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RESIDUAL RISK AND THE EARTHQUAKE INSURANCE PROTECTION GAP

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ABSTRACT

Residual risk can be defined as the level of risk that is not offset by adopting and enforcing building codes and must be borne by homeowners. Insurance represents a well-tested mechanism for coping with the financial losses resulting from adverse events, such as natural hazards, by transferring them to a broader community. Reinsurance aims to minimize financial exposure to residual risk complementing mitigation measures in order to reduce the financial burden of a catastrophic loss. Nevertheless, big protection gaps continue to exist. The Nat Cat protection gap is defined as the uninsured portion of financial losses resulting from a disastrous event, i.e., the difference between total economic and insured losses. Many countries are exposed to major losses in the case of natural catastrophe events. Yet, very few have a private insurance scheme in place. The purpose of this paper is to present the (re)insurance perspective of managing the residual risk and provide a global overview of the existing earthquake insurance protection gap. Further, findings from past earthquakes and the difficulties in accurately modelling earthquake risks for insurance purposes are also discussed. Lessons learnt from the recent earthquakes in New Zealand clearly show that there are inherent uncertainties associated with the assessment of seismic risks for insurance products.

Keywords: risk transfer; tail risk; earthquake insurance; protection gap.

1. INTRODUCTION

Building codes and regulations establish minimum requirements for buildings to withstand the effects of natural hazards with specific return periods, providing then a baseline level of risk reduction. However, even constructing buildings to the highest standards does not guarantee that earthquake-related property damage will not occur. This reality was demonstrated in New Zealand a few years ago. Awareness of the exposure to earthquake risk is high in New Zealand, where building codes are among the most stringent in the world. Even so, the nation suffered very high losses from property damage when earthquakes struck the Christchurch area in 2010 and 2011. That is because "earthquakes do not read the code" and the primary aim of building codes is to save lives, not buildings. More recently, seismic building codes around the world have been revisited to implement elements of a performance-based engineering framework, which address damage limitation and reparability issues. However, much of the building stocks predate performance-based design considerations. In addition, seismic design codes provide minimum safety construction requirements, not targets, for structural engineers around the world. Hence, even when seismic design codes are present and enforced, there remains a residual risk that would have to be borne by homeowners. One way to help minimize financial exposure to residual risk is to purchase insurance.

Insurance is a well-tested mechanism for coping with the financial losses resulting from adverse events. Based on its fundamental role of risk pooling and sharing, insurance spreads the losses to a broader

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community. By limiting the financial burden of severe disasters, insurance allows individuals, businesses and the overall economy to recover faster from the fallout of a disaster. In doing so, insurance contributes to improving the resilience of societies. Nevertheless, big protection gaps continue to exist.

The Nat Cat protection gap is defined as the uninsured portion of financial losses resulting from a disastrous event, i.e., the difference between total economic and insured losses. The shortfall in cover is a challenge for both advanced and emerging economies. Pockets of underinsurance of earthquake risk are present even in advanced countries highly exposed to seismic hazard. In addition, a substantial part of the existing building stock might even predate traditional seismic design codes in certain countries and thus remain highly vulnerable to ground shaking. All of this calls for different mitigation measures. The purpose of this paper is to present the (re)insurance perspective of managing the residual risk and provide a global overview of the existing earthquake insurance protection gap. In particular, the protection gap for residential risks is investigated in several countries and loss values are given together with take-up rates indicating the variation of the protection gap among the countries. This study will also show that well-developed societies may have to bear big losses after earthquake events as a result of the protection gap.

Further, findings from past earthquakes and the difficulties in accurately modelling earthquake risks for insurance purposes are discussed. Lessons learned from the New Zealand earthquake clearly show that there are inherent uncertainties associated with the assessment of seismic risks for insurance products.

2. RESIDUAL RISK AND RISK TRANSFER

Risk reduction against catastrophic natural events can be achieved essentially through two mechanisms: physical risk mitigation and economic risk transfer. Physical risk mitigation strategies consist of adopting and enforcing building codes with appropriate design and construction requirements. Among these are requirements that buildings should be constructed to withstand the effects of natural hazards with respect to specified return periods. For example, in the case of earthquakes, main design decisions may include the level of seismic resistance together with the size and shape of the building, elevation, construction materials and quality and methods used in its construction as they all affect a building's capacity to withstand the wrath of natural hazard events. These represent the primary ways a community may protect itself and its citizens from potential natural disasters. When building codes are met, the vulnerability of buildings to natural hazard is reduced and a baseline level of risk reduction is provided.

However, meeting code requirements for design and construction of a building do not guarantee a "zero" risk. This reality was demonstrated in New Zealand in 2010 and 2011. There, building codes are among the most stringent in the world. Even so, the nation suffered very high physical property damage and resulting financial losses when earthquakes struck the Christchurch area both in 2010 and 2011, leading to a total economic loss of USD 36.6 billion according to data from the *sigma* catastrophe database of the Swiss Re Institute. That is because building codes are designed with the safety of the occupants in mind – not the prevention of damage to the building. Hence, even when design codes are present and enforced, it is not possible to completely eliminate the risk, and in most cases, the cost of further reducing the risk beyond this acceptable level is uneconomical.

The level of risk that is not offset by adopting and enforcing building codes, but must be accepted by the homeowner, can be defined as *residual risk*. Risk transfer mechanisms (e.g., use of insurance) represent a solution to minimize financial exposure to such residual risk. They complement mitigation measures to help reduce the financial burden of a catastrophic loss. Insurance represents a form of pre-disaster funding paid in advance in the form of premiums. Because the arrangements are made before the catastrophic event, the funding system can be quickly put in place and the payments made through claims on insurance policies whenever an event such as an earthquake occurs. This facilitates the recovery process and reduces the financial stress on the homeowners. The insurance industry can provide important protection in the form of funds, helping communities improve their resilience, rebuild and move forward after a natural disaster. Most of the financial losses resulting from the New Zealand earthquakes in 2010 and 2011 were covered by insurance companies because of the country's high insurance penetration, see Grollimund (2014).

Many insurance solutions have been implemented in different parts of the world to financially manage catastrophic risk. These include mandatory extension of basic fire policies to cover natural hazard risk (in particular earthquake), the establishment of government-sponsored insurance pools and mortgage default insurance for institutional investors to include natural catastrophes and increase robustness of the financial system. Next to indemnity solutions, there has been an increased demand for parametric insurance solutions, which allow for quick payout and settlements and extend coverage to areas where insurers traditionally feel less comfortable when assessing insurance payouts. Insurance solutions vary by region and country, depending on the development stage of the insurance market and/or the hazard exposure.

A crucial aspect for insurance companies is represented by the (residual) risk pricing. In order to avoid either insolvency (underpricing) or uncompetitiveness (overpricing), the risk has to be properly priced. To achieve this, the (re-) insurance industry has developed sophisticated catastrophe models over the last 30 years. These models are used to assess the risk and manage it by defining proper premiums and reserves to ensure that the pricing of products is competitive and that insurers can maintain a high level of solvency. The resulting premium represents the market cost of the transferred risk, with insurance companies usually seeking to charge policyholders a premium close to this. Since the market value reflects the vulnerability of the specific property to the natural event causing the loss, this can be an incentive to mitigate further the risk, i.e. reduce the present residual risk. In fact, lower vulnerability means a lower premium may be charged. In some cases, insurance companies may even require a specific level of mitigation as a condition of insurance. Consequently, insurance can also play a role in incentivizing mitigation measures, in addition to the risk mutualization mechanism.

3. CHALLENGES IN MODELLING RISKS FOR INSURANCE

3.1 Unmodeled risk

Over the past decades, catastrophe risk models have progressed to a mature pillar of risk assessment in the insurance industry and the society at large. Models integrate relevant science, data and engineering knowledge and thereby provide re/insurers, as well as property owners and policy makers, with a toolset in which all this knowledge can be harnessed for decision making. However, many limitations and inherent uncertainties exists.

Risk models only provide an oversimplified picture of a very complex reality. Nonetheless, if these risk models are appropriately applied within the context of their scope, they serve as a valid basis to quantify risks for the purpose of pricing residual risks for risk transfer solutions.

These models also have to quantify tail risks, i.e. risk of low probability-high consequence events. By definition, such tail risks are very rare and there is little to no empirical information that help to quantify them and hence, the inherent uncertainties involved with their assessment are large. Assessment of tail risks requires consistent consideration of all model components in earthquake risk modelling. For instance, the 1994 Northridge earthquake is known as an epsilon positive event, which means that ground motions were higher than average compared to average ground motions from quakes at the same location with the same magnitude. Grollimund & Tscherrig (2016) illustrate the impact of higher hazard uncertainty by means of the Puente Hills moment magnitude (Mw) 7.1 scenario. For this scenario, the insured loss would yield USD 153 billion, which is 58% higher than for an average event.

This highlights the importance of the consideration of all model components, especially of the hazard uncertainty. Decision makers, which rely on risk models for their decisions, should understand the underlying uncertainties and the impact they can have on their decisions because incomplete considerations of the uncertainties may increase the residual risk.

3.1.1 Post loss amplification

On top of this complexity, additional factors, which can be caused by the underlying event, can create additional complexities and increase losses and thereby the cost of insurance coverage. These factors are commonly called post loss amplification (PLA) in the insurance industry, and are usually separated into *demand surge*, *claims inflation* and *super-cat effects*.

- **Demand surge:** Due to widespread damage in the aftermath of a large event, demand for building materials and labor tends to outpace supply during rebuilding. This often leads to price increases, especially if rebuilding takes place during a relatively short period of time or if the building sector in the affected region has already been stretched for resources prior to the event.
- **Claims inflation**: Claims resources can be overwhelmed by the large number of claims after big events. The insureds may have to wait for their claim settlements for prolonged periods of time. As a result of this, the public resentment towards the insurance industry may rise. This in turn increases the likelihood of litigation and expensive settlements increase. Moreover, insurers also tend to settle more generously in such situations, which can strengthen their reputation or prevent litigation; however, this leads to an above average settlement per policy.
- **Super-cat effects**: Large earthquake events can lead to damages of critical infrastructures such as roads, bridges, gas, telecommunication and electrical power supply. Damages to such infrastructure can significantly slow down the reconstruction process because materials may need to be obtained from more distant locations. Super-cat effects account for such unknown loss drivers; past events have highlighted that each event can have its own specific effect, which leads to an underestimation of losses.

3.1.2 Non-modeled perils

Residual risk may also increase due to secondary hazards/perils that are either not considered in the risk assessment or because there is no design requirement for those perils. Examples of this are the risk of damage due to earthquake-induced landslide and liquefaction, tsunami risk or volcanic eruptions because those perils may not be modelled. These risks are also usually not covered by structural design and thereby increase the residual risk.

In recent years, some attempts to better understand these perils have been made in the insurance industry. Since 2012, for example, the insurance industry has modelled tsunami risk explicitly due to the high uncertainty associated with tsunami caused by the 2011 Tohoku earthquake. Volcano hazard is also now on the radar of the insurance industry, with insurers recently developing a worldwide volcanic ash fall risk model, which allows a better quantification of volcano risk (e.g. Tscherrig et al. 2016).

3.2 Experience from the 2010-2011 Canterbury earthquakes

The Canterbury earthquake sequence that occurred in New Zealand in 2010-2011 provided a real test of how earthquake risk models perform. The events revealed the complexities of the real loss event, caught insurers off guard and identified what drives losses.

The Canterbury earthquake sequence started on November 4th, 2010 with the Mw 7.1 Darfield earthquake. It was the first earthquake sequence for which it is known that the aftershock, on February 22nd, 2011 with a magnitude Mw 6.3, produced a by far larger loss. The subsequent June 13th 2011 event also contributed significantly to the total damage and loss.

Before 2010, Christchurch was not known as a seismic hot spot. Nonetheless, this earthquake sequence led to one of the highest insured loss from earthquake events worldwide, only exceeded by the 2011 Japan and the 1994 Northridge quakes. The learnings from these Canterbury earthquakes are so valuable because such a small magnitude earthquake can literally re-occur anywhere and at any time. Insurers were caught off guard by these events because they were not aware of the extent of the claims and the complexity of the claims process. This led to spiraling claims costs over time.

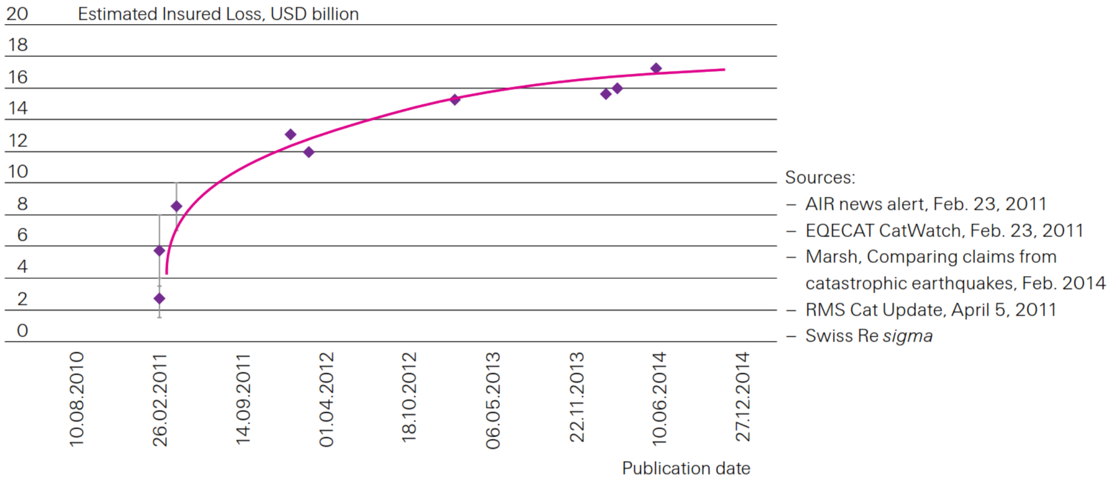

Figure 1. Development of estimated insured loss of the Feb 2, 2011 quake in New Zealand (Grollimund 2014)

Today, the total economic loss is estimated at USD 36.6 billion from the series of seismic events between 2010 and 2011 in New Zealand. Most of this is covered by insurance companies because of the high insurance penetration in New Zealand. The insured loss for the three major quakes is USD 29.2 bn. The Reserve Band stated that "extensive offshore reinsurance will fund a substantial share of the rebuild costs and thus has helped reduce the financial impact on New Zealand" (Parker & Steenkamp (2012).

Figure 1 shows the development of the claims. Model vendor companies ranked the loss initially between 1.5 and 8 billion. Hence, the final number was more than twice as the highest estimate. It was not expected that in a country, with an earthquake engineering culture of its own, and where the insurance penetration is among the highest in the world, that earthquake models would underestimate the modelled losses to such an extent. But why were those modelled losses underestimating the final loss number by that much? And where did earthquake risk models have their blind spots? And can these blind spots also apply to other countries and regions? Below, we list the loss contributors, which contributed most.

- **Claims settlement and preparedness:** The Canterbury events made clear that a country with a high earthquake risk awareness can get overwhelmed by claims handling and settling. Well over 400,000 claims had to be processed and on certain days 13,000 assessments by 350 loss adjustors were carried out. This meant 37 assessments per day, which did not leave time for detailed assessments. Claims were also susceptible to challenges, which subsequently led to a prolonged settlement process. Moreover, claims costs also increased because of claims advocates who worked on a contingency basis and *neighboritis* because policyholders who might have accepted to settle early on witnessed how some neighbors initially rejected offers to settle and later received more generous settlements.
- **Liquefaction and landslide:** Liquefaction and slope instability contributed to the losses. Although liquefaction has not been a new phenomenon, all models by far underestimated the impact of this type of loss. The Christchurch experience provided new insights in liquefaction loss modelling and those learnings have been incorporated in the latest earthquake models. Still, property owners were not only faced with rebuilding their buildings, but also with damages to their land. Land damage was also included in policies where only insured values for the property were provided. This highlights difficulties in assessing losses that land damage can incur.
- **Aftershocks:** The aftershock in February 2011 had a far more damaging effect to Christchurch than the main shock of the preceding September. The contribution of June 2011 event was also significant. Aftershocks can easily trigger second event or stop-loss covers. If they are neglected, the losses that can occur from such covers can be significantly underestimated. Aftershocks also highlighted the difficulties in assigning the losses to individual events because loss adjusters may

not have assessed the property before the aftershock occurred or the first assessment was questioned and the reapportionment of losses was discussed, which contributed to further delays.

- **Business interruption:** Christchurch's central business district (CBD) was cordoned off by the authorities. This reduced business activity in the CBD and also slowed its reconstruction. This often led to business interruption claims in excess of the full limit.
- **Government involvement:** The government became highly involved because of the size of the loss and the extreme circumstances that ensued. It appointed a minister of recovery, limited the access to the CBD, issued demolition orders, increased building codes and designated red zone areas. These actions were decided with the best interest of the civil population in mind. However, they increased reconstruction costs at the same time. In addition, the increased number of stakeholders in the settlement process created additional challenges for the claims accessors. It also highlighted that open communication and public relations are of utmost importance.
- **Policy wording:** Policy wording was such that full replacement value policies were issued. This meant that the damaged property had to be restated "as new". In case of heavy damages, this led to claims that could significantly exceed the value of the property. Risk models do generally model losses as not being able to exceed the replacement value of the property. However, this occurred, for example, when it was necessary to rebuild with stronger foundations.
- **Multiple policies:** Many residential properties were insured by more than just one policy. The Earthquake Commission (EQC) of New Zealand covers almost all residential properties. Homeowners can top-up with additional insurance from private insurance companies. Unfortunately, these policies were not well aligned in terms of coverage. For instance, EQC also provided coverage for land damage, while the private insurers did not. This misalignment created debates, delayed the claims process and finally increased costs.
- **Foreign exchange rate:** The New Zealand Dollar appreciated in value during the settlement process, which led to a 14% increase of losses in US dollar terms.

3.3 The potential impact of a major earthquake in Istanbul

Sulzer and Schönholzer (2016) investigated which difficulties the insurance industry would face if a very strong earthquake struck Istanbul. Because of Istanbul's importance for Turkey, a 100 year loss could wipe out 10% of Turkey's GDP in seconds. A Mw 7.5 scenario (Erdik, 2003) is estimated to generate economic losses in the range of USD 90-120 billion, of which only USD 25-30 billion will be insured. In the following, we list the loss contributors, which would contribute most to this estimate (Sulzer and Schönholzer, 2016):

- **Number of available experts:** The Turkish Catastrophe Insurance Pool (TCIP) alone has 1.7 million policies registered in Istanbul. This could mean that hundreds of thousands of properties would need to be assessed within weeks. Furthermore, policies with additional coverage from private insurance companies would need to be assessed twice, which clearly highlights the potential of a coordinated claims process. It is estimated that 2000 loss adjusters would be needed in case of a large Istanbul earthquake. Even if such a high number of adjusters were present, they would still need to process 40 claims per day, which could lead to a significant number of claims challenges. Bringing loss adjusters to Christchurch was challenging because of its remote location. This might be different in Istanbul; nonetheless, the language barrier will add to the difficulty of having enough adjustors with local expert knowledge.
- **Interaction of multiple policies:** TCIP provides cover to homeowners. On top of this, homeowners can buy additional coverage from private insurance companies. Compared to New Zealand, the TCIP coverage is limited and does not provide full replacement value. This will likely make the claims process leaner from this perspective. However, claims settlement can be improved by coordinating the claims process and aligning insurance policy wordings.
- **Aftershocks:** also followed the 1999 Mw 7.4 Kocaeli and the 1999 Mw 7.2 Ducze earthquakes. This means, aftershocks will likely occur as well for the scenario considered. In order to separate the loss contributions best, visits from loss adjustors would be required between the events. The earthquake event definition in Turkey is usually defined by a very short 72 hour time period. This will add

uncertainty to the assessment of losses per event.

- **Liquefaction:** Liquefaction might also occur in Istanbul locally. However, due to the geological setting, liquefaction is not expected to be as significant as it was for the Canterbury quakes in New Zealand.
- **Government involvement:** It is very likely that in such a scenario, the Government will act in the interest of the population and search for stable conditions in an extreme event. Actions could include implementation of new building code requirements after structural deficiencies were identified or designation of red zone areas. These actions will lead to a more resilient city; however, it will also increase rebuilding costs.
- **Foreign exchange risk:** In the Istanbul scenario, there is foreign exchange risk for the insurance companies that have the underlying risk nominated in Turkish Lira, but use a different currency for financial reporting.
- **Reinsurance coverage:** Sulzer & Schönholzer (2016) show that international insurers shield themselves with more reinsurance coverage compared to their local competitors. A key driver of this development is the increasing awareness of tail risks and model uncertainty after recent events worldwide. The authors also show that as a result of this, 40% of the insurance companies would exhaust their reinsurance coverage in case of a large earthquake near Istanbul, thereby increasing insolvency risks.

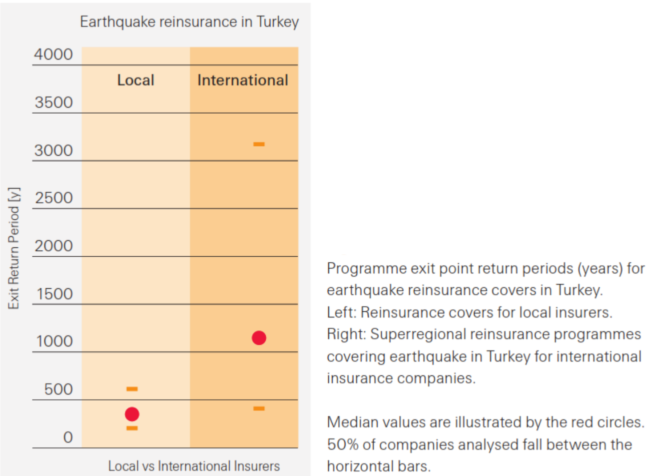

Figure 2. Exit point return period of reinsurance coverage from Sulzer & Schönholzer (2016).

The insurance industry advocates proactive preparation for the next major quake and initiated discussions about it in the Turkish market. Subsequent actions were taken on the way to a better preparedness for big events. However, further steps are needed. Careful consideration of tail risks where the large uncertainty lies can lead to better preparedness and therefore better risk assessment and better assessment of the residual risk.

4. PROTECTION GAP

4.1 Nat cat protection gap

Based on its fundamental role of risk pooling and sharing, insurance is a well-tested mechanism for coping with the financial losses resulting from adverse events by spreading them through a broader community. By limiting the financial burden of severe disasters, insurance allows individuals, businesses and the overall economy to recover faster from the fallout of a disaster. In doing so, insurance helps improve the resilience of societies. Nevertheless, big protection gaps continue to exist. Property insurance mainly encompasses coverage for buildings and their content such as furniture and machinery. It typically includes fire insurance, which provides protection against losses from fire, lightning and explosion. Additional perils usually covered include wind damage, theft, vandalism and non-flood water damage. However, natural risks such as flood or earthquake/tsunami are not always included in the standard homeowner/fire insurance policy. Generally speaking earthquake coverage is available as an optional rider, but in many countries is rarely purchased. In fact, earthquake insurance coverage penetration is still quite low, even in some advanced countries that are highly exposed to seismic hazard, and where the insurance market is mature. Yet among all the natural disasters, earthquakes are potentially the most destructive, both in terms of loss of life and property damage, which results in substantial protection gaps. Nat Cat protection gap is defined as the uninsured portion of financial losses resulting from disastrous events, meaning the difference between total economic and insured losses. Swiss Re Institute's *sigma* data show economic losses from earthquakes averaged about USD 56 billion each year in the last decade, with 84% of that uninsured (Swiss Re *sigma* disaster database, last accessed in December 2017). Many countries are exposed to major losses in the case of an intense earthquake. Yet, very few have a private insurance scheme in place.

4.2. Examples of the protection gap around the world

In eastern Canada, 70% of the population lives in high seismic risk regions and three of the biggest cities in Canada – Montreal, Ottawa and Quebec City – are all located in the most earthquake-prone regions of the east (Lamontagne and Flynn, 2016). Yet, awareness of the seismic risk is low and so is the earthquake insurance take-up rate, for the purpose of this paper defined as the percentage of buildings carrying earthquake insurance coverage. A repeat of the 1663 earthquake in the Charlevoix seismic zone in Quebec, a Mw 7.3 earthquake, could produce total damage to residential property in the seismic zone of CAD 10.6 billion. There is a 25% probability that the losses could exceed CAD 14.4 billion, on the basis of an estimated Quebec province-wide residential building stock portfolio currently valued at CAD 1 210 billion (Bevere et al., 2017). A repeat today of the Mw 5.8 earthquake that occurred very close to the city of Montreal in 1732 would lead to even higher losses, estimated at CAD 45 billion.

Such quakes near city centers are less likely, however, they have happened in the past and the Canterbury earthquake in New Zealand clearly illustrates the severe consequences that such moderate earthquakes can have. A more comprehensive approach would be to also account for damage to commercial, cultural and heritage property, infrastructure and indirect losses. According to the industry's estimates, with all these variables, the total economic loss from the earthquake could reach close to 8% of Quebec’s GDP, or CAD 30 billion, making it the costliest natural catastrophe event ever in Canada (Air Worldwide, 2013). However, only CAD 0.48 billion, or just 4.6% of the economic losses, would be insured, leaving around CAD 10 billion of the residential damages uninsured (based on estimated residential building stock insured for earthquake risk Quebec-wide of CAD 40.7 billion, or 3.4% of the total residential property value).

Italy, a country with multiple seismic sources and a vulnerable building stock whose majority predates any form of seismic provisions, is home to the most damaging and deadliest earthquakes in Europe. Probabilistic models show that a Mw 6.5 earthquake near Parma (central Italy) or a Mw 7.0 earthquake in Campania (southern Italy) would inflict losses of EUR 53 billion to residential property alone (based on a countrywide residential building stock portfolio with reconstruction value of EUR 5,144 billion (Bevere, 2015). Of the EUR 53 billion in economic losses, only EUR 1.13 billion (or 2.1%) would be insured in the case of the Parma scenario, and an even lower share (0.94%) of that loss would be insured in the case of the Campania scenario, reflecting different earthquake insurance take-up rates in the different regions of the country (Bevere, 2015).

Italy is, in fact, the European country with the biggest earthquake protection gap in seismic risk. Awareness of the risk is not low, as major loss events struck the country with a high frequency in recent years. However, the popular perception and inflated expectations are that in the event of a disaster, the government will provide full relief efforts including residential building restoration. That the Italian state has not held back on spending and in many cases has overspent on emergency response and reconstruction programs has led to the expectation that the government will always step in as the insurer of last resort. This has reduced the incentive for individuals to personally manage disaster risk. However, in a country with high public debt and economic stagnation, the scope for ex-post state financing for reconstruction is restricted. Hence, this reliance on public financial relief may be increasingly misplaced.

The 1356 Basel earthquake was by far the strongest earthquake both in Switzerland and north of the Alps and the Swiss Seismological Survey estimates its recurrence between 1,000-2,000 years (Giardini et al., 2004). A similar event today could trigger losses as high as CHF 120 billion, while a Mw 6.2 earthquake in central Switzerland is more likely to occur and would inflict a loss of CHF 17.6 billion in residential property alone, only CHF 1.5 billion of which would be insured (Schmale et al., 2016). In Switzerland, 53% of the residential buildings were built before the first earthquake provision came into force, hence most of the existing building structures predate the current building codes.

In Table 1 below, insurance penetration, defined as insurance premiums as percentage of national GDP, is compared for selected countries with high seismic risk. Many factors influence insurance penetration. For example, penetration depends on earthquake hazard, risk perception, state involvement and insurance conditions (e.g., high versus low deductibles and limits). The structure of the economy also has an impact. Generally speaking, physical-investment intensive economies tend to have higher insurance penetration, as opposed to service-based economies, which have less physical assets to protect. Therefore, the numbers in this table are not fully comparable. However, they provide an indication of the role insurance would play in financing the post-seism reconstruction.

Table 1. Earthquake insurance penetration in earthquake-prone selected countries in 2014, as % of GDP

	Non-Life premiums	**Property**	**Commercial property**	**Residential property**	**Commercial earthquake**	**Residential earthquake**
Chile	1.75%	0.53%	0.48%	0.05%	0.28%	0.03%
New Zealand	5.15%	1.30%	0.85%	0.44%	0.22%	0.15%
California	2.90%	0.71%	0.32%	0.39%	0.02%	0.04%
Mexico	0.84%	0.14%	0.11%	0.02%	0.06%	0.01%
Japan	2.44%	0.37%	0.16%	0.20%	0.02%	0.05%
Turkey	1.27%	0.23%	0.15%	0.08%	0.03%	0.04%
Italy	2.30%	0.36%	0.17%	0.19%	0.07%	0.01%

Source: Swiss Re Institute

Insurance penetration varies considerably among regions with high seismic risk. For example, earthquake insurance penetration for commercial property is highest in Chile and New Zealand and considerably lower in Japan, California, Mexico and Turkey. For residential property, earthquake insurance penetration is highest in New Zealand again, and very low in other high-risk countries such as Mexico and Italy. In Chile, the third largest insurance market in Latin America, a favorable regulatory environment has helped boost participation by international insurers. Private insurance is now a key component of private seismic risk management, particularly for commercial property. In New Zealand, a mandatory government program is applied to every residential fire policy written by private insurance companies. The combination of private and public insurance makes a substantial contribution towards financing losses due to major earthquakes. On the other hand, California's current level of earthquake insurance penetration is deemed insufficient for a region with high seismic risk, high accumulation of property value and high economic activity. Equally earthquake-prone Japan, lying in one of the most seismically active regions of the globe, has a low level of insurance penetration for commercial property. Devastating earthquakes are rarer and more geographically concentrated than weather-related events. As such they could be insured for less per year. The unfortunate reality is that a large majority of these losses would be uninsured, thus leaving the responsibility to shoulder their cost to the societies at large. Insurance plays a key role within an *ex ante* risk management framework, one that can lower the overall cost of earthquakes over the long term by pricing risk correctly.

5. CONCLUSIONS

Building codes establish minimum requirements for buildings to withstand the effects of natural hazards providing then a baseline level of risk reduction. However, even constructing buildings to the highest standards does not guarantee that property damage will not occur. Insurance represents a solution to minimize financial exposure to residual risk complementing mitigation measures in order to reduce the financial burden of a catastrophic loss. This facilitates the recovery process and reduces the financial stress on the homeowners. Insurance premiums represent the market cost of the transferred risk. Since the market value reflects the vulnerability of the specific property to the natural event causing the loss, this can be an incentive to mitigate further the risk. In fact, lower vulnerability means a lower premium will be charged. Consequently, insurance can also play the role of incentivizing mitigation measures, in addition to the risk mutualization mechanism, e.g. requiring a specific level of mitigation measure as a condition of providing insurance coverage.

Over the past 30 years, the (re)insurance industry has developed sophisticated catastrophe models to assess natural hazard risk and manage it by defining proper premiums. Despite this, many limitations and inherent uncertainties exists. Risk models only provide an oversimplified picture of a very complex reality. These models also have to quantify risk of tail events that by definition are very rare and where little to no empirical information is available that would help to quantify them. Hence, the inherent uncertainties involved with their assessment are large. Events like the 2010-2011 Christchurch earthquake sequence and the 2011 Tohoku earthquake have highlighted various aspects of tail risk. On top of this complexity, additional factors, commonly called post loss amplification in the insurance industry, can increase losses and thereby the cost of insurance coverage. Furthermore, secondary perils, such as liquefaction or tsunami risk, can increase the residual risk if they are not accounted for in risk assessment or structural design. Understanding the parameters driving the risk of large losses can help establish resilient (re)insurance programs. This has been especially true in recent years when regulators have become increasingly worried about balance sheet protection and capital adequacy. As a result of residual risk and low risk awareness, big protection gaps exist. In the case of earthquakes, the uninsured portion of potential financial losses has been estimated at USD 47 billion each year. Many countries are exposed to earthquakes, but very few have a private insurance scheme in place, even in some advanced countries that are highly exposed to seismic hazard, and where the insurance markets are mature.

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