9 Concluding remarks

Five years of building and damage data for more than 4,000 individual buildings over a five-year period in Danish municipalities have been investigated to estimate the expected financial savings achievable by investing in loss prevention technologies. While it is expected that most building owners invest in loss prevention with the expectation of a positive net benefit, the results indicate that the net benefit will likely be negative.

Based on the results, organisations should carefully consider why they invest in damage prevention, as the organisation cannot generally expect a high positive return on the investment per building. One consideration that we have not discussed is the organisation's resilience. Increased resilience should perhaps be the organisation's primary cause of investing in loss prevention, as we now have tentatively shown that investing in loss prevention is not straightforwardly financially beneficial. While financial savings in physical building damage may not be sufficient to achieve a positive net benefit, the return would likely appear stronger if effects on resilience, including non-property or non-physical damage in the form of business interruptions and other non-quantifiable damages, were included in the estimation. These are often difficult for organisations to quantify, however. One indication that these could contribute substantially to savings comes from the evidence that the right tail of the damage distributions is reduced by the presence of loss prevention technologies across the board. Since the magnitude of the direct costs and indirect costs from e.g. business interruption should be positively correlated, we would expect increased savings.

The low levels of damage across Danish municipal buildings also affect prospects for financial benefits. Only five out of the nine groups of technologies were found to significantly influence the damage cost; however, this is likely due to the limited number of events. Higher risk environments could be expected to have potentially greater returns, though data on property risk damages across countries that could confirm Denmark as a comparatively low risk environment are not readily available. Ideally, given the evident positive role of loss prevention technologies in reducing the right tails of damage distributions, the models should be divided into influence on small frequent damages and influence on rare larger damages. This was not possible with the data available, and thus the results must not be considered conclusive but as among the first attempts to quantify the financial returns of loss prevention through damage reduction.

10 Acknowledgements

A big thank you goes to the municipalities who provided data for this project and helped validate the data. A special thank you goes to the staff at Willis Towers Watson, Denmark for assisting many municipalities in finding these data and answering questions related to the data. Without their support and backing, this article would not have been possible.

11 Funding

The work is funded by Willis Towers Watson with financial contribution from the Region of Southern Denmark and the municipalities of Faxe Kommune, Frederikshavn Kommune, Hedensted Kommune, Hjørring Kommune, Horsens Kommune, Københavns Kommune, Mariagerfjord Kommune, Middelfart Kommune, Nordfyns Kommune, Randers Kommune, Ringkøbing-Skjern Kommune, Skanderborg Kommune, Stevns Kommune, Struer Kommune and the insurance companies Protector Forsikring and RiskPoint.

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12 Appendix

12.1 Full results from Table 4

Table 7: Regression - effect on target risk - probability, fire claim = 1

	Scenario 1				Scenario 2					
	No interaction						With Interaction			
							$NotSchool = 0$		$Notschool = 1$	
Cost/m2	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	dy/dx	p-value
FireAlarm	0.562*** (0.121)	0.000	0.0107*** (0.00237)	0.000	0.448** (0.186)	0.016	0.0174** (0.00784)	0.026		
FireAlarm −NotSchool					0.440* (0.226)	0.052			0.0178*** (0.00345)	0.000
FireAlarm & Sprinkler	0.215 (0.316)	0.498	0.00412 (0.00608)	0.498	0.584 (0.466)	0.210	0.0260 (0.0261)	0.319		
FireAlarm & Sprinkler −NotSchool					−0.462 (0.614)	0.451			0.00208 (.00746)	0.781
Building size in m^2	0.000118*** (1.29e−05)	0.000	2.26e−06*** (2.62e−07)	0.000	0.000122*** (1.23e−05)	0.000	4.22e−06*** (4.22e−07)	0.000	1.97e−06*** (2.47e−07)	0.000
PopulationDensity	8.65e−06 (6.07e−06)	0.154	1.66e−07 (1.17e−07)	0.155	7.06e−06 (6.03e−06)	0.242	2.44e−07 (2.07e−07)	0.238	1.14e−07 (9.78e−08)	0.243
Administration	−1.071*** (0.272)	0.000	−0.0205*** (.00529)	0.000						
Residential	−0.917*** (0.238)	0.000	−0.0176*** (0.00463)	0.000						
Other	−1.198*** (0.176)	0.000	−0.0230*** (0.00353)	0.000						
Entertainment	−1.676*** (0.515)	0.001	−0.0322*** (0.00999)	0.001						
Workshop	−0.888** (0.399)	0.026	−0.0170** (0.00770)	0.027						
CommunityCenter	−1.324*** (0.284)	0.000	−0.0255*** (0.00557)	0.000						
DayCare	−0.605*** (0.171)	0.000	−0.0116*** (0.00332)	0.000						
NursingHome	−0.202 (0.188)	0.284	−0.00388 (0.00362)	0.285						
SportsVenue	−0.330 (0.233)	0.157	−0.00633 (0.00447)	0.157						
NotSchool					−0.952*** (0.156)	0.000	−0.0200*** (0.00389)	0.000	−0.0200*** (0.00389)	0.000
constant	−3.751*** (0.156)	0.000			−3.725*** (0.169)	0.000				
Number of obs	20,192		20,192		20,192		20,192		20,192	
Deviance	3628.52				3661.49					
AIC	0.181				0.182					

Nota: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 8: Regression - effect on target risk - probability, crime claim = 1

	Scenario 1				Scenario 2					
	No interaction						With Interaction $NotSchool = 0$		$Notschool = 1$	
Cost/m2	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	dy/dx	p-value
BurglarAlarm	0.337*** (0.0668)	0.000	0.0225*** (0.00446)	0.000	0.962*** (0.117)	0.000	0.137*** (0.0176)	0.000		
BurglarAlarm −NotSchool					−0.791*** (0.147)	0.000			0.0105* (0.00563)	0.063
BurglarAlarm & AccessControl	0.190 (0.117)	0.103	0.0127 (0.00777)	0.103	0.462*** (0.159)	0.004	0.0613*** (0.0229)	0.008		
BurglarAlarm & AccessControl − NotSchool					−0.137 (0.237)	0.563			0.0214 (0.0132)	0.105
BurglarAlarm & CCTV	0.257** (0.115)	0.025	0.0172** (0.00764)	0.025	0.0832 (0.171)	0.626	0.00994 (0.0208)	0.632		
BurglarAlarm & CCTV − NotSchool					0.611*** (0.221)	0.006			0.0526*** (0.0135)	0.000
BurglarAlarm & CCTV & AccessControl	−0.298** (0.152)	0.050	−0.0199** (0.0101)	0.050	−0.800*** (0.233)	0.001	−0.0729*** (0.0170)	0.000		
BurglarAlarm & CCTV & AccessControl − NotSchool					1.428*** (0.294)	0.000			0.0468*** (0.0168)	0.006
Building size in m^2	0.000138*** (7.49e−06)	0.000	9.18e−06*** (4.93e−07)	0.000	0.000140*** (7.20e−06)	0.000	0.0000163*** (8.14e−07)	0.000	8.19e−06*** (4.86e−07)	0.000
Crime/population	3.063 (2.112)	0.147	0.204 (0.140)	0.147	4.508** (2.102)	0.032	0.526** (0.245)	0.032	0.265** (0.123)	0.032
PopulationDensity	−2.14e−05*** (4.50e−06)	0.000	−1.42e−06*** (3.01e−07)	0.000	−2.43e−05*** (4.57e−06)	0.000	−2.83e−06*** (5.54e−07)	0.000	−1.43e−06*** (2.69e−07)	0.000
Administration	−0.633*** (0.115)	0.000	−0.0422*** (0.00767)	0.000						
Residential	−1.867*** (0.171)	0.000	−0.124*** (0.0115)	0.000						
Other	−1.405*** (0.0948)	0.000	−0.0937*** (0.00644)	0.000						
Entertainment	−1.274*** (0.207)	0.000	−0.0850*** (.0139)	0.000						
Workshop	−1.118*** (0.215)	0.000	−0.0745*** (0.0144)	0.000						
CommunityCenter	−1.141*** (0.125)	0.000	−0.0761*** (0.00841)	0.000						
DayCare	−0.562*** (0.0863)	0.000	−0.0375*** (0.00576)	0.000						
NursingHome	−1.027*** (0.140)	0.000	0.0685*** (.009321)	0.000						
SportsVenue	−0.999*** (0.144)	0.000	−0.0666*** (0.00958)	0.000						
NotSchool					−0.842*** 0.0992)	0.000	−0.0823*** (0.00798)	0.000	−.0823 (.00798)	0.000
constant	−2.008*** (0.187)	0.000			−2.285*** (0.197)	0.000				
Number of obs	20,800		20,800		20,800		20,800		20,800	
Deviance	10227.85				10293.02					
AIC	0.493				0.496					

Nota: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 9: Regression - effect on target risk - probability, Water claim = 1

	Scenario 1				Scenario 2					
	No interaction						With Interaction $NotSchool = 0$		$Notschool = 1$	
Cost/m2	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	dy/dx	p-value
$WaterLeak, Stop$	−0.217 (0.214)	0.312	−0.00757 (0.00749)	0.312	−0.949** (0.413)	0.022	−0.0515*** (0.0163)	0.002		
$WaterLeak, Stop$ $-NotSchool$					1.473*** (0.474)	0.002			0.0176* (0.00977)	0.072
BMS	0.311* (0.163)	0.0558	0.0109* (0.00569)	0.056	0.530*** (0.197)	0.007	0.0475** (0.0195)	0.015		
BMS $-NotSchool$					−0.654* (0.354)	0.065			−0.00322 (0.00756)	0.671
BMS & $WaterLeak, Stop$	0.830*** (0.229)	0.000288	0.0290*** (0.00803)	0.000	0.707** (0.336)	0.035	0.0695* (0.0407)	0.088		
BMS & $WaterLeak, Stop$ $-NotSchool$					0.439 (0.434)	0.312			0.0520*** (0.0199)	0.009
$Age31-60$	0.352* (0.205)	0.0864	0.0123* (0.00718)	0.087	0.310 (0.204)	0.129	0.0234 (0.0153)	0.126	0.00842 (0.00559)	0.132
$Age61-90$	0.611*** (0.226)	0.00695	0.0214*** (0.00794)	0.007	0.543** (0.225)	0.016	0.0411** (0.0170)	0.016	0.0148** (0.00623)	0.018
$Age91-x$	0.887*** (0.233)	0.000136	0.0310*** (0.00819)	0.000	0.726*** (0.226)	0.001	0.0549*** (0.0174)	0.002	0.0197*** (0.00629)	0.002
$AgeNA$	0.288 (0.195)	0.141	0.0101 0.00684	0.141	0.223 (0.194)	0.250	0.0169 (0.0146)	0.247	0.00607 (0.00531)	0.253
$Building\ size\ in\ m^2$	0.000109*** (1.35e−05)	0.000	3.80e−06*** (4.83e−07)	0.000	0.000112*** (1.26e−05)	0.000	8.44e−06*** (8.68e−07)	0.000	3.03e−06*** (4.08e−07)	0.000
$PopulationDensity$	−5.17e−06 (7.78e−06)	0.506	−1.81e−07 (2.72e−07)	0.506	−6.66e−06 (7.45e−06)	0.372	−5.03e−07 (5.64e−07)	0.372	−1.81e−07 (2.03e−07)	0.373
$Administration$	−1.132*** (0.239)	0.000	−0.0396*** (0.00845)	0.000						
$Residential$	−1.180*** (0.235)	0.000	−0.0412*** (0.00831)	0.000						
$Other$	−2.047*** (0.205)	0.000	−0.0715*** (0.00763)	0.000						
$Entertainment$	−2.581*** (0.594)	0.000	−0.0902*** (0.0210)	0.000						
$Workshop$	−1.891*** (0.519)	0.000	−0.0661*** (0.0183)	0.000						
$CommunityCenter$	−0.888*** (0.260)	0.001	−0.0310*** (0.00914)	0.001						
$DayCare$	−0.825*** (0.169)	0.000	−0.0288*** (0.00600)	0.000						
$NursingHome$	−0.336* (0.180)	0.062	−0.0118* (0.00629)	0.062						
$SportsVenue$	−1.561*** (0.324)	0.000	0.0546*** (0.0114)	0.000						
$NotSchool$					1.220*** (0.149)	0.000	−0.0570*** (0.008)	0.000 0.000	−0.0570*** (0.008)	0.000 0.000
$constant$	−2.918*** (0.235)	0.000			−2.872*** (0.236)	0.000				
Number of obs	11,094		11,094		11,094		11,094		11,094	
Deviance	3183.44				3251.48					
AIC	0.290				0.296					

Nota: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

12.2 Full results from Table 5

Table 10: Regression - effect on target risk, Fire cost > 0

	Scenario 1				Scenario 2					
	No interaction				With Interaction		$NotSchool = 0$		$Notschool = 1$	
Cost/m2	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	dy/dx	p-value
$FireAlarm$	−0.731* (0.392)	0.062	−222.90 (150.54)	0.139	−0.452 (0.739)	0.540	−19.254 (31.508)	0.541		
$FireAlarm$ $-NotSchool$					−1.305 (0.950)	0.169			−509.14*** (229.45)	0.026
$FireAlarm$ & $Sprinkler$	1.391 (0.957)	0.146	424.31 (350.06)	0.225	2.267 (1.685)	0.179	327.25 (604.33)	0.588		
$FireAlarm$ & $Sprinkler$ $-NotSchool$					−2.490 (2.256)	0.270			−79.267 (484.04)	0.870
$FireResponse$	−0.244* (0.130)	0.061	−74.456 (55.111)	0.177	−0.169 (0.147)	0.250	−7.740 (8.140)	0.342	−66.364 (66.985)	0.322
$PopulationDensity$	7.50e−05** (3.37e−05)	0.026	0.0229 (0.0157)	0.146	8.04e−05** (3.63e−05)	0.027	0.00368 (0.00266)	0.167	0.0315 (0.0211)	0.134
$Administration$	0.0184 (0.893)	0.984	5.606 (272.41)	0.984						
$Residential$	2.158*** (0.771)	0.005	658.12 (358.54)	0.066						
$Other$	2.755*** (0.563)	0.000	840.11 (386.32)	0.030						
$Entertainment$	4.625*** (1.661)	0.005	1410.44 (932.14)	0.130						
$Workshop$	1.545 (1.329)	0.245	471.21 (430.42)	0.274						
$CommunityCenter$	2.700*** (0.910)	0.003	823.49 (453.06)	0.069						
$DayCare$	1.716*** (0.479)	0.000	523.40 (252.25)	0.038						
$NursingHome$	−0.0298 (0.570)	0.958	−9.088 (173.75)	0.958						
$SportsVenue$	2.179*** (0.779)	0.005	664.48 (357.03)	0.063						
$NotSchool$					2.620*** (0.569)	0.000	347.08*** (121.44)	0.004	347.08*** (121.44)	0.004
$constant$	5.199*** (1.089)	0.000			4.290*** (1.346)	0.001				
Number of obs	403		403		403		403		403	
Deviance	1635.40				1835.56					
AIC	11.325				11.793					

Nota: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 11: Regression - effect on target risk, Crime cost > 0

	Scenario 1				Scenario 2					
	No interaction						With Interaction			
							$NotSchool = 0$		$Notschool = 1$	
Cost/m2	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	dy/dx	p-value
BurglarAlarm	−0.000882 (0.219)	0.997	−.0402 (9.954)	0.997	0.262 (0.327)	0.424	4.846 (6.042)	0.423		
BurglarAlarm *−NotSchool*					−0.613 (0.445)	0.169			−19.097 (14.571)	0.190
BurglarAlarm & *AccessControl*	−1.426*** (0.361)	0.000	−64.939*** (18.679)	0.001	−2.054*** (0.450)	0.000	−16.584*** (3.549)	0.000		
BurglarAlarm & *AccessControl − NotSchool*					0.722 (0.735)	0.326			46.140*** (11.820)	0.000
BurglarAlarm & *CCTV*	−1.247*** (0.329)	0.000	−56.754*** (17.057)	0.001	−1.430*** (0.480)	0.003	−14.391*** (4.0130)	0.000		
BurglarAlarm & *CCTV − NotSchool*					0.138 (0.667)	0.836	 −12.849***	 0.010	−45.575*** (10.416)	0.000
BurglarAlarm & CCTV & *AccessControl*	−0.265 (0.441)	0.548	−12.064 (20.260)	0.552	−1.213* (0.706)	0.086	(4.974)			
BurglarAlarm & CCTV & *AccessControl − NotSchool*					1.136 (0.912)	0.213			−4.368 (31.748)	0.891
Crime/population	−1.967 (8.371)	0.814	−89.570 (381.68)	 0.814	−5.069 (8.812)	0.565	−90.008 (156.10)	0.564	−297.13 (519.31)	0.567
PopulationDensity	−2.66e−05 (1.71e−05)	0.121	−.00121 (.000811)	0.135	−1.69e−05 (1.85e−05)	0.361	−0.000299 (0.000325)	0.356	−0.000988 (00111)	0.374
Administration	0.374 (0.379)	0.324	17.013 (17.570)	0.333						
Residential	0.203 (0.564)	0.718	9.260 (25.714)	0.719						
Other	2.076*** (0.280)	0.000	94.504*** (20.489)	0.000						
Entertainment	0.702 (0.675)	0.298	31.953 (31.139)	0.305						
Workshop	2.381*** (0.688)	0.001	108.42*** (36.299)	0.003						
CommunityCenter	0.984** (0.382)	0.010	44.806*** (18.535)	0.016						
DayCare	1.039*** (0.245)	0.000	47.307*** (13.221)	0.000						
NursingHome	0.00456 (0.429)	0.992	0.208 (19.535)	0.992						
SportsVenue	0.984** (0.438)	0.025	44.820*** (20.865)	0.032						
NotSchool					1.337*** (0.285)	0.000	40.857*** (7.374)	0.000	40.857*** (7.373)	0.000
constant	3.323*** (0.693)	0.000			3.442*** 0.731	0.000				
Number of obs	1,663		1,663		1,663		1,663		1,663	
Deviance	5275.24				5628.32					
AIC	8.810				9.0174					

Nota: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 12: Regression - effect on target risk, Building risk related damages, Water damage cost > 0

	Scenario 1				Scenario 2					
	No interaction						With Interaction $NotSchool = 0$		$Notschool = 1$	
Cost/m2	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	Coef. (St.Err)	p-value	dy/dx (St.Err)	p-value	dy/dx	p-value
$WaterLeak, Stop$	0.0584 (0.459)	0.899	6.530 (51.393)	0.899	−0.748 (0.974)	0.443	−7.321 (6.904)	0.289		
$WaterLeak, Stop$ $-NotSchool$					0.952 (1.142)	0.404			34.981 (114.64)	0.760
BMS	−0.410 (0.359)	0.25	−45.908 (41.770)	0.272	−0.0135 (0.521)	0.979	−0.181 (6.980)	0.979		
BMS $-NotSchool$					−0.540 (0.890)	0.544			−71.704 (76.629)	0.349
BMS & $WaterLeak, Stop$	0.176 (0.440)	0.689	19.722 (49.578)	0.691	0.928 (0.699)	0.184	18.833 (20.639)	0.362		
BMS & $WaterLeak, Stop$ $-NotSchool$					−1.970* (1.011)	0.051			−105.75*** (49.357)	0.032
$Age31-60$	0.619 (0.434)	0.154	69.227 (51.724)	0.181	−0.212 (0.558)	0.704	−2.872 (7.730)	0.710	−33.230 (87.301)	0.703
$Age61-90$	0.466 (0.534)	0.383	52.092 (62.329)	0.403	−0.246 (0.672)	0.714	−3.332 (9.335)	0.721	−38.558 (104.01)	0.711
$Age91-x$	0.0951 (0.506)	0.851	10.642 (56.678)	0.851	−0.499 (0.577)	0.387	−6.746 (8.261)	0.414	−78.063 (91.554)	0.394
$AgeNA$	0.370 (0.440)	0.400	41.369 (50.890)	0.851	−0.0900 (0.540)	0.868	−1.217 (7.387)	0.869	−14.082 (84.413)	0.868
$PopulationDensity$	$-1.29e{-}05$ $(1.88e{-}05)$	0.492	−0.00144 (0.00210)	0.493	$-3.54e{-}05$* $(2.13e{-}05)$	0.097	−0.000479 (0.000325)	0.141	−0.00554 (0.00344)	0.108
$Administration$	1.429*** (0.504)	0.005	159.90*** (64.019)	0.013						
$Residential$	2.421*** (0.483)	0.000	270.85*** (77.852)	0.001						
$Other$	2.706*** (0.401)	0.000	302.76*** (78.171)	0.000						
$Entertainment$	1.222 (1.226)	0.319	136.74 (140.01)	0.329						
$Workshop$	−0.188 (1.081)	0.862	−21.027 (121.13)	0.862						
$CommunityCenter$	3.761*** (0.543)	0.000	420.78*** (117.99)	0.000						
$DayCare$	2.879*** (0.325)	0.000	322.11*** (77.526)	0.000						
$NursingHome$	0.374 (0.381)	0.327	41.792 (43.669)	0.339						
$SportsVenue$	0.408 (0.670)	0.543	45.653 (75.556)	0.546						
$NotSchool$					2.612*** (0.321)	0.000	142.92*** (26.567)	0.000	142.92*** (26.567)	0.000
$constant$	2.367*** (0.514)	0.000			3.061*** (0.632)	0.000				
Number of obs	433		433		433		433		433	
Deviance	1036.61				1250.44					
AIC	9.621				10.093					

Nota: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$