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Loss prevention technologies and property insurance:

Findings and unanswered questions from research using Danish municipal data

Preface

The research presented in this written dissemination is the summary of the PhD thesis titled *"The economic net benefits of loss prevention technologies in the context of risk management and insurance"*. The thesis is the result of three years of work focusing on the net benefits of investing in property loss prevention technologies for property owners. It contributes to the field of economics with an understanding of how property loss prevention technologies affect the cost of building damages and how investments in loss prevention affect insurance pricing. The theory developed in this thesis deepens the current understanding of how the policyholder should prioritise investment in loss prevention and acceptance of deductibles ex-ante risk transfer.

After having worked with risk management, loss prevention and insurance for more than a decade in different roles – installing loss prevention as a technician, selling loss prevention as a salesman, advising about risk management and insurance as a management consultant and researching the topic – I genuinely believe that this thesis adds significant value, new knowledge and a better understanding for many fellow researchers and risk managers as well as the whole loss prevention and insurance industry.

The project is a fully externally funded PhD project conducted at the University of Southern Denmark's Department of Sociology, Environmental and Business Economics (SEBE) under the guidance of principal supervisor Brooks Kaiser, co-supervisor Niels Vestergaard and industry co-supervisor Kurt Henriksen. It was conducted from 1 February 2019 to 31 January 2022. The project was funded by Willis Towers Watson with financial contributions from the Region of Southern Denmark and the Danish municipalities of Faxe, Frederikshavn, Hedensted, Hjørring, Horsens, Københavns, Mariagerfjord, Middelfart, Nordfyns, Randers, Ringkøbing-Skjern, Skanderborg, and Struer as well as the insurance companies Protector Forsikring and RiskPoint. Financial support from all parties (Willis Towers Watson, clients, potential clients and the insurance industry) was given with no intention of influencing the research results. The financial partners gave financial support to this project and helped with the data but have in no way – either directly or indirectly – tried to influence or manipulate the results.

The aim of this written dissemination is to convey the main results of my PhD thesis to stakeholders in the industry who are faced with the dilemma of having to find appropriate and efficient ways to mitigate risks.

I hope you enjoy your reading.

Simon Sølvsten

Content

Introduction

Background

Both Danish and building owners worldwide spend billions of Danish kroner annually on mitigating the risk of building damage. Therefore, it is reasonable to consider investments that directly limit risk of financial loss from building damage. At the same time, investments can have indirect impacts through insurance pricing and contracts. Whether such investment can - and do - return a positive net benefit when the interactions between insurers and policyholders are considered is the overarching question of the PhD thesis.
Building owners face a dilemma where they can choose to invest in adjusting the risk of building damage, choose to transfer - some or all - risk to a third party or choose to do both with the expectation of increasing their own net benefit through a combination of lower damage and insurance costs. Unfortunately, existing research provides little understanding of the effect property loss prevention technologies have on building damage and how they possibly influence property insurance pricing under risk transfer.

To address the overarching question, the thesis aims to quantify the effect of property loss prevention technologies on building damages, and how investment in property loss prevention technologies may affect property insurance pricing. Finally, the thesis explores how property owners should prioritise investment in loss prevention ex-ante risk transfer.

Risk Managers are in an interesting dilemma when they choose between property loss prevention technologies investments, risk transfer and acceptance of own risk. To gain a better understanding of how property owners (i.e., potential policyholders) should prioritise investments in loss prevention, the following three main questions are answered in the PhD thesis:

- → What quantitative effects do the most frequently used loss prevention technologies have on property damage cost?
- → What influence does the use of property loss prevention technologies have on property insurance pricing?

→ How should policyholders choose to invest in property loss prevention technologies before risk transfer to maximise their own net benefit?

The first research question gives valuable understanding of what pure effect the technologies may have on property risk. Hence, the effect of using loss prevention is first to be understood with no contamination from potential risk transfer to a third party.

The second question focusses on how the use of property loss prevention technologies might influence property insurance pricing. The answer to this question increases the current understanding on the field and provide an important understanding of whether insurance companies are capturing risk heterogeneity between policyholders when pricing insurance.

The first two questions reduce current gaps in the literature with a better understanding of the quantitative effects of using property loss technologies and highlight the expected net benefits of investing in such technologies. The last research question leans on the knowledge gained through the answers to determine how policyholders can maximise the choice of optimum level of investment in loss prevention technologies under uncertainty. The answer to this question provides an important contribution to the behavioural economics theory and increase understanding regarding policyholders' choices to take ex-ante risk transfer to optimise their economic net benefits.

Limitations

The focus of the thesis is to establish an understanding of loss prevention technologies' quantitative effect regarding property risk management and insurance pricing for Danish municipalities. Throughout the thesis, knowledge of the effect and influence of using loss prevention technologies is sought from the investors, i.e., policyholders, perspective. Thus, although it is recognised that the problem is equally relevant for both the supply and demand side of insurance theory, the PhD thesis solely adopts a demand-side perspective of the problem.

This delimitation both helps to contend with the known challenge of getting access to privately held data that are not easily accessible and ensures the required academic depth and breadth for a PhD Thesis. Access to data has been acknowledged as one of the biggest challenges to overcome in analogous research projects (Welsh and Farrington 2000, Swaray, Bowles et al. 2005, Frank, Gravestock et al. 2013, Tilley, Thompson et al. 2015, Welsh, Farrington et al. 2015). To cope with this challenge, the scope of data providers is restricted to Danish municipalities. The data is restricted to Danish municipalities for four main reasons. First, Danish municipalities constitute some of the largest organisations in Denmark, and they own numerous buildings of varying uses and sizes. Second, Danish municipalities are required by law to give access to data under The Freedom of Information Act (LBK nr 145 af 24/02/2020 (Freedom on information act) 2020) and are therefore likely more willing to provide data for research projects.[1] Third, Danish municipalities are required to disclose their insurance purchases regularly to competition and accordingly archive data on building characteristics, claims history, etc. Fourth, Danish municipalities have no competitive considerations when sharing data which likely means they are more willing to share said data.

[1] The Freedom of Information Act was not used under the project. All data was provided voluntarily.

A Literature Review - Technologies and property loss prevention

The use of technologies to lessen exposure and control vulnerability is rapidly changing. Due to speed of this change, very little is yet known on how new loss prevention technologies can affect property risk. But, if organisations worldwide are to use these technologies in their strategic planning of risk mitigation, knowledge of where the highest net-benefits are to be achieved is crucial.

But the question is, who cares?

With higher demands for financial focus, prioritization of efforts, and proof of what solution will add to the highest possible net benefit to the organization, the role of risk managers is changing. Furthermore, most senior corporate risk mangers do not report to C-level executives, and thus their voice is often filtered through layers of management before top-level board decision-making can focus on risk mitigation. This, coupled with a similar positioning of technology within many organizations, begs the question: How are risk managers supposed to succeed with their communication and prioritization of efforts when so little is known about the effect the numerous loss prevention technologies have on property risk?

Has there been sufficient research to support industry needs?

If we are to rely solely on academic research, the perception of loss prevention technologies impacts on property risk is non-conclusive. By dividing property risk into four sub-categories: Natural Catastrophes, Fire and Explosions, Crime and the Risk from Building installations, it is reasonable to argue that the most used technologies, in most countries, are perceived as:

- → Wet-floodproofing and Dry-floodproofing used to mitigate the risk of flooding.
- → Fire suppression systems, e.g. Sprinklers system and Automatic fire detection system used to minimise the risk of fire damage.
- → Target hardening, Burglar alarm and Closed-Circuit Television (CCTV) in order to reduce risk from crime.
- → Automatic water detection systems and Automatic water leak detection systems to cope with the risk from water baring installations.

Specific research supports that both Wet-floodproofing and Dry-floodproofing are associated with smaller damage when used; however, the results are not conclusive. Kreibich, Bubeck et al. (2015) stressed this problem in their review from 2015, and found that it is most likely that Wet-floodproofing reduces the damage ratio by approximately 47%; Dry-floodproofing approximately 26%; and temporary floodproofing with an approximately 24 % reduction in damage. One likely reason for the difference between wet and dry floodproofing is that dry-floodproofing most often requires appropriate human interaction to be most effective.Whilst it is difficult to simulate real-world building fires and associated costs, it is found that most research supports the use of sprinkler systems.

Despite variation in the meaning of the word effectiveness[2] , Frank, Gravestock et al. (2013) find in their review that sprinkler systems do work with a total effectiveness between 70% to 99%. Surprisingly, it has not been possible to find literature that establishes the affect of automatic fire alarms, so it is unclear how these technologies influence fire damage.

Similarly, there is no clear research that addresses the use of either Automatic water detection systems or Automatic water leak detection systems, and thus the advantages of investing in such technologies is unknown. More research is needed before the true net-benefits of Automatic water leak detection can be understood.

In understanding how technology can be used to influence crime risk, research is seen to be particularly challenged by understanding how the technology influences criminals' behaviour. In general, target hardening, e.g. locks, fences etc., is perceived to have the highest impact on burglar reduction; however, no clear estimation of the effect is definite. Even though there is a general belief that burglar alarms have a positive affect on risk, there is a great deal of variation in results. While Tilley, Thompson et al. (2015), Tseloni, Thompson et al. (2017) and Tseloni, Farrell et al. (2017) found that burglar alarms are associated with a decrease in risk, others find that burglar alarms increases the risk. These variations in research results makes it hard to assess whether investment in burglar alarms can be justified. A common theoretical discussion hints that the effect of burglar alarms may be diminishing, but that the technology will have a positive effect on the actual cost of the damage if exposed to crime. The general argumentation suggests that noise from burglar alarms increase the burglar's level of stress and thus limit the time available. Welsh and Farrington (2003), Welsh and Farrington (2009) and Piza, Welsh et al. (2019) studied the existing literature on the outcome of video surveillance on crime. They clearly describe the variation in research results and the complexity of measuring its effect. In general, the positive impact of CCTV is seen to be greatest in delimited areas, such as car parks, where 37% reduction in crime can be seen. However, the use of video surveillance in other settings such as residential areas has far less influence – around 12% reduction.

Trust in the progress

Common to the general research on loss preventions impact on property risk is the lack of inclusion of economic models e.g. cost-benefit analysis, which in particular limits the application of the research in an industrial context. However, there are clear benefits to developing a better understanding to support risk managers' challenges and provide clear guidance to organization and government initiatives in the future.

The following three sections summarize the articles from the PhD thesis. The first summarized article describes the quantitative effects and the economic net benefits that building owners can achieve by limiting property damage through investing in loss prevention (e.g. fire alarms, sprinkler systems, burglar alarms, access control, surveillance cameras, leakage protection systems, etc.). Secondly, describe how insurers respond to the use of loss prevention during premium determination. In the third summarized article, it is described how Risk managers can estimate the optimal need for investment in claims prevention and level of deductible during risk transfer.

[2]Effectiveness ranges from acceptable a maximum 20% damage to the building to fire spread between fire cells.

Loss prevention technologies' effect on property damage cost and financial savings

Investments in loss prevention technologies are made with the intention of preventing financial loss and reducing the cost of damage; however, uncertainty and lack of knowledge regarding what effect loss prevention technologies have challenges risk managers' ability to efficiently prioritise investments. As presented in the previous section "*A Literature Review - Technologies and property loss prevention*", only limited focus has been given to understanding these effects and economic net benefits. Consequently, the article presented in this section answers the question *what quantitative effects do the most frequently used loss prevention technologies have on property damage cost?* and explore what financial returns can be achieved through loss prevention investments when risk transfer is excluded.

Main results

First, the probability of a damage event is empirically estimated as a function of building characteristics, building types and the loss prevention technology in use[3]. This analysis shows that damage probability tends to be higher when property loss prevention is used. It is noted that this is not a causal relationship as it was not possible to control for underlying factors like policyholder prioritisation of where to install the technology. Hence, it is expected that the higher probability of damage in buildings with loss prevention is a likely result of policyholders' prioritisation of lowering risk in buildings where risk is highest.

Second, the difference in damage reduction for properties with and without loss prevention technologies is quantified by regressing damage cost per square metre on building characteristics, building types and loss prevention technology in use. The analysis also shows that loss prevention technologies' effect on damage reduction is dependent on the building type, and thus the usage of the building.

Crime loss prevention technologies are the only loss prevention technologies that show a significant influence on damage at the .99 confidence interval, and crime related damages are the most frequent damage expected to be influenced by the loss prevention technology in use. The only non-crime related loss prevention technology that shows significant influence on damage cost is building management systems combined with water leakage detection with stop valves for non-schools at the .9 confidence interval. The effect of using fire loss prevention technologies shows insignificant results as do the results for non-school buildings regarding crime loss prevention technologies.

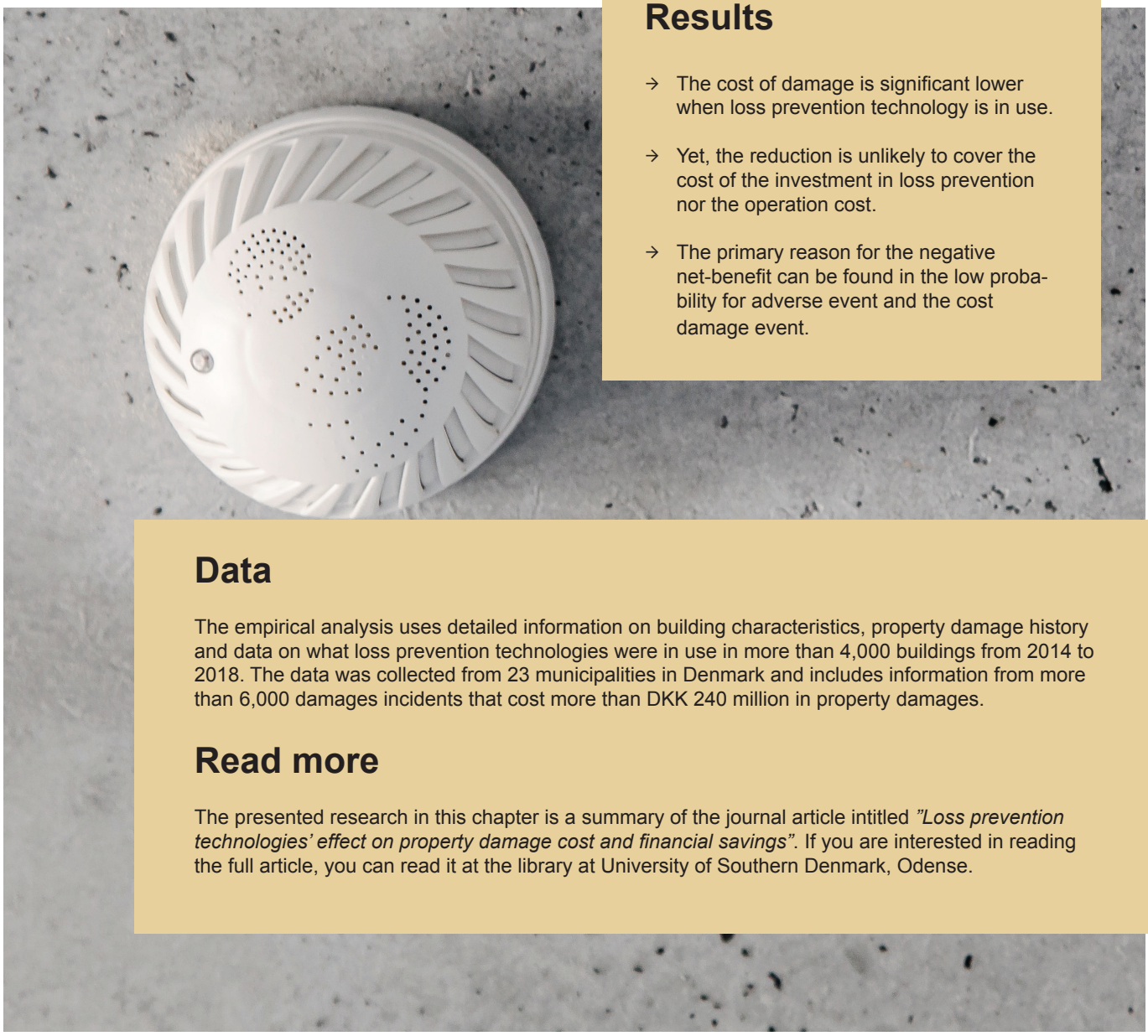
Third, the quantified relationships are used to calculate potential financial savings from loss prevention technologies by using the regression coefficients to estimate the probabilities and damage costs for the properties without loss prevention technologies should they be adopted. For example, damage costs related to crime were found to be DKK 3.36 lower per square metre yearly if the building is a school and there is a burglar alarm combined with access control in use.

[3]The Danish municipalities use Fire suppression systems, Sprinkler system, Automatic fire detection system, Automatic water leak detection systems, Burglar alarm, Access control system, Closed-Circuit TeleVision (CCTV) and Building Management System.

This equates to financial savings for a mean size school of DKK 16,778.44 per year. This is one of the higher savings calculated, as one might expect, given that several of the technologies do not have demonstrable impacts on damage costs.

Conclusion

While property loss prevention technologies reduce damage cost, the reductions are likely insufficient to finance investments or operation costs regarding these technologies. It should be noted that non-physical damages such as business interruption are not included in the calculation; thus, more positive results are likely to be found if these costs are included. Organisations should carefully consider why they are investing in loss prevention technologies as positive financial net benefits are likely unachievable.



Results

- → The cost of damage is significant lower when loss prevention technology is in use.
- → Yet, the reduction is unlikely to cover the cost of the investment in loss prevention nor the operation cost.
- → The primary reason for the negative net-benefit can be found in the low probability for adverse event and the cost damage event.

Data

The empirical analysis uses detailed information on building characteristics, property damage history and data on what loss prevention technologies were in use in more than 4,000 buildings from 2014 to 2018. The data was collected from 23 municipalities in Denmark and includes information from more than 6,000 damages incidents that cost more than DKK 240 million in property damages.

Read more

The presented research in this chapter is a summary of the journal article intitled *”Loss prevention technologies’ effect on property damage cost and financial savings”*. If you are interested in reading the full article, you can read it at the library at University of Southern Denmark, Odense.

Do insurers adjust prices for the adoption of loss prevention?

In theory, loss prevention should, as the name implies, reduce the loss for the risk carriers and the expected present value of losses. In a competitive insurance market, where the premium is given through market bidding, expected potential savings from investing in loss prevention technologies should become measurable in the insurance price. In this section, it is therefore sought to understand *What influence has the use of property loss prevention technology on property insurance pricing?* This understanding is sought empirically by regressing price of policy on number of bidding carriers, total insured square metres, history of experienced claim events, all claims cost and loss prevention technologies in use.[4]

Main results

There is a tendency in the data that shows that smaller claims[5] influence the cost of insurance more than larger claims when plotting the data. This aligns with the pure premium method which states claims influence the cost of insurance (Houston 1956, McClenahan 2006, David 2015). It is therefore expected that claims likely matter when underwriters set the price of the contract. As large claims and frequency claims potentially have different impacts on the insurance premium, this relationship was further investigated. It was found that the size of claims has a significant yet different influence on prices. The results of the empirical analysis show that as the size of the claim increases, the relative influence the claim has on the price decreases.

While policyholders claim history ex-ante risk transfer significantly influences the cost of insurance, little evidence supports that the use of loss prevention technologies influences the price. Only water leak detection technology seems to have any measurable downward influence on the price at the .9 confidence level. This leads us to the understanding that technologies that reduces the cost in the tail of the risk distribution where the probability for claims are lowest have less influence on the price compared to technologies that limit smaller yet likely more often experienced damages. While risk carriers' price should reflect policyholders' risk, risk heterogeneity is likely more challenging to measure in the tail of the distribution where there are few claims. It is therefore likely that the influence of loss prevention technologies is muted if they primarily influence severe and costly damages.

[4]Automatic Fire alarm systems, Sprinkler systems, Water detection system, Building management system, Burglar alarm, and CCTV

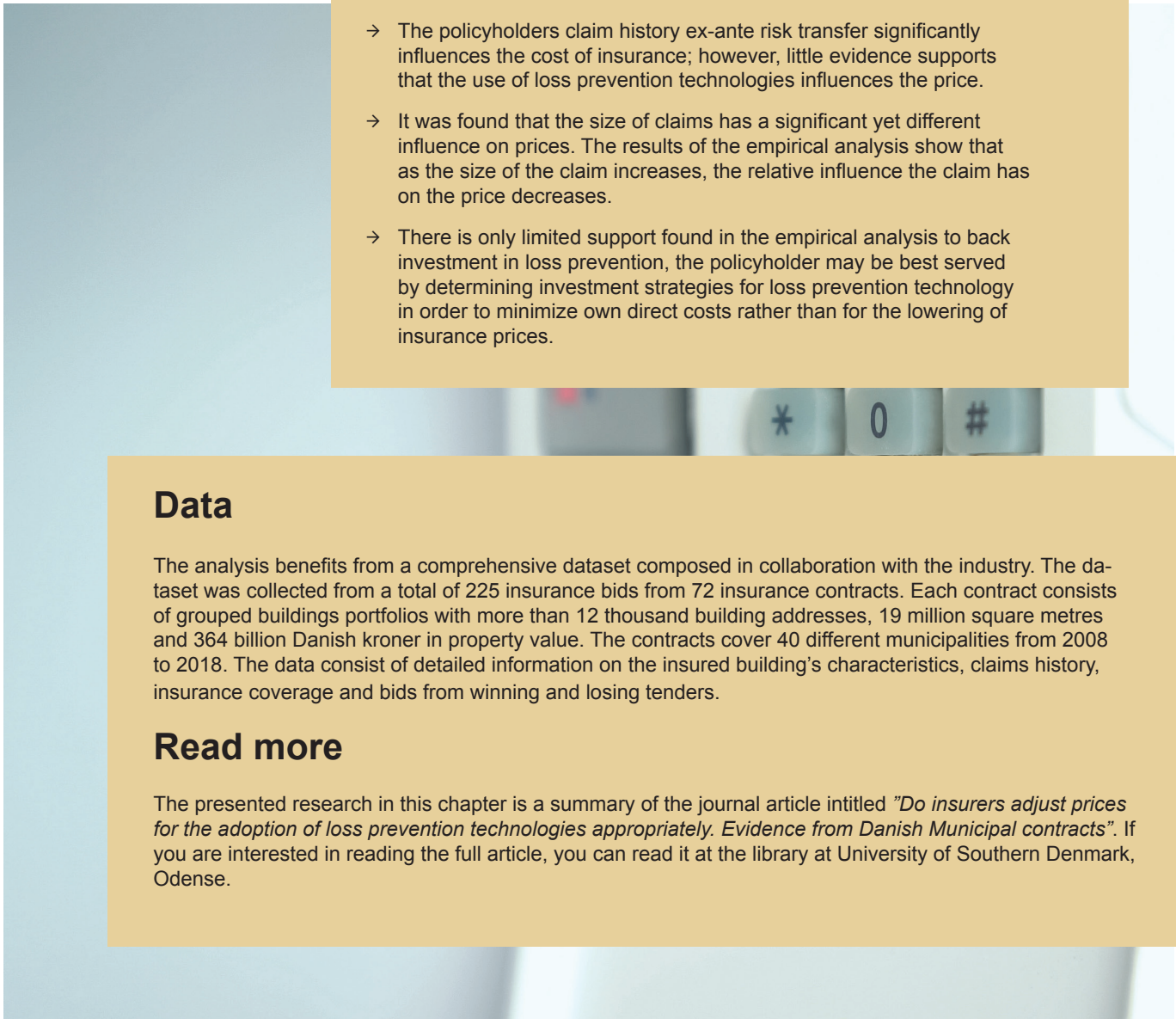
[5]Claims < DKK 1,000,000

Conclusion

As only limited support is found in the empirical analysis to back investment in loss prevention, the policyholder may be best served by determining investment strategies for loss prevention technology in order to minimise own direct costs rather than for the lowering of insurance prices. One explanation may be that all municipalities have invested to a degree where further investments no longer influence the price of the contract. This explanation seems unlikely due to the variation in the use of loss prevention technologies amongst the municipalities. Another explanation may be that there is not sufficient competition between insurers for the price to reflect the marginal cost in the contract. The latter is consistent with the findings in the empirical analysis that highlight an increased number of competitors significantly reduce the price.

Results

- → The policyholders claim history ex-ante risk transfer significantly influences the cost of insurance; however, little evidence supports that the use of loss prevention technologies influences the price.
- → It was found that the size of claims has a significant yet different influence on prices. The results of the empirical analysis show that as the size of the claim increases, the relative influence the claim has on the price decreases.
- → There is only limited support found in the empirical analysis to back investment in loss prevention, the policyholder may be best served by determining investment strategies for loss prevention technology in order to minimize own direct costs rather than for the lowering of insurance prices.



Data

The analysis benefits from a comprehensive dataset composed in collaboration with the industry. The dataset was collected from a total of 225 insurance bids from 72 insurance contracts. Each contract consists of grouped buildings portfolios with more than 12 thousand building addresses, 19 million square metres and 364 billion Danish kroner in property value. The contracts cover 40 different municipalities from 2008 to 2018. The data consist of detailed information on the insured building's characteristics, claims history, insurance coverage and bids from winning and losing tenders.

Read more

The presented research in this chapter is a summary of the journal article intitled *"Do insurers adjust prices for the adoption of loss prevention technologies appropriately. Evidence from Danish Municipal contracts"*. If you are interested in reading the full article, you can read it at the library at University of Southern Denmark, Odense.

Insurance market pricing conundrums regarding loss prevention investments

The balance for optimal prioritisation between acceptance of own risk, and investment in loss prevention technologies when risk is transferred is dependent on insurers response to policyholders' prioritisation. Thus, to understand how policyholders can maximise their investment strategy in loss prevention technologies, this section seeks to answer *How should policyholders choose to invest in property loss prevention technologies before risk transfer to maximise their own net benefit?* when the decision is seen as dependent on the insurance company's response to the use of loss prevention through a reduction in insurance price or lack thereof.

Main results

A simple game theoretical framework is developed to illustrate the interdependent choices policyholders and insurers face with respect to ex-ante risk transfer through loss prevention technologies. Insurers may choose to ignore loss prevention technologies in setting insurance prices or to discount prices in expectation of lower claims. Policyholders' best responses to two possible insurer reactions is then to optimize loss prevention technology investments as a function of insurance prices as well as any expected reductions in the probability of damage events and/or damage costs. While optimal investment strategies are calculated for both responsive and unresponsive insurers and the difference between the two states of the world is quantified theoretically, the potential equilibria are further investigated with the use of empirical data and Monte Carlo simulations. First, how automatic fire alarms influence the distribution of expected damage cost is simulated. Second, how fire alarms affect the expected cost of claims distribution in the contract is estimated. Third, how policyholders use of loss prevention technologies may influence the insurer's contribution margin is simulated.

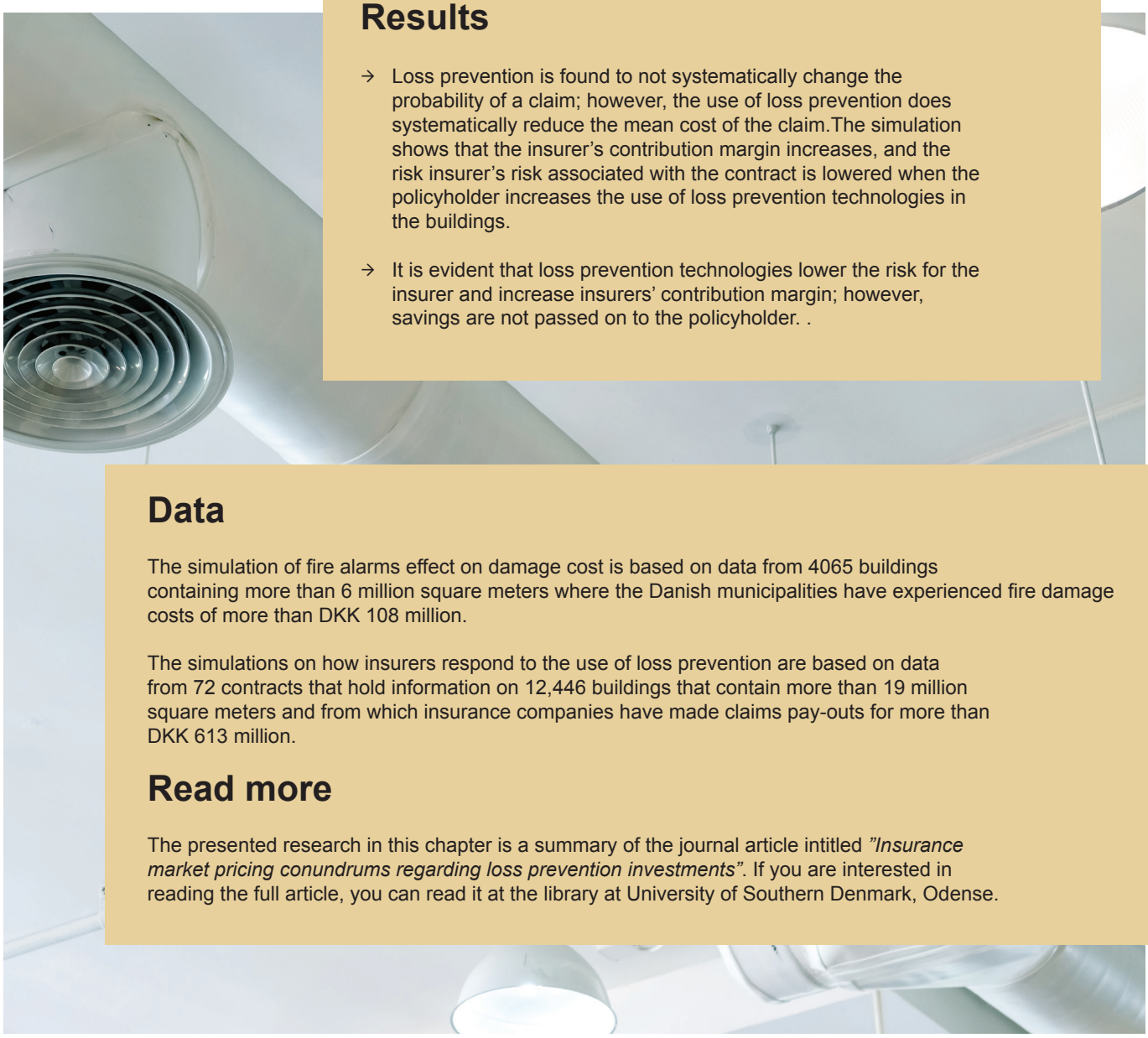
It is simulated how fire loss prevention influences the distribution of expected damage cost. Increased use of automatic fire alarms shifts the distribution, lowers the cost of fire and reduces the standard deviation.

To understand how loss prevention influences claims cost, i.e., damages above deductibles, how fire alarms affect the expected cost of claims is simulated. From the simulation of how loss prevention affects insurance pay-out, loss prevention is found to not systematically change the probability of a claim; however, the use of loss prevention does systematically reduce the mean cost of the claim.

From the 72 insurance contracts, how the insurer's estimated contribution margin is influenced by policyholders use of loss prevention technologies is simulated. The insurer's contribution margin is found to increase as policyholders' use of loss prevention increases. Furthermore, the lower bound of the contribution margin is found to have decreased, and the standard deviation of contribution margin also decreases by increased use of loss prevention. The simulation thus illustrates that the insurer's contribution margin increases, and the risk insurer's risk associated with the contract is lowered when the policyholder increases the use of loss prevention technologies in the buildings.

Conclusion

The simulations show that policyholders should not expect price to change as a function of the deductibles and investments in loss prevention technologies. It is evident that loss prevention technologies lower the risk for the insurer and increase insurers' contribution margin; however, savings are not passed on to the policyholder. Consequently, the insurers benefit from policyholders' investment in loss prevention increases in contribution margin and lowers risk associated with contract. While there is no clear evidence as to why the insurers do not price the contract according to the marginal cost of the contract, one possible explanation which is consistent with the game theoretical analysis is that the industry can be perceived as non-competitive. This allows the insurer to ignore information about the use of loss prevention and benefit from those policyholders that do invest.



Results

- Loss prevention is found to not systematically change the probability of a claim; however, the use of loss prevention does systematically reduce the mean cost of the claim.The simulation shows that the insurer's contribution margin increases, and the risk insurer's risk associated with the contract is lowered when the policyholder increases the use of loss prevention technologies in the buildings.
- It is evident that loss prevention technologies lower the risk for the insurer and increase insurers' contribution margin; however, savings are not passed on to the policyholder. .

Data

The simulation of fire alarms effect on damage cost is based on data from 4065 buildings containing more than 6 million square meters where the Danish municipalities have experienced fire damage costs of more than DKK 108 million.

The simulations on how insurers respond to the use of loss prevention are based on data from 72 contracts that hold information on 12,446 buildings that contain more than 19 million square meters and from which insurance companies have made claims pay-outs for more than DKK 613 million.

Read more

The presented research in this chapter is a summary of the journal article intitled *"Insurance market pricing conundrums regarding loss prevention investments"*. If you are interested in reading the full article, you can read it at the library at University of Southern Denmark, Odense.

Conclusion

The thesis was motivated by a desire to understand what economic net benefits property owners and policyholders could achieve by investing in loss prevention technologies. The thesis has been guided by three main research questions that have made it possible to come to a better understanding of the quantitative effects property loss prevention technologies have on property damage, how property loss prevention technologies influence insurance pricing and how policyholder should prioritise investments in property loss prevention technologies under risk transfer to maximise own net benefit.

Effect of loss prevention technologies

In article *"Loss prevention technologies' effect on property damage cost and financial savings"* it was found that the financial cost from crime risk-targeted damages was significantly reduced by Burglar alarms combined with Access control[6], Burglar alarms combined with CCTV6[6] as well as Burglar alarms combined with access control and CCTV[7]. While it is not possible to conclude that all technologies cause a significant reduction in damage cost, the analysis shows consistent reduction in cost for all technologies that have a statistically significant influence on the expected targeted risk for the technology.

Although loss prevention technologies reduce the cost of damage, the shift in cost is likely only sufficient to co-finance operation costs of the technologies. Thus, organisations should not invest in loss prevention technologies solely to gain a positive financial net benefit from lower costs of damage. Consequently, property owners should be reluctant when investing in loss prevention technologies if the investment is done solely for financial gains.

One important limitation for the research presented in the article *"Loss prevention technologies' effect on property damage cost and financial savings"* is that it has not been possible to establish causality between change in probability and the use of loss prevention during this study. While the probability of a damage event is found to be mostly higher when there are loss prevention technologies in use, it is unlikely this is caused by the technology but rather by priorities previously made regarding a municipality's investments and prioritisations between the buildings.

Adjusting of prices

While it has been shown that loss prevention reduces the cost of claims, it is rational to believe that the use of loss prevention should also reduce the cost of insurance as insurers total cost of claim pay-outs in the contract should be reduced. According to the discussion in the insurance industry, the use of loss prevention technology should have an unspecified influence on the premium. However, the analysis in the article *"Do insurers adjust prices for the adoption of loss prevention?"* found no sufficient evidence that insurance companies adjust the price of the contract to the use of loss prevention. The only signalling influence was found when water leakage detection technologies were in use at the .9 confidence interval.

As stated in the article *"Do insurers adjust prices for the adoption of loss prevention?"*, there is no clear explanation as to why the insurance companies do not adjust the price according to investments in loss prevention. One explanation may be that the use of loss prevention in the municipalities have reached a level where further investments do not show any marginal influence on price and are thus undetectable in the analysis. This appears unlikely given the low use of property loss prevention technologies in the municipalities overall. An alternative explanation may be lack of competition in the market which may be too low to force the insurers' price to reflect the marginal cost per contract and will thus not accurately reflect the change in risk enforced by the use of loss prevention technology. On the other hand, it was found in the article *"Do insurers adjust prices for the adoption of loss prevention?"* that claims history prior to insurance purchase have a significant influence on insurance cost.

[6]When model is interacted with building type school and not-school, the effect is only significant for building type schools.
[7]When model is interacted with building type school, and not-school, the effect is only significant for building type schools at the .9 confidence interval.

Thus, the discount in insurance price does not reflect the investments in loss prevention but is inferred indirectly though lower cost in claims. This might decrease policyholders' incentives to invest in loss prevention as the investments in technology might shift larger claims to smaller claims. This will lead to an increase in the relative amount of the claim that has to be paid by the policyholder, lowering the cost for the insurance companies and increasing the overall profit of the contract.

How to invest

Policyholders may thus be best served by focussing on investments that reduce smaller and more frequent claims to minimise their own direct costs rather than focussing on investment strategies to reduce the cost of insurance. As argued in the article *"Do insurers adjust prices for the adoption of loss prevention?"*, a potential yet unintended free-rider effect may occur as investments by others will reduce the insurance companies' overall cost which might lead to an overall lower market insurance price. Thus, the policyholder that did not invest may have gained the most among policyholders.

Even though loss prevention may not change the cost of insurance and may not provide a positive financial return to the property owner through lower damage costs, it is clear that investments in loss prevention provide benefits for those who carry the risk. The empirical analysis shows that the total cost of damage, claims and the uncertainty of risk is diminished by the use of loss prevention technologies. Even so, it is clear that insurers do not price insurance according to the marginal cost in the contract; subsequently, damage savings from the use of loss prevention is not passed on to the policyholder. Policyholders should be reluctant to invest in loss prevention and only invest in a minimum of loss prevention technologies to get insurers to accept the risk transfer.

Inefficiency in the market

The research presented in the thesis highlights that there is inefficiency in the market and that the overall effect of loss prevention on loss reduction or change in insurance price is not sufficient to achieve a positive economic return for the investor. Additionally, while perhaps not immediately intuitive, the technology is seen to redistribute net losses between insurance companies and the insured so that in a claim situation, the insured bears a relatively greater burden as a consequence of having invested in loss prevention technologies. Conversely, if the market was responsive to the use of loss prevention technologies, the investor would achieve greater returns through a reduction in direct damage costs and lower insurance prices.

Research implications

Understanding the effects of property loss prevention is relevant to many stakeholders: academic researchers, policyholders and within the insurance industry. Nonetheless, limited focus, rapid technological development and limited access to data have challenged the understanding of this issue within academia and the industry. It is my aspiration that the results from this PhD thesis will push the current state of academic research and help the insurance industry and many policyholders around the world to better understand how loss prevention technologies influence property risk.

Researchers like Botzen, Monteiro et al. (2017), Tseloni, Thompson et al. (2017), Kreibich, Bubeck et al. (2015), Tilley, Thompson et al. (2015), Lee and Wilson (2013), Frank, Gravestock et al. (2013), Hirschfield, Newton et al. (2010) and Hearnden, Magill et al. (2004) have highlighted the need for an increased understanding and research focus on quantifying the effect of loss prevention technologies. Researchers such as Botzen, Monteiro et al. (2017), Kreibich, Christenberger et al. (2011) and Marvin (1993) have furthermore recognized the need for inclusion of financial cost to understand the economic net benefits associated with investing in loss prevention technologies. Based on the existing literature, it is clear that the work presented in the thesis adds significant and new insights to the literature with three main contributions.

First, it advances the understanding of what quantitative effect loss prevention technologies have on property damage. The empirical work reduces the current literature gap and includes a new and better understanding of what financial influence property loss prevention technologies have on property risk as it casts light on potential financial returns the investor may expect to gain from investing in property loss prevention. To the best of my knowledge, the work in the article *"Loss prevention technologies' effect on property damage cost and financial savings"* is the first to report this effect on financial returns based on empirical data.

Second, the empirical analysis in the article *"Do insurers adjust prices for the adoption of loss prevention?"* contributes to economics literature by increasing understanding of how insurance companies' pricing is influenced by policyholders' investment in loss prevention.

Ehrlich and Becker (1972) argued in their theory that self-protection and insurance should complement each other. Yet, limited research has been done to understand the extent of how property loss prevention technology actually influences property insurance pricing.

To the best of my knowledge, no one has previously established an empirical understanding of how insurance companies react to the use of loss prevention when setting the price of insurance. Thus, the analysis provides a deeper understanding of the market reaction to the use of property loss prevention technologies and challenges the belief that loss prevention and insurance is always complementary.

Third, further advancement to economic theory is achieved through the formulation of a theory that addresses how policyholders should prioritise actions ex-ante risk transfer to maximise the economic net benefit for the policyholder in the article *"Insurance market pricing conundrums regarding loss prevention investments"*. The theory, which has empirical support, addresses how policyholders can maximise their net benefit through the choice of investments in property loss prevention technologies and acceptance of own risk (level of deductible) ex-ante risk transfer. It should be noted that surprisingly little attention has been given to the understanding of how policyholders should behave when risk is mitigated in the economic literature to increase policyholders' net benefit (Hofmann and Peter 2016). Thus, the theory developed in the thesis adds to behavioural economics literature with a significant contribution of new understanding of how policyholders should prioritize actions prior to risk mitigation.

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