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DESIGNING OPTIMAL RISK MITIGATION AND RISK TRANSFER MECHANISMS TO IMPROVE THE MANAGEMENT OF EARTHQUAKE RISK IN CHILE

By Robert Muir-Wood



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Abstract/Résumé

DESIGNING OPTIMAL RISK MITIGATION AND RISK TRANSFER MECHANISMS TO IMPROVE THE MANAGEMENT OF EARTHQUAKE RISK IN CHILE

Abstract: The property losses from the Feb 27th 2010 Maule earthquake are assessed as \$18.1Bn paid for 38% by insurers, 47% by the Government of Chile and 15% by individuals and businesses. Including \$4Bn damage to infrastructure and the costs of lost economic activity the total loss in 2010 values is estimated to have been close to \$28Bn. The report considers policy options for expanding the proportion of future Chilean earthquake losses that would be covered via new and expanded risk transfer mechanisms: for low income homeowners, small commercial enterprises and government buildings. Consideration is also given to how the overall levels of earthquake risk in Chile could be reduced through targeted efforts at risk mitigation. Recommendations are made for how the insurance industry and government in Chile should expand the use of probabilistic catastrophe loss models for defining and pricing risk management options.

JEL codes: H54, H12, G22, C63

Keywords: Risk Mitigation; Risk financing, Catastrophe model, Microinsurance, catastrophe insurance, Catastrophe risk securitization

CONCEVOIR LES MEILLEURS MÉCANISMES POSSIBLES D'ATTÉNUATION ET DE TRANSFERT DES RISQUES POUR AMÉLIORER LA GESTION DU RISQUE SISMIQUE AU CHILI

Résumé: Les sinistres immobiliers causés par le tremblement de terre qui a frappé, le 27 février 2010, la ville de Maule au Chili sont évalués à 18.1 milliards USD, pris en charge à hauteur de 38 % par les assureurs, de 47 % par l'État chilien et de 15 % par les particuliers et les entreprises. Si l'on y ajoute les 4 milliards USD de dommages aux infrastructures et les coûts liés à la perte d'activité économique, on estime que le montant total du sinistre avoisinait, en 2010, 28 milliards USD. Le rapport analyse les solutions permettant aux pouvoirs publics chiliens d'augmenter la proportion des futurs sinistres sismiques qui pourrait être couverte par des mécanismes nouveaux et renforcés de transfert des risques, applicables aussi bien aux propriétaires de logement à faible revenu, aux petites entreprises commerciales et aux bâtiments publics. Il étudie en outre comment le Chili pourrait réduire son risque sismique global en ciblant ses efforts d'atténuation des risques. Le rapport contient par ailleurs des recommandations sur le fait que le secteur de l'assurance et les pouvoirs publics chiliens devraient davantage utiliser des modèles probabilistes de sinistre catastrophique pour définir et déterminer le coût des différentes solutions de gestion des risques.

Codes JEL : H54, H12, G22, C63

Mots clés : Réduction des risques, Financement des risques, Modélisation du risque catastrophique, Micro-assurance, Assurance de risques catastrophiques, titrisation des risques catastrophiques

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By Robert Muir-Wood*

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EXECUTIVE SUMMARY

The first section of this report considers the direct and indirect losses from the Feb 27th 2010 earthquake, relating to immediate relief costs, long term reconstruction and indirect economic impacts. The total damage to property is identified to be \$15.6Bn (in 2010 values), paid for 40% by insurers, 50% by the Government of Chile and 10% by individuals and businesses. Including \$4Bn damage to infrastructure and economic costs the total loss in 2010 values is estimated to have been close to \$25Bn, with \$1.5-1.8Bn of the c \$5Bn economic disruption refunded by business interruption insurance coverages.

The second section concerns the need to give the insurance market in Chile a stronger technical foundation in how it prices risks and manages solvency through the use of probabilistic catastrophe loss models. There is a need to expand insurance and other risk transfer options in Chile to sectors that are currently significantly underinsured, and in particular: a) lower income homeowners without mortgages, b) small commercial enterprises and c) government and state owned buildings – in particular in the Health and Education sectors as well as public water supply agencies. This report considers policy options for the Chilean Government to expand insurance into these sectors, including establishing a new earthquake microinsurance system for poor homeowners as well as creating a new risk pooling system for earthquake damage to government property. Appendix (A) explores how an appropriately managed network of earthquake strong motion instruments can facilitate new forms of earthquake risk transfer.

The third section of the report explores how to drive a long term reduction in earthquake catastrophe impacts and costs in Chile. This national perspective on catastrophe risk needs to be developed using a probabilistic catastrophe analysis model framework, covering both earthquake and tsunami, run against the total building stock of Chile and including not only potential damage to property (and disruption to economic activity), but also human exposure and loss of life. Using catastrophe loss models, optimum benefit costs of alternative risk reduction activities should be explored. Three key areas of risk concentration and hence opportunities for focused risk reduction are: a) the replacement, or retrofitting, of 'legacy buildings' built prior to modern building codes, b) the development and enforcement of planning zonations to prevent people living in high risk tsunami zones, and c) enhancements to the building code to look beyond life safety to an increased focus on reductions in damage costs. Progress on long term earthquake risk reduction in Chile should be independently monitored and publicized.

(Throughout this report, to assist in providing an international context, costs are listed in US\$. Government expenditure in Chile is however quoted in UF - Unidad de Fomento: a unit designed to maintain constant value, requiring continuous adjustment in exchange relative to the Chilean peso to take account of inflation. The UF to \$ conversion rate used in this report is that which applied on Feb 26th 2010 when 1UF = 39.8797 (rounded to US\$40). However as of April 2011, appreciation of the Chilean peso relative to the US\$ means that 1 UF unit = US\$46. This would require the conversion of Chilean government expenditures to \$US quoted in this report to be raised by 15% (although some costs, such as international reinsurance recoveries, have already been paid in 2010 \$ values).

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I would like to acknowledge thanks to the IPCC and in particular Ms Cecile Vignial, for arranging OECD support for a mission to Chile in January 2011 to interview many of those involved in the government and private sector response to the 2010 Feb 27th earthquake. In particular I would like to thank the following for their time and assistance in Santiago: Cristobal Gigoux L. Advisor, Ministry of Finance of Chile; Claudio Soto, Chief Macroeconomic Analysis, Banco Central de Chile; Ignacio Briones Rojas, Coordinador de Finanzas Internacionales, Ministerio de Hacienda; David Duarte Arancibia, Jefe Unidad de Pasivos Contingentes y Concesiones Division Finanzas Publicas, Dirección de Presupuestos, Ministerio de Hacienda; Sonia Adriasola Ovando, Jefa Programacion Financiera, Dirección de Presupuestos, Ministerio de Hacienda; Jose Pablo Gomez Meza, Jefe Division Finanzas Publicas, Jefe Division Finanzas Publicas; Eduardo Contreras Darvas, Ingeniero Civil Jefe Division Tecnica de Estudio y Fomento Habitacional, Ministerio de Vivienda y Urbanismo ; Daniel Johnson Rodriguez, Jefe Division Finanzas, Ministerio de Vivienda y Urbanismo Jorge Tornquist Miranda, Jefe Division de Presupuesto, ONEMI; Alejandro Burr Ortuzar, Sub Director of Studies S.I.I., Servicio de Impuestos Internos; Osvaldo Macias Munoz, Intendente de Seguros; Jorge Mastrangelo, Division Control Financiero Seguros ; Fernando Coloma Correa, Superintendente; Patricio Espinoza, Head of Regulation Department from the Superintendencia Valores Y Seguros; Jorge Claude, Gerente General, Asociacion de Aseguradores De Chile A.G.; Victor Manuel Jarpa Riveros (President), Ignacio Barriga Ugarte (CEO), & Juan Ignacio Alvarez Troncoso (VP of Indemnification of RSA Chile; Egle Pulgar J. & Aaron Martinez M. of the Chilena Consolidada (Zurich) insurance company; Marcela Silva G. & Andres Sanfuentes A. of Philippi Yrarrazaval Pulido & Brunner law firm; Patricio Bustamante Navarro & Ricardo Peralta L. from Viollier & Asociados, Claims Assessors.

This report should also be read in conjunction with a parallel report written by Dr Alberto Monti who participated in the meetings in Santiago in January 2011, and whose report 'Policy Framework for the Improvement of Financial Management Strategies to Cope with Large Scale Catastrophes in Chile', goes into significant details around the policy options and legal issues to extend risk transfer in Chile (the subject of Section 2 of this report). The Appendix A section in this report on new forms of parametric catastrophe risk securitization structures should also be read in conjunction with the analysis of the Mexican experience of designing a trigger structures for a catastrophe risk securitization transaction in a parallel OECD (and World Bank) sponsored report by Michel-Kerjan, Zelenko I, Cardenas V and Turgel D. (2011) Catastrophe Financing for Governments, learning from the 2009-2012 Multicat program in Mexico.

SECTION 1

THE ALLOCATION OF COSTS OF THE FEB 27TH 2010 EARTHQUAKE

1.1 Costs of Rescue and relief

1.1.1 As paid by the government of Chile

Immediately following the Feb 27th earthquake rescue and relief activities were set in motion, in particular in the coastal towns directly impacted by the tsunami as well as in the towns and cities worst affected by the earthquake shaking. 800,000 people were identified as homeless after the earthquake. Over the first 2-3 months the costs for rescue and relief provided by the Government of Chile were identified to be \$200M (5M UF). The money to support these activities was found within emergency contingency funds held by the Ministry of Finance. Of these costs around \$100M (2.5M UF) were channeled through ONEMI – the Office of National Emergencies. Since May 2010 costs of continued temporary housing and subsidies have been captured under the budget for the Ministry of Housing that also includes the costs of subsidies provided to homeowners whose houses were damaged or destroyed in the earthquake.

1.1.2 Paid by other parties

A wide range of foreign governments, international relief agencies, private companies as well as individuals, made offers of support for relief efforts after the earthquake. Many contributions were made in the form of food, materials or equipment. Among the larger contributions there was \$2 million of emergency materials from China, 3M Euros from Europe, \$10M from Anglo American intended for housing and schools, 1800 tons of food from Argentina and a contribution of \$1M from Wal-Mart stores. Within a week of the earthquake a Chilean television telethon raised 30.2 billion pesos (about US\$58 million). The total value of all relief from non-government sources is likely to have been around \$100M.

1.2 Costs for repairs or replacement of damaged buildings and infrastructure

1.2.1 As paid by the government of Chile

A total of 370,000 houses were assessed as damaged in the earthquake out of a total of a little more than 4 million houses in Chile (representing 9% of the total). The cost of this damage was borne by: insurers (as they paid claims), the government (as it paid subsidies to individual homeowners), individuals as they covered that part of their losses that were neither covered by insurance or subsidies, and business owners in funding what was not insured.

1.2.2 Damage to houses paid by insurers

There are an estimated 4.06 million houses in Chile of which 964,000 (representing 23.8% of the total) are insured. Insurance penetration is highest in the Santiago Metropolitan region (at 31.5%) but is less than half this in the Bio Bio region (including the city of Concepcion), where only 15.6% of houses are insured. Insurers made claims payments to 125,000 homeowners. Beyond this number approximately 22,500 homeowners were considered to have claims for earthquake damage less than the 1% (or \$1000) deductible. The total cost of residential insurance payments, as of Dec 31st 2010 was \$2.78Bn.

The total number (147,500) of paid insurance claims and claims for damage below the deductible reflects 40% of the total number of houses assessed as 'damaged' in government statistics (370,000). This percentage is almost 70% higher than the national rate of insurance penetration. While one could hypothesize that insured buildings proved susceptible to damage, and that the proportion insured was overall higher than the national average in the regions impacted by the earthquake the reason for this difference is also likely to be that insurance claims included many properties with minor 'cosmetic' damage too low to be counted in the national survey of damaged properties. Excluding claims below the 1% deductible the proportion of insurance claims to total damaged properties falls to 34%. However up to an additional 140,000 properties with light levels of damage (less than 5% of the value?) would need to be added to the national total to reconcile the insurance penetration rates. This implies that there is a hidden tail of low level property damage to lower income homes not being recorded in these figures. According to this estimate therefore the total number of properties with both minor and significant earthquake damage was 510,000.

1.2.3 Damage to houses as compensated by the government of Chile

In April 2010 the Ministry of Housing established a system of subsidies for the lowest three quintiles (ie 60%) of the population of homeowners whose properties were considered to have been '*damaged*' in the earthquake. (As described in section 1.2.2 it appears that the definition of 'damage' employed by the Ministry of Housing may not be consistent with that defined from insurance claims.) In the additional budget of April 2010 \$2.5Bn (62.5M UF) was assigned to the Ministry of Housing to replace and repair houses in a program intended to run from 2010-2014. This program includes costs for temporary accommodation as well as two levels of subsidies provided to homeowners according to whether a property was deemed to be 'damaged' or 'destroyed'. At the initiation of this program the ratio of 'repair' to 'rebuild' was expected to be 60:40 but has in fact become closer to 50:50. (In the April 16th 2010 Emergency Budget the costs were broken down as 67.5% for rebuilding and 32.5% for the repair of damaged houses.)

The typical individual subsidies made for 'repair' were 60UF = \$2400, while grants were made for 400UF = \$16000 for a complete rebuild. In situations where the owner wished to reconstruct a property on the original site, a subsidy of 475UF = \$19000 was being made – as applied in particular to adobe houses in towns. (For the 222,500 properties covered by the subsidies, within the \$2.5 Bn budget, the average subsidy per property was equivalent to 275UF = \$11,000.) Prior to making the grant the owner had to show they were the sole owner and this was their only property at which they lived before the earthquake. The full address of each damage and subsidized property has also been recorded.

1.2.4 Residential damages as paid by property owners

For a damaged property with earthquake insurance the homeowner had to bear the costs of the deductible, losses over the insured limit (if that was less than the value of the property) and for any items not included in the insurance coverage. The total costs of the self funded deductible can be estimated to have been c. \$150M.

Those in receipt of subsidies, had, on average, to bear a greater proportion of their true repair costs. As already mentioned, based on known insurance penetration rates, there seem likely to be a 'hidden' 140,000 homeowners without insurance, whose properties suffered some low level damage but not enough to be counted as 'damaged' in the national survey, and therefore to merit a payment from the government. If the average damage cost to this sector is assessed to have been \$1000, then the total losses to homeowners who missed out on subsidies because damage to their property was too slight, would add up to \$140M. (This estimate has a high degree of uncertainty.)

For ‘partially damaged’ properties in many cases the subsidy would not have covered the full costs of damage. Again one can estimate that if half of the uninsured homeowners who received the partial subsidy of \$2600 were underpaid by \$2000 on average that would add up to \$220M of additional unsubsidized repair costs. (Again this figure has a high degree of uncertainty.)

Also many of those who received a full subsidy for the total loss of their house, may have been paid less than the property’s true rebuild cost.

Then there is the sector of the 16% of middle income homeowners who lie between the 60% of low income homeowners covered by subsidies and the 24% with insurance. Assuming that the property damages to this section of the market were midway between the average values compensated by insurance and the average values compensated by the subsidies, the total cost of these uninsured and uncompensated losses is calculated to be \$1250M. Conservatively, therefore, one can estimate a total \$1750M of damages were left to be paid by homeowners. This would explain part of the significant expansion of the numbers of people assessed as being in poverty after the earthquake (see section 1.5). The biggest share of these personal costs was carried by those of middle incomes but without mortgages (and hence insurance).

1.3 Damages to commercial/industrial properties

Among the small commercial business owners an estimated 30% had earthquake insurance while this rises to greater than 75% for large commercial and industrial facilities.

Policies for the highest value commercial/industrial facilities are commonly written outside Chile within facultative reinsurance. A survey of the largest facultative reinsurance losses in Chile, prepared by Aon Benfield a couple of months after the earthquake, provides estimated insured losses for the top 16 policies worst impacted. The highest loss in this list is assessed as \$400-600M for the Grupo Arauco pulp producer, of which 35% is related to property damage. The lowest loss in this list is an insurance claim for \$40M. Based on those risks where the direct property and business interruption losses have been split, and making some simple assumptions about the relative proportion of property to business interruption losses in this list, the high value commercial industrial facultative property losses are assessed to sum to \$1330M.

High value commercial and industrial business was also written directly in Chile. There were 2840 claims for commercial risks with a value in excess of \$50M (UF 1.25M), which generated a loss of \$1422M, of which (again based on those risks where the proportionality of damage to BI loss is known) \$900-1100M are estimated to reflect property damage. Commercial business beneath the \$50M insured limit, included 29,000 claims for an estimated \$1355M in payments of which \$1050-1200M are estimated to be property damage related. This means the total property related commercial and industrial claims payments were in the range \$3280-3630M.

1.3.1 Damages paid by business owners

In the small commercial area, 70% of businesses had no insurance cover (AonBenfield, 2010). While the insurance take up is likely to have been greater for the higher value businesses, the uninsured property related losses (covering lost goods and damaged properties) could have been as high as \$500M in this sector.

The deductible for commercial is typically 2% of value. Therefore across all business owners with a significant insurance loss, a significant proportion of the costs were not recoverable from insurance. If the average loss ratio for this sector was 15% of values, then approximately \$500m of deductibles were paid by business owners.

1.3.2 Damage to government buildings

In the April 16th 2010 emergency budget the total damage to public buildings and infrastructure was assessed as US\$10.6B (251.5M UF). After taking into consideration what would be recovered through insurance (\$1300M) the total cost was estimated to be US \$ 8431M spread over four years. This included the costs to repair and rebuild 56 hospitals and 4500 schools. However this total sum includes the subsidies being made to homeowners and the actual budgets for rebuilding schools (US\$1500M (37.5M UF)), hospitals and the health sector (US \$2100M = 52.5M UF) as well as infrastructure and public works (US \$1200M = 30M UF). Together the program of payments to repair and rebuild damage to Government property adds up to \$4800M (120 UF).

It is likely that local budgets will be needed to support the reconstruction or repair of government buildings themselves. It was observed that some key government buildings in Santiago were significantly (but largely superficially) cracked but were being cosmetically repaired.

The government has also developed a system of tax relief to encourage the donation of funds to support the repair of historical 'patrimonio' buildings.

1.3.3 Total costs of damage to buildings and infrastructure

In adding up all the sums identified for the costs for repairing damage to buildings and infrastructure, the total value is assessed at \$18.1Bn. Of this total 38% was paid by insurers, 47% was paid by the Government and 15% was paid by property and business owners (see Fig 1). The Chilean Government's published estimate, consistent with these figures, was that there was \$16Bn of property damage from the earthquake with an additional \$4Bn of infrastructure damage costs.

Table 1: Allocation of total \$18.1Bn property repair costs

	Houses	Commercial	Public Sector
Insurers	\$2800M	\$4100M	
Government	\$2500M		\$6050M
Personal	\$1750M estd.	\$1000M estd.	

1.4 Lost Business/Economic activity

1.4.1 Direct losses

The earthquake affected a region comprising 30-40% of national manufacturing capacity in Chile. Almost all commercial activity was suspended in this area for a few days and while most industries were able to restart production, some major industries, in particular relating to pulp paper production, wine making and oil refining had no, or significantly reduced, commercial activity for months. As one example the total loss due to the earthquake for ENAP (the owner of the Bio Bio Refinery) was initially assessed as US\$154MM. As of Sept 30th 2010 ENAP has was claiming US\$86,1MM from its insurance carriers: - US\$30,9MM for Business Interruption and US\$55,2 for physical damage.)

http://www.enap.cl/investor_relations/doc/presentaciones/ENAP_3Q_2010_Results.pdf

The share of business interruption losses in the list of the top facultative losses in the earthquake sums to \$1150M (AonBenfield, 2010). Among high value (greater than UF 1.25M = \$50M)insured value commercial policies written in Chile an estimated 20-30% (\$300-500M) is assessed as related to business interruption. Commercial business beneath the \$50M insured limit, included 29,000 claims of which 10-20% \$135-270M are assessed as relating to business interruption.

Adding these estimates the total insurance payments for business interruption are likely to amount to \$1500-\$1800M approximately 20% of the total insurance payments.

The total decline in national economic activity measured by the Bank of Chile in March 2010 was assessed at 5%. Given a total annual 2009-2010 GDP of \$204Bn this would represent a reduction of \$850m in economic activity for the month. An interruption in economic activity also continued over the next three months with the Bank assessing the economy had returned to where it was before the earthquake by July. If one assumes a linear recovery to the end of June the total cost of interrupted economic activity is likely to be in the range of \$2.5-3Bn. It therefore appears that 50-60% of this reduced economic activity was covered by insurance.

1.4.2 As paid by workers and business owners

In terms of who else paid for the reduction in economic activity a significant amount of the uninsured costs for small business owners were not repaid by insurance. Increase in poverty in the Concepcion area reflects that many small businesses may have been forced to close after the earthquake (Ministerio de Planificación Jan 2011). While the government had a subsidy program for low income homeowners it did not have a comparable system in place for small businesses that had chosen not to purchase insurance.

1.4.3 In the form of reduced tax receipts

Reduced economic activity associated with interrupted businesses and increased unemployment reduced government tax receipts. Property owners whose houses were damaged were also excused paying property taxes. However within a few months economic activity generated by the reconstruction was itself likely to be bringing additional tax receipts. It has not proved possible to quantify this impact on government revenues. However it is understood that the majority of government revenues come from major companies in Chile, and that as many of these major companies would have been fully insured, the impact on the profitability and hence the government's tax take may not have been significant. By summer 2010 the economic activity generated by the earthquake appears to have compensated for the reduction in economic activity immediately after the earthquake.

1.4.4 Additional costs from losses in infrastructure

No estimates are available of business costs associated with damage to infrastructure – in particular from the need to find alternative transport routes, employ alternative port facilities, use alternative electricity supplies etc. However these costs are not considered to be very appreciable.

1.4.5 Reductions in revenues from tourism

In early 2011 Gabriel Gonzalez, president of the Viña del Mar Tourism Chamber, commented that in his region there were between 5% and 10% lower revenues in comparison to the previous year with “ *the concern regarding the Tsunami/Earthquake.*” being a key factor along with fluctuations in the dollar.

<http://www.ilovechile.cl/2011/02/23/calls-for-measures-to-improve-tourist-numbers/17845>

In Feb 2011 the Chilean federation of Tourism Enterprises revealed that in 2010 tourism activity expanded 0.5%, from 2.750.000 to 2.754.000 tourists well below the historic average (and the South American growth of 10%). At the same time tourism revenue in Chile increased 5% compared to 2009. The percentage of Argentinians that crossed the Libertadores road to Chile during January 2011 decreased 20% in comparison to 2010. Big drops have also been seen in the number of North Americans and Europeans visiting Chile.

<http://en.mercopress.com/2011/02/21/weak-dollar-strong-peso-batters-chilean-tourism-industry>

It is not possible to separate out global economic factors from the impact of the earthquake. However the earthquake happened at the end of the summer season, and therefore had a lower impact than if it had occurred in October/November.

Tourism receipts were \$1.845Bn in 2010, up from \$1.707 in 2009 and \$1.757 in 2008. If the expected 7% growth estimates are appropriate, then lost tourism receipts may have accounted for up to \$100M of lost revenues.

<http://www.euromonitor.com/chile/country-factfile>

1.4.6 Business activity generated by the response to the earthquake

Within a few months the response to the earthquake had begun to generate significant economic activity. Even the number of overseas claims assessors in the country helped offset the reduction in tourist numbers in Concepcion. In particular the injection of \$8Bn of overseas reinsurance capital into the system compensated for lost productive capacity. The total GDP of Chile in 2010 was \$204Bn <http://si3.bcentral.cl/Siete/secure/cuadros/home.aspx> of which reinsurance recoverables reflected almost 4% of the total money entering the economy. While approximately \$1.5Bn of that amount directly substituted for reduced business activity, the additional \$6.5Bn was to fund economic activity around reconstruction.

A consequence of reduced potential output as a result of damaged productive capacity is inflationary pressure. However at the same time as marginal utility is higher, there should be an incentive to invest in new plant. The Bank of Chile produces a quarterly report on inflation, and while imports of steel, oil and machinery grew significantly in March and April 2010, if there was a macroeconomic impact it was very small. While there was a decline of economic activity of 5% identified in March 2010, in June and July 2010 there was a rebound, so that at the end of July 2010 the economy was at the level it was before the earthquake. By Jan 2011 it was said that 'it was not possible to show any long term economic impact of the earthquake'.

No price hikes were identified as a result of shortages of labour or reconstruction materials. There was clearly substitution of domestic consumption with imports, but given the very open economy it appears this did not lead to any inflation in repair costs. It was also said that, given the national significance of the earthquake, attempted price hikes would have been 'socially punished' in a 'mourning environment'.

1.5 Total economic impact

As a result of the earthquake, it was announced in January 2011, the poverty index increased by 3 percent (500,000 people) to reflect 19.4 percent of the total population – the level only last encountered in the year 2000 (Ministerio de Planificación Jan 2011). Poverty levels had reduced to 13.7% in 2006 but had already risen to 15.1% by 2009. At the same time, after the earthquake the ranks of people considered destitute rose by 80,000 to 700,000. This demonstrates that the economic impact of the earthquake has been most severely experienced by those on lowest incomes. The reduction in economic activity at the bottom of the pyramid has been severe. One example of a community from which people remain homeless and/or who have lost their livelihood – is that of fishermen from coastal communities who have lost their ports and boats – and who have been prevented from reconstructing their houses because the site has been red-zoned relative to the tsunami risk. Also those on lower incomes may be out of work as a result of the uninsured small commercial enterprises going out of business. Lost annual income associated with this increase in poverty could be equivalent to at least \$4000 per person, representing at least \$2Bn of money taken out of the lower levels of the economy.

The total 'economic' cost of the earthquake was put at \$30Bn in 2010 values by the Chilean government including \$10Bn of lost revenues. However the figure for lost economic activity independent

of damage to buildings and infrastructure looks to be too high. Even a 5% reduction in output for three months equates to only \$2.5Bn. The arrival of \$8Bn of reinsurance funds provided a significant boost to economic activity in the second half of the year that more than offset the remaining loss in productive activity. Loss of incomes and spending among the lowest income section of society in Chile looks likely to have removed \$1-2Bn from the economy. It seems difficult to identify how the total economic costs (not compensated by business interruption insurance) were more than \$5bn. Hence the total loss from the event (covering buildings, infrastructure and economic impacts) was likely to have been no higher than \$25Bn (in 2010 \$ values).

(However the reduction in the value of the US\$ relative to the official government currency the UF between Q2 2010 and Q2 2011 means that costs in Chile expressed in April 2011 \$US would rise by 15% - or almost \$4Bn - on a total of \$25Bn – making a total economic loss of \$29Bn. Because of this depreciation in the dollar, later reinsurance payments have been higher than expected in dollar terms and the insurance payments from the catastrophe are now estimated to reach US\$8.5Bn.)

SECTION 2

POLICY ISSUES AROUND THE EXPANSION OF EARTHQUAKE INSURANCE IN CHILE

2.1 Current earthquake insurance in Chile

Non Life insurance premiums in Chile were \$2.8Bn (Fitch, 2011) and grew by 11.5% in 2010.

2.1.1 Residential

Among residential mortgage holders in Chile, 100% take fire insurance, as required by the bank offering the mortgage. Based on the strong encouragement of the bank, 95% of these mortgagees agree to purchase an earthquake insurance extension. It is understood an additional tsunami extension is also provided.

However for house-owners without a mortgage the voluntary take-up of fire insurance is estimated to be only 20%. Only one quarter of these discretionary purchasers of insurance also buy the additional earthquake insurance. Among the small commercial business owners an estimated 30% had earthquake insurance while this rises to greater than 75% for large commercial and industrial facilities. (SVS, 2010)

The householder's earthquake extension is offered without Value Added Tax. However the tsunami extension is not VAT free. This leads to anomalies around whether VAT paid on repair costs can be deducted by the insurer.

For residential policies, deductibles are typically set at 1% of the Total insured value with a minimum of \$25UF (= \$1000 in 2010).

2.1.2 Commercial

One Commercial sector that is 100% insured against both fire and earthquake damage is that of the Public-Private Partnership schemes, known as 'Concessions' (Chadwick, 2008). Concessions have become widespread in Chile since the 1980s as used for funding toll-roads, major bridges, water companies, and even some hospitals. At least \$8Bn of Concessions are currently active and a similar value are being planned. PPP Concessions awarded by the Government require that comprehensive insurance is in place for both fire and earthquake, and there appears to be 100% compliance with this requirement.

For commercial and industrial business, deductibles are typically set at 2% of the TIV with a minimum of 50UF = \$2000 (in 2010 dollars).

2.1.3 Pricing earthquake insurance in Chile

The experience of the Feb 27th 2010 earthquake and the significant size of insured earthquake losses highlights questions about how insurers in Chile currently price earthquake risk and manage their earthquake accumulations, including determine how much reinsurance to buy. While questions about the appropriate cost of earthquake insurance and the 'probable maximum loss' for Chilean insurers were formerly considered from simple insurance yardsticks, today in other comparable OECD countries these questions are addressed using catastrophe loss models.

For catastrophe risk the actual experience of earthquake losses over the past few decades will be insufficient to determine either the underlying geography or cost of risk. While there may be a historical record of catastrophic earthquakes extending back several centuries these events cannot be known in sufficient detail to determine their impact at every location. Also not every possible earthquake will have occurred over this period. Therefore it becomes necessary to consider risk from a probabilistic perspective, in which a very wide range of potential earthquakes are considered according to their respective probabilities. The risk cost that determines the earthquake insurance premium should be adequate to reconstitute all those future losses expected to be incurred according to their probabilities.

Currently the earthquake insurance extension offered in Chile has employed a uniform flat rated premium, charged as a % of rebuild cost, at least for residential properties. This reflects the fact that catastrophe loss models and their risk cost outputs have not been widely adopted in Chile.

While some earthquake insurance systems (such as those in Taiwan and New Zealand) are flat-rated and designed to mutualize losses across the community, where risk is known to vary significantly by geography and building type it is also appropriate that premiums should reflect risk. Risk-based premiums facilitate the use of financial incentives to encourage actions taken by the property owner to reduce risk, such as retrofitting an unreinforced masonry building or tying a wooden house onto its foundations.

Box on Catastrophe loss models



Catastrophe loss models comprise a series of five modules (see Grossi and Kunreuther, 2005).

The stochastic module reflects the population of potential earthquake events – their sizes and locations along with their relative probabilities of occurrence within a year. This set of events is developed based on a seismotectonic understanding of earthquake generation, including fault mapping, crustal strain measurements, earthquake history and the geological record of previous earthquakes.

The hazard module concerns the spatial geography of the key shaking parameters from each event at each geographic location. The totality of the distribution of shaking for each event is termed the ‘earthquake footprint’. The hazard parameter could be the intensity at each location, but today most models use the spectral acceleration – relating the strength of ground shaking to its vibrational period. Spectral acceleration can then be linked to the resonant period of a building with taller buildings responding to longer period shaking than shorter buildings.

The exposure model concerns what is exposed to damage or loss by the earthquake. For most insurance purposes exposure concerns the distribution of buildings, their locations, values, ages, styles of construction, size etc. For modeling business interruption costs exposure can also include the business activity undertaken at a location, as measured by the income or profits of a company.

The vulnerability module concerns how the hazard turns into loss to a particular building or facility. Vulnerability functions relate the % of the value of a property that is expected to be lost as a result of a particular level of hazard – such as ground shaking. Vulnerability functions can also be applied to the reduction in business income or profits and also to how many casualties to expect for human exposure.

The final module – the financial module - considers the loss in terms of monetary value. Through employing uncertainty distributions linked to vulnerability there is a distribution on loss from a single simulated event at an individual building or at a set of properties. By evaluating the loss from each of the stochastic events in the simulation it becomes possible to generate an exceedance probability curve displaying the probability that a loss will be in excess of different thresholds. The integral under the exceedance probability curve is the average annualized loss – also known as the technical price for the risk. This is the amount that would need to be set aside each year to fund all potential future losses and is the critical parameter to be considered when mapping risk cost – for example.

In terms of catastrophe model outputs it is important to switch between two perspectives - the ‘probabilistic perspective’ in which the potential impacts are weighted by their respective probabilities – and the ‘scenario perspective’ in which specific catastrophes are reconstructed in significant detail, to determine the interdependencies of their consequences.

2.2 What determines the variation in earthquake risk across Chile?

The principal source of catastrophic earthquakes in Chile is the ‘interplate’ subduction zone plate boundary, which dips down beneath Chile from the offshore Pacific trench. The fault ruptures of earthquakes along the subduction zone are principally located offshore. As a result, the strength of ground shaking tends to be higher close to the coast than far inland towards the Andes. However along the western front of the Andes there are also other active ‘intraplate’ fault sources capable of generating earthquakes up to Magnitude 7. These faults have much slower slip-rates than the subduction zone and, as a result, typical recurrence intervals of these shallow crustal Andean faults are measured in thousands of years as compared with the 100-200 years of Magnitude 8+ earthquakes along the subduction zone. Therefore, while the gradient of hazard from earthquakes on the subduction zone reduces inland – at longer return periods and lower probabilities - hazard and risk is also concentrated around these inland fault sources. One such fault source, known as the San Ramón Fault, is located at the foot of the Andes immediately to the east of Santiago (Armijo et al., 2010).

Along the main subduction zone plate boundary the recurrence interval of major earthquakes is sufficiently short that each section of the subduction zone has broken several times within the 400 years of recorded history in Chile. From this record it is possible to identify ‘seismic gaps’ where fault rupture has not occurred for a long period of time. For example, before 2010, a gap had been identified around the coast adjacent to Concepcion, where the last major subduction zone earthquake had been in 1835, and where it was known that more than 10m of plate boundary displacement had accumulated over the previous 175 years (Lorito et al., 2011). This gap was bounded to the south by the northern end of the section of the subduction zone that had broken in the Mw9.5 1960 earthquake. As the Feb 27th 2010 Mw8.8 earthquake has now largely filled this gap, another comparable earthquake is not likely to recur on this section of the plate boundary for more than 100 years. However the region to the north of the 2010 rupture is now identified to be the area most likely to have a major subduction zone earthquake in this region. The 1985 Mw8.1 fault rupture along the subduction zone to the south of Valparaiso did not fully break the subduction zone along the whole of this coastline in the way that it has broken in far larger earthquakes in 1730 and 1906. Hence there remains a significant potential for a major plate boundary earthquake to break some part of the subduction zone in the latitude of Santiago and Valparaiso. The Catastrophe analysis model needs to include a range of possible subduction zone earthquakes in this area, appropriately weighted. Meanwhile the probability of a repeat of the 2010 earthquake, can, for the next few decades be assigned a very low or negligible probability.

The significant claims experience of the Feb 27th 2010 earthquake will make it possible to refine further how risk should be differentiated both geographically and by building type in Chile. Geographical differentiation includes the affects of shallow geology, such as shallow ‘soil amplification’ and the impacts of resonance and focusing of strong motions in sedimentary basins. Differentiation in

vulnerability by building type is determined by the construction materials and age relative to building codes and height.

2.3 Use of Catastrophe models for defining insurer's capital adequacy

The proper use of catastrophe analysis models requires that the insurance organization has the appropriate data on all its insured risks. Catastrophe modeling imposes high standards of data management that benefit all the functions of an insurance operation including its regulation.

For the purposes of regulating capital needs of insurers in Chile, the country is currently divided into five Cresta zones for measuring accumulations of earthquake aggregate insured values. Zone 3, where Santiago is located, represents, on average, 50 to 70 percent of the countrywide exposures. Zone 4, covering the City of Concepcion, represents 10 to 20 percent of the countrywide exposures (Perez, 2011).

Currently the Superintendencia Valores y Seguro has required that insurers purchase balance sheet protection, either through reinsurance, or support from an international insurer parent, to a value equal to 10% of their maximum property exposure accumulation in any one zone in Chile, or 15% of their zonal accumulation for business interruption coverage. These percentages do not, however, fully reflect the degree to which a major Mw9 subduction zone earthquake, with a fault rupture extending for hundreds of kilometers, could cause damage in more than one zone at the same time – as happened in the earthquake of Feb 27th 2010. Among the major insurers in the Chilean market it is understood that at least one did exceed its local Chilean reinsurance program in 2010, although, fortunately, being a local subsidiary of an international company, was able to fall back on the global reinsurance cover of its parent company.

Regulation of insurance by the Superintendencia Valores y Seguro should now move to the best international practice, as in the application of the new Solvency II regime for determining the capital adequacy of insurers and reinsurers in Europe (FSA, 2011). In particular the Solvency II standard of using appropriate trusted Catastrophe analysis models, fully understood and interpreted by their insurer users, should now be employed to measure capital for the 0.5% annual probability of exceedance (ie 200 year return period) event in Chile. The regulator needs to determine how to approve the detailed use by insurers of internationally accepted catastrophe models, for measuring the risk at this critical return period.

2.3.1 Use of Realistic Disaster Scenarios for measuring market-wide accumulations

The Superintendencia Valores y Seguros should also consider employing selected major earthquake scenarios for measuring the concentration of risk across the whole market, and for showing that there is market wide resilience against events as large as all of those that are known to have occurred through history. Modeling of these catastrophic events should include not only the impacts of shaking, but where appropriate, the accompanying tsunamis.

Within the 450 years of recorded earthquake history in Chile two key 'scenario' events stand out which should be considered as accumulation scenarios across the market.

- i. A major M9 subduction zone earthquake along the section of the subduction zone to the north of the 2010 Maule earthquake fault rupture. Such an earthquake would be moderately loss causing in Santiago but highly destructive in Valparaiso. This scenario is equivalent to the 1730 earthquake which was accompanied by a particularly destructive tsunami reaching heights of up to 10m above sea level in Valparaiso.
- ii. A rupture on the San Ramón Fault located at the base of the Andes mountains immediately to the east of Santiago. This fault is considered to be capable of a M6.8 earthquake (with a return period of a few thousand years - see Armijo et al. 2010). This event would be comparable to that of 1647 in Santiago, when an earthquake was experienced that proved far more destructive in the

city than any earthquake since, and which is considered to have had a local shallow crustal source.

2.4 The three uninsured sectors in Chile

Three key sectors of property in Chile remain predominately uninsured against major earthquakes:

- a) lower income homeowners without mortgages (constituting 76% of the home-owning population),
- b) owners of small businesses (70% of whom are not insured) and
- c) the public sector - in particular schools and hospitals.

As evidenced by the Feb 27th 2010 earthquake, all these uninsured sectors fall back on requiring direct (or indirect) government subsidies post catastrophe, or contribute to a rise in levels of poverty. It is strongly in the interests of the Chilean government to take action now to expand risk transfer across these sectors in Chile and thereby reduce government liabilities in future major earthquakes.

2.4.1 Low income homeowners

Following the Feb 27th earthquake the government set up a compensation scheme for the 60% of the home-owning population, with damaged properties and with lower levels of income, who did not have a mortgage or insurance. Based on the experience of receiving these subsidies, unless they move up to take on a mortgage, there is no reason or incentive for a lower income homeowner to consider purchasing insurance (even though there is no contract or guarantee to suggest they would get compensated again for damage after a future quake). Under current government policy the expectations for post earthquake compensation will continue to diverge between those homeowners who purchase mortgages and insurance and those who have been in receipt of subsidies.

It has been said that ‘ownership of a property is considered a fundamental mark of citizenship in Chile’ – and that ‘only the wealthy would rent’. However the ability to raise a mortgage through sufficient salary and creditworthiness is the key test into which ‘track’ of the economy an individual falls. (The only home owning sector in Chile who do voluntarily purchase residential insurance are likely to be the relatively wealthy, who have lived in their properties a long time, or have inherited them, who have no loan on the property outstanding, but who see the benefits of having insurance on their principal asset.)

The simplest way of expanding insurance among low income homeowners without a mortgage would be to promote the role of the private insurance sector. Discussions with reinsurers as part of this survey have suggested that there is no impediment to an expansion of aggregate values of reinsurance for Chile. Chilean earthquake risk would never reach the levels of global exposure concentration of US Hurricane (for example).

There is however one area, in which reinsurers currently put restrictions on what private earthquake insurance business insurers in Chile can write – in imposing an ‘adobe exclusion’. As a result private insurers will not write adobe buildings. However, if insurers no longer applied uniform earthquake insurance rates, adobe buildings could be properly priced for earthquake insurance (although at a higher % of Total Insured Value premium than the rate for modern residential buildings). The building stock of adobe buildings in Chile has already been significantly ‘reduced’ by past earthquakes in all those coastal locations in which strong earthquake motion can be expected more often than once in a 100 years. Therefore the typical risk cost (expressed as % of TIV), for remaining adobe buildings is likely to be below 0.5% of their value and more often, in inland cities, to be closer to 0.2%. Opening the insurance market to variable earthquake insurance rates would make some classes of currently uninsured risks, like adobe buildings, insurable. However establishing an insurance market among low income adobe homeowners

would almost inevitably require government subsidies to be sustained. Yet setting and publicizing technical earthquake rates for these risks will help drive policy decisions as to whether properties should either: be strengthened against earthquakes, when the risk cost for insurance would be reduced; or replaced with a much more resilient style of building.

Another policy action with the potential to increase the take up of earthquake insurance would be for the government to promote the benefits of a low income rental sector. Private landlords, or government owners of properties, could then include the insurance costs in the rent. In the UK, when government-owned social housing is rented to tenants, the local government entity purchases a collective ‘municipal insurance’ to cover property losses to this sector, while the tenants purchase their own contents insurance coverage. This UK municipal insurance business was formerly offered through a mutual (Municipal Mutual) which was later acquired by the Zurich Insurance Company in 1992.

In place of making ex-post subsidies to those lower income sections of the community whose properties were destroyed, local government entities should maintain ownership of a property and could require that part of the rent for the property (as subsidized by the government) went to fund ongoing earthquake insurance. The test of this procedure would be to offer a pilot program in which households are offered a better standard of housing in a rental sector than would have been otherwise available for purchase. The terms of the rental should include (with the appropriate conditions) lifetime tenancy so that people know they can stay in the same property long term (a major reason why at present the rental sector is not considered appropriate for lower income homeowners).

2.4.2 Establishing an earthquake microinsurance system

There is also the potential to explore the creation of an alternative insurance mechanism for low income homeowners that provides earthquake (and tsunami) insurance at competitive rates through simplifying all aspects of the collection of premiums and the process of making payouts post-event. Such a system is termed microinsurance.

It would, for example, be possible to turn the current level of subsidies paid after the Feb 27th earthquake into a microinsurance scheme with two levels of payment for ‘partial’ and ‘total’ damage to a property. Subsidies after the Feb 27th earthquake have themselves been based on a simple system to determine whether the building would need to be demolished or could be repaired. The ATC 20 tagging system (Ostaraas et al., 2006) is a widely accepted standard for the post-earthquake safety review of structures by a qualified structural engineer, according to whether the building can be occupied (green tag), has partial damage (yellow tag) or should be closed until demolition or major upgrading (red tag). The tagging system was originally developed to determine whether the building is safe enough to be occupied in the face of aftershocks. In general, damage to those elements of the structure that determine its safety (against the potential for collapse) also determine the potential for the structure to be cost-effectively repaired and restored.

In the principles of microinsurance, claims payments are simplified so that they can be made without incurring a detailed survey of damage (see Walker, 2008). However to prevent moral hazard, it is important that payments are only triggered when a property is in fact damaged (rather than being triggered when the overall shaking intensity in a town is deemed to be above some threshold). Within a microinsurance system it will also be important to have an earthquake magnitude trigger so that coverage is not accidentally extended to buildings which are simply in a poor state of repair, independent of whether there has in fact been an earthquake.

Given the prior history of *ex-post* subsidies in Chile, such a scheme may need to be made compulsory with premiums re-allocated from property taxes, or from a proportion of pre-existing housing subsidies.

The entity that organized the microinsurance could be either state-backed or a public-private partnership scheme. In either case it may need to purchase some form of reinsurance, before sufficient catastrophe reserves are accumulated.

A pre-existing example of an earthquake microinsurance scheme is the Gujarat State Disaster Management Authority (Pandya et al., 2006), which applies to houses rebuilt after the 2001 Gujarat earthquake. A premium providing cover for ten years was deducted from the final payment made on the property prior to its occupation. At a village level the houses are insured as a group, not individually, with claims also being submitted and paid on a group basis. The scheme covers a range of perils including earthquake.

Going forward the Chilean Government needs to clearly advertize its position around future post earthquake subsidies. Actions taken in offering subsidies following the 2010 earthquake have signaled that lower income homeowners have no need for insurance. To change this situation will require designing a simplified insurance system for the lower income 60% of Chilean homeowners that is both deemed fair and achieves a near universal earthquake insurance coverage. Microinsurance can provide the most cost-effective ex-ante catastrophe funding for this sector.

2.4.3 Insurance for Small commercial

Unless insurance was in place, owners of small commercial operations had no chance of recovering their losses in the earthquake. There were no Government subsidies available for this sector. Uninsured losses to this sector are likely to have had a significant impact in driving up levels of poverty in Chile as many small businesses will have closed or make workers redundant to compensate for the costs of recovering from the earthquake. Loss of income of workers in small commercial enterprises will also have impacted other dependent businesses.

The government should work with insurers to undertake a survey in the small commercial sector to find out the reasons why business owners chose not to purchase insurance and what actions need to be taken to expand the insurance take up in this sector. It seems likely, for example, that where businesses have taken out bank loans they should have had to purchase insurance and this linkage could be more widely enforced. The government should also encourage insurers to lead a marketing effort across the sector.

2.4.4 Insurance for Government property

To expand insurance across properties in the Government sector will require formulating and promoting a strategy to get schools and hospitals and other municipal buildings to be covered by a form of insurance.

Given the geography of Chile, and the opportunities to pool risks across regions unlikely to be impacted in the same earthquake, the Government is recommended to consider the design of a mutual earthquake catastrophe pool for Government assets in which premiums are collected from each region and annual losses up to some overall limit are funded from premiums. Such a pool would need to purchase international reinsurance for a top layer, when the losses impact a large number of schools, hospitals and other government buildings, across more than one region, in the same event or year. The management of this pool would require to follow rules for capital adequacy determined by the Superintendencia Valores y Seguros. Again the advantage of such a system will be that the losses in a future earthquake catastrophe will have been funded *ex ante*.

2.5 Summary and Overview

Historically, new earthquake insurance systems have only emerged in the aftermath of a catastrophe. Chile now has the opportunity to make a number of innovations in how earthquake insurance is structured and supervised in Chile and also to take actions to bring currently uninsured sectors of the Chilean economy into a more comprehensive and coherent set of risk transfer arrangements.

For those sectors that were insured, the private insurance sector performed well in the Feb 27th 2010 earthquake. The private market has achieved higher levels of coverage for residential earthquake risks than, for example, has been achieved in California and on a level that is comparable to that in Japan. However Catastrophe analysis models that underlie the pricing and structuring of insurance and reinsurance arrangements in many developed countries should now become more widely used for pricing and managing earthquake insurance pricing and accumulations in Chile. The Insurance Regulatory office (Superintendencia Valores y Seguro) should mandate the use of such models to determine insurer capital adequacy and the expected levels of reinsurance coverage. Technical risk rating should also be encouraged among insurers writing business in Chile to cover both earthquake and tsunami risks.

For three key sectors in which there is currently very low insurance penetrations the Government is advised to explore actions that will expand the take-up rate of insurance.

- The government should consider actions to encourage local government entities (or their PPP representative agency) to build houses for long-term rental to the lowest income 60% of Chilean homeowners. It should then be compulsory that ‘municipal’ earthquake insurance is purchased across all the properties owned by the agency, and added to the cost of the rent.
- For the lower income residential sector, it is recommended to explore the creation of a simple microinsurance system, that will make fixed price payments to property owners according to a tagging classification of the level of damage. Such a microinsurance system could either be run by the government or by a private entity- for example as a PPP Concession, but with government subsidy of premiums for the poorest sectors of homeowners.
- For small commercial earthquake insurance, it is recommended that the government should work with the insurance industry to identify how to expand their take-up rates of earthquake insurance. It is likely that the lowest income sector of small commercial enterprises might benefit from being included within a microinsurance scheme.
- For Government properties, it is proposed that the government should explore the creation of a mutual pooling system for earthquake catastrophe losses, across all those properties in Government ownership. This would require the creation of a new entity, funded by insurance premiums, able to pay moderate claims within a given year but also with a reinsurance facility (or a Catastrophe Bond facility) designed to ensure that money is available to pay for major earthquake catastrophe losses – as in 2010.

By taking actions to expand *ex ante* risk transfer, the Chilean Government can significantly reduce its expected *ex post* liabilities in a future major earthquake in Chile. Just as actions already taken to develop the mortgage market and to expand the use of Concessions have been highly successful in expanding the take up of earthquake insurance, so the Government of Chile now has the opportunity to be a leader in expanding the development of earthquake risk transfer mechanisms to those sectors of the economy that remain largely uninsured.

One key area in which the Government can sponsor and direct activity that will assist in the creation of improved risk transfer products concerns the development of a suitably administered network of earthquake strong motion instruments around the principal concentrations of property exposure in Chile. This is discussed in detail in Appendix A, of this report.

SECTION 3

THE ROLE FOR THE CHILEAN GOVERNMENT IN DRIVING LONG-TERM EARTHQUAKE RISK REDUCTION

3.1 Introduction

As a pre-requisite to the design of policy measures that can lead to long term risk reduction in Chile, and to reduce the costs to the Government in the aftermath of a major earthquake, it is important to be able to ‘measure’ the current state of national catastrophe risk. While expanded risk transfer options can help reduce the ‘spikes’ of catastrophe risk costs, total insurance premiums will always exceed the costs of the damage. Therefore, over the long term, the government should focus on policy actions that will be effective in actually reducing Chilean earthquake catastrophe risk costs.

However before it is possible to identify and prioritize where investments should be made in risk reduction, it is first necessary to undertake a comprehensive survey of the ‘landscape’ of catastrophe risk in Chile. Within this ‘risk landscape’ there will be hotspots of risk and it is these hotspots that should be the focus of optimal investments in risk reduction.

For this purpose it is necessary to perform a detailed analysis of national catastrophe risks in Chile using probabilistic Catastrophe loss modeling capability.

3.2 Expanded Catastrophe loss modeling for measuring national risk

The Catastrophe analysis model required for analyzing the risk landscape of Chile needs to have capabilities that extend beyond the standard earthquake Catastrophe loss models currently employed by the insurance industry.

3.2.1 *Tsunami impacts*

For each simulated major subduction zone interplate earthquake, based on the associated sea floor deformation, the accompanying tsunami needs to be represented in the form of high resolution ‘footprints’ of the geographic extent, depth and velocity of tsunami inundation along the low lying coastal areas of Chile.

Damage to buildings within the tsunami zone will reflect the speed and depth of the tsunami at that location.

Tsunami catastrophe loss modeling has already been employed for other regions of the world – as for example in southern California.

3.2.2 *Generation of National exposure data*

The Government needs to sponsor a comprehensive database of all the building stock and infrastructure of Chile. This building stock database should include information on the occupancy of each building along with details of its height, area, age and materials of construction. The information should cover commercial and industrial facilities, all government assets, infrastructure including roads, bridges,

ports, electricity supply networks, and mobile phone transmission systems etc. The assembly of such information is significant facilitated by detailed aerial and satellite imagery data. The total inventory dataset could also cover moveable assets such as trucks, cars and boats.

3.2.3 Human exposure impacts from building collapse

Human exposure reflects the distribution of the population in the building stock according to the time of day at which the earthquake occurs (Allen et al., 2009). Offices are filled with people in the weekday daytime but empty at weekends and at night. Houses are more likely to be occupied in the evening and night time. Such human population exposure models have been developed for other countries, such as the US and Japan, as part of modeling potential casualties from earthquakes.

The Catastrophe analysis model also needs to include casualty vulnerabilities that link the level of building damage to the expected casualty rate for those within the building at the time of the earthquake. For high rise buildings there is a pronounced difference in the casualty rate between a building that is subjected to significant damage but without collapse, and one that collapses. The methodologies for modeling earthquake casualties are based on those developed by Coburn and Spence (1992). For Chile the casualty model can be calibrated against the actual experience of casualties and exposure occupancies (with regard to the time of day) of the Feb 27th 2010 earthquake.

3.2.4 Human exposure impacts from tsunami

There also needs to be consideration of the potential casualties from future tsunamis in Chile (which caused approximately one quarter of the 2010 earthquake casualties). Modeling the casualty impacts of a tsunami is more complex than for earthquake casualties because there is time available for individuals to move to a location out of reach of the anticipated wave. Therefore the modeling needs to consider not only the location of the population at the time of the earthquake but also what proportion of this population is unable to evacuate or be evacuated. This would include people of low mobility, the elderly or disabled. It may also include people who do not evacuate high enough, because they underestimate the height of the tsunami - as happened in Tohoku Japan in the March 11th 2011 earthquake and tsunami.

High number of tsunami casualties occur where people find themselves without a suitable path of evacuation. For example, in the Feb 27th 2010 tsunami, a number of fatalities occurred at a camp site on an island in a river close to the coast. In the future it could be made a requirement of any official campsite that there had to be an accepted vertical tsunami evacuation route.

3.3 Measurement of national catastrophic risk in Chile

Having acquired and expanded a Catastrophe loss modeling capability to cover both earthquake and tsunami impacts, for property and human exposure data and by applying datasets on the actual building and human exposure data for Chile, a series of perspectives on risk should be generated.

- A risk map showing the ‘average annualized’ property loss for each location in Chile, expressed both in terms of % of value and total monetary loss. This map would help identify where earthquake and tsunami risk are currently concentrated by geography.
- A risk map showing the annual probability of life loss by location across Chile.
- The total risk costs at some annual probability of exceedance (such as one in 100 and 1 in 200 per year) to different sectors, such as government, residential, commercial, industrial and infrastructure as well as to different building types.
- The annual probability of total life loss in an earthquake across Chile expressed as a expected casualties vs return period.

3.4 Exploring options for risk reduction

A key purpose of the national risk modeling framework is to make it possible to explore alternative loss and casualty mitigation strategies in Chile, and in particular where action should be focused.

In anticipation of what would be the output of such an analysis, three areas of risk concentration can be identified, each of which would be likely to be the focus of actions taken to reduce national risk.

3.4.1 Relocating people living in Tsunami zones

A principal concentration of high property and casualty loss in Chile concerns communities and ports located close to sea level in high tsunami hazard zones. Along the coast of Chile tsunami hazard should first be modeled and potentially mapped in two or three hazard levels (ie tsunami inundation at the 0.5% and 0.1% annual probability). Based on this zonation, planning controls should be established around what type of buildings and occupancy are appropriate to that hazard level.

As in Hawaii, for example, people should be prevented from living in the highest tsunami hazard zones. Only harbor-side buildings related to marine employment should be permitted. Wherever possible, buildings in high tsunami hazard zones should be designed so that the basic structure will withstand expected water velocities and inundation depths.

The first areas along the coast of Chile requiring such hazard zonation are those which experienced the 2010 tsunami. A number of ongoing studies are underway to define the tsunami hazard (in particular the *Estudio de riesgo de sismos y maremoto para comunas costeras de las regiones de O'Higgins y del Maule*), carried out by the government of Chile in collaboration with the Pontificia Universidad Catolica de Chile. It is understood that the Ministry of Housing has been working on a plan to attempt to prevent the tsunami zones becoming resettled by those who lost their houses in the 2010 tsunami. It is recognized there may be strong resistance to such resettlement and that people may tend to relocate their properties in these villages once again, in particular once they perceive that the reconstruction effort is complete and the attention of the relevant government agency is distracted. However, for long term national risk reduction the government needs to be resolute in relocating people currently living in tsunami zones, by offering comparable plots of land above the tsunami zone and assisting in resettlement costs. As part of this exercise it will be necessary to involve the communities themselves in understanding the severity of the risks and the benefits of relocation.

3.4.2 Legacy building stock

A key concentration of risk in Chile, both reflecting risk of property damage as well as risk of loss life, concerns the 'legacy building stock', in particular buildings dating from before modern building codes as developed since 1970. An important goal of the national earthquake and tsunami catastrophe risk study will be to understand where the earthquake risk from older buildings is situated and to what degree this older building stock contributes to the overall earthquake economic and casualty risk in Chile.

For example it is likely that the city of Valparaiso remains a significant hotspot of national risk in Chile as many buildings in the city were constructed before modern building codes and there have been low levels of investment in new building in the city over the past fifty years. The last major earthquake in 1989 was not a full rupture of the adjacent plate boundary and is by no means the probable maximum loss event for the city. Low lying parts of the city are built on alluvial sediments and in the last complete rupture of the adjacent subduction zone in 1906 many fires broke out. Low lying areas are also at risk from a substantial tsunami that reached heights of up to 10m above sea level in the earthquake and tsunami of 1730, comparable to that seen in the coastal cities of North-East Japan in the March 11th 2011 earthquake.

A key objective should be to publicize the problem and formulate what should be done about the Valparaiso urban risk concentration from both earthquake (shaking and fire) and tsunami. This could include: subsidizing the retrofitting or demolition of the most dangerous buildings or identifying how certain activities in the city should be relocated. Long term there should be the goal to migrate the building stock in Valparaiso to become more resilient and lower risk. A goal could be set to drive the level of earthquake and tsunami risk in the city down below thresholds deemed to be acceptable.

3.4.3 Improvements in the building code focused on reducing economic impacts

One demonstrable success of Chilean government policy that emerges from the experience of the 2010 earthquake concerns the performance of the strong engineering culture of the development and policing of building codes. Already some enhancements in these codes have been identified from this experience.

Building codes are principally designed for driving improvements in life safety of building occupants, not reductions in the costs of damage caused by earthquake shaking. Shear wall construction may be designed to absorb inter-storey drift and reduce building collapses, but will be subject to internal damage in an earthquake. A future goal for building codes in Chile could also be to aim to reduce the costs of damages of buildings in earthquakes.

3.5 International experience of governmental involvement in national Catastrophe risk reduction

There are likely to be important lessons to be learnt from other developed countries in mapping and implementing long term plans for risk reduction. The role of FEMA in the US includes the involvement of affected communities in understanding local flood hazard and involvement in flood risk reduction activities. The FEMA system around flood risk considers the Base Flood Elevation, whereby, to be able to purchase insurance, a new building needs to be built above the height of the modeled 1% annual probability ('100 year return period') flood height at that location (FEMA, 2011).

Another example of the development of a national strategy around long term risk reduction concerns work on national climate change adaptation, and associated risk reduction activities in the UK (DEFRA, 2011).

3.5.1 Risk Auditing

A key feature of developing and implementing a successful long term strategy of risk reduction is to monitor performance through time. Based on a stable catastrophe modeling platform it would be possible to re-evaluate the building, infrastructure and human exposure across Chile and perform a new study to explore the landscape of risk in Chile, perhaps every five years. This would provide the means to audit performance in the country towards long term earthquake risk reduction. To make the results of such an audit most tangible it would be worth focusing on the expected losses and expected casualties from two specific event scenarios that reflect repeats of the 1730 and 1647 earthquakes.

A key question concerns where in Government the function of measuring and reducing risk in Chile should be managed. Ultimately there is a role for a national Chief Risk Officer who should have overall responsibility for determining how risk is investigated and the merits of investing in specific risk reduction actions and policies.

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APPENDIX A

A.1 Establishing a strong motion network in Chile that can be employed for driving index- based risk transfer products

The Appendix considers how dense networks of digital earthquake strong motion recorders in Japan and California have facilitated the development of new risk transfer mechanisms based on the compilation of exposure-weighted ground motion metrics. Such a network should now be established in Chile with instruments distributed around the main concentrations of exposure, with their own guaranteed back-up power supply and the ability to transmit data remotely. The network also needs to be supervised by a reputable and independent institution. The recordings of ground motions, telemetered from these recorders, will also enable the Chilean government to develop an immediate perspective on the likely level of damage and casualties by location in a future major earthquake.

A.1.1 Introduction

A network of digital earthquake strong motion instruments can generate data in support of a number of aims and for a number of users (Boore and Bommer, 2005). Principally the network is intended to support determinations of the expected damages, losses and casualties in a future earthquake. Data supplied by the network will also serve a strong scientific and engineering research function - in reconstructing details of the earthquake source, as well as understanding the local properties of ground motion and the inter-relation between specific ground motions and neighbouring building damage. However there is also another key use for this data among those who design, market, invest in and monitor new forms of index based risk transfer – such as Catastrophe risk securitizations. In designing and planning a new network of strong motion instruments in Chile, it is important to identify all the potential users of strong motion data and the requirements of these users. A dense network can help enable a more efficient risk transfer market: on behalf of insurers and reinsurers covering risks in Chile or even on behalf of the Chilean government itself transferring its own earthquake liabilities.

In terms of identifying the user needs for the provision of earthquake strong motion data in Chile one can frame a number of questions:

- what are the characteristics of an institution best able to run the network of Chilean strong motion recorders (so that observations will be considered independent and scientific) ?
- how should the network be configured geographically so that stations are principally located where the people and buildings are concentrated?
- how should the instrumentation and power supplies be designed to ensure the instruments function in an emergency, to guarantee data is recorded even when the power supply systems are not functioning?
- how should information from the network be telemetered to one or more central locations so the data can be guaranteed to be available in real time without needing to rely on off-site power supplies or mobile telephone transmitters?
- how should data from the network be made generally available and employed for identifying the real time impacts of any earthquake in Chile?

A.2 Strong motion recording networks

A.2.1 Japan

The best instrumented country in the world for earthquake strong motion data is Japan. In Japan the Japan Meteorological Agency (JMA) is the national agency that is responsible for tsunami forecasts, short-term prediction of large earthquakes, and all the information services on earthquakes, tsunamis and volcanic eruptions. The JMA operates a network of about 180 seismographs that continuously record all seismic activity as well as 600 'seismic intensity meters' (derived from strong motion recorders) across the whole of Japan. All this data is telemetered to the headquarters of the JMA in Tokyo as well as six District Meteorological Observatories. After an earthquake the JMA processes and publishes maps of the observational data. Acceleration data files are also distributed at cost.

In parallel with the work of the JMA, since 1996 the Japanese National Research Institute for Earth Science and Disaster Prevention (NIED) Science and Technology Agency, constructed a large network, (K-Net), of 1,000 strong motion instruments deployed all over Japan at intervals of about 25 km. Each station has a digital strong-motion instrument with a broad frequency-band and a wide dynamic range on the free field and transmits data to the control center in NIED, Tsukuba, through an Integrated Services Digital Network (ISDN) line. After the occurrence of an earthquake, all the peak ground acceleration data is reported by e-mail or Fax and within a few days digital acceleration records are posted on the web site.

Also in Japan there are a number of other local strong motion networks in support of particular functions, government agencies and private service companies. These include:

The Public Works Research Institute (PWRI) of the Ministry of Construction, is a national institute in the field of civil engineering. The Seismic Assessment Tool for Urgent Response and Notification (SATURN), consists of about 700 strong motion instruments placed along highways and rivers with an interval of 20 to 40 kilometers. Peak ground accelerations and spectrum intensities are transmitted to the headquarters in real-time, and are used to estimate liquefaction possibilities and damage of highway bridges. The PWRI also operates the Dense Instrument Arrays for Strong Motion Monitoring in nine sites comprising 1672 instruments at 361 bridges, river embankments and dams.

The Port and Harbour Research Institute (PHRI), Ministry of Transport, runs a network of strong motion recorders at 57 ports as well as at some key airports built on reclaimed land.

The Tokyo Gas Co. Ltd. Since 1998 has run the most extensive ultra-high-density real-time seismic motion monitoring and disaster mitigation system in 1998 involving 3,600 sensors.

There are also a number of other research networks of strong motion instruments in Japan designed to collect data on specific research problems around expected ground motions in specific parts of the country (Kashima, 2000).

A.2.2 California

California has the second best strong motion network of any region in the world. The network is concentrated around the principal areas of high exposure in the vicinity of the main plate boundary faults around the San Francisco Bay area and across southern California.

The California Strong Motion Instrumentation Program (CSMIP) has inherited a series of previously independent networks. TriNet was developed after the 1994 Northridge earthquake and involved the combination of three pre-existing networks – one run by CalTech in southern California, a second by the US Geological Survey in Pasadena and a third the California Strong Motion Instrumentation Program in the California Geological Survey. After 2000 TriNet transitioned to CISN, the California Integrated

Seismic Network, which also added two further networks in northern California – that run by the US Geological Survey in Menlo Park and another run from UC Berkeley.

The program currently covers more than 900 stations, including 650 ground-response stations, 170 buildings, as well as the monitoring of 20 dams and 60 bridges. Data from monitoring devices are retrieved by modem or for some stations by physically recovering the records at the station. The most recent instrumentation is designed to automatically call CSMIP headquarters when it senses ground shaking.

After an earthquake, records collected by CSMIP are processed and disseminated to government agencies, engineers and the research community. All processed data are available upon request or can be downloaded from the U.S. National Center for Engineering Strong Motion Data at <http://strongmotioncenter.org>.

A.3 The use of strong motion data for index based Catastrophe risk transfer structure

In those territories where there is a dense network of strong motion recorders, it has been possible to create and employ ‘index based’ triggers for determining payment on Catastrophe risk securitizations. Index based triggers have two strong advantages over indemnity based risk transfer mechanisms (ie based on the actual sum of losses) in that: a) they rely on instrumented observations that can be collected very soon after an earthquake and b) are considered independent of all the complexities of claims settlement, demand surge, additional sources of loss etc., which underlie an indemnity loss.

A.3.1 First generation ‘earthquake in a box’ parametric indices

Index based triggers derived from strong motion recordings reflect the ‘second generation’ of earthquake catastrophe risk securitization triggers.

‘First generation’ trigger structures for earthquakes were based on ‘earthquake in a box’ procedures, in which the trigger for payment was determined by whether the epicenter of an earthquake, above some threshold magnitude, was located within a particular geography, defined typically from the Lat-Long coordinates of some square or rectangle orthogonal area – or alternatively as a circle in terms of distance from a site and also taking into consideration the depth of the earthquake hypocentre (Franco, 2010). Sometimes there would be an inner and outer box with a higher threshold magnitude for the larger geographic area. Some trigger structures employed a varying distance of the circle to the site according to the magnitude. However all such ‘earthquake in a box’ procedures had a relatively high basis risk (ie that determines the relationship between the payment from the bond relative to the actual underlying loss). First the epicenter of the earthquake is the location where the rupture starts, and not the overall geometry of the rupture from which vibrations are radiated (that for a large earthquake may extend hundreds of kilometers away from the epicenter). Second it may be difficult to create trigger structures that fully reflect the significance of the depth of the earthquake source – which can be very sensitive in determining the impact of an earthquake (as in the New Zealand earthquake of Feb 2011 when a shallow but relatively small M6.3 earthquake devastated the city of Christchurch). Also, as highlighted in the Mw9 March 11th 2011 Tohoku Japan earthquake, a major earthquake at a distance, located beyond the area considered within a ‘box’, may be a significant source of damage and loss. .

For all these reasons, earthquake parametric ‘box structures’ may not be appropriate except in regions where expected earthquake sizes are no larger than Moment Magnitude 7/7.5 and also where earthquakes are known to occur at consistent depths and not unusually deep or shallow.

In particular in Chile, where subduction zone earthquakes can reach the highest magnitudes, and there are also relatively deep earthquakes with epicenters on land, earthquake parametric box structures, or structures dependent on calculating indexes based on distance of specified cities to the epicenter – should

not be employed. Instead the most suitable parametric indices for future forms of earthquake risk transfer will be based on actual measured earthquake strong motion data.

A.3.2 Methods for interpolating strong motion data

In terms of how to turn the values at individual locations into an overall index – there have been a number of methods employed in the design of different trigger structures (Rockett, 2009). The key to all these alternative procedures is to be able to interpolate through the readings (as the recorders may not be at the centre of the exposure concentrations) and also to have a methodology that takes into consideration the potential that individual recorders may not report a reading (ie have some redundancy according to how values are calculated when data is missing). Since 2007, however, interpolation procedures have tended to converge around using USGS ShakeMap strong motion footprints, which are developed in the aftermath of all significant earthquakes. The Shake-Map is interpolated against the actual strong motion recordings so that it becomes a best interpolation of all the underlying strong motion data. A number of recent earthquake Catastrophe bonds have employed Shake-Map as the means to have interpolated the strong motion readings (Wald et al., 2010).

With sufficient density of instrumented data, it becomes possible to demonstrate that it is possible using catastrophe loss modeling capability, to design a set of weights by location to create a single index that matches the behavior of expected losses. This requires assigning weights to each location, which represent the values exposed and the relative vulnerabilities of the properties covered by the transaction. For example, by calculating the strong motion at each postcode centroid, and knowing the value of what is insured against earthquakes at that postcode, it becomes possible to calculate a loss in each postcode and then the overall index can be simply the summed losses across all postcodes.

A.3.3 Recent second generation parametric earthquake Catastrophe risk securitization structures

Montana Re – was a 3 year \$120Million transaction issued at the end of 2009 on behalf of Flagstone Re involving two \$60 M tranches, one of them covering US earthquake risk. The earthquake trigger was determined from an index based on weightings applied to strong motion recordings in California. This involved taking the USGS shake-map output on an earthquake, interpolating the 0.3, 1 and 3 second peak spectral accelerations to postcode centroids, and then interpolating to a single 0.6 second period for calculating losses in that postcode. Losses were summed in a look-up table of total estimated loss, according to the value of exposure in each postcode.

The 70M Euro Atlas VI Catastrophe Bond, issued in December 2009 on behalf of the French reinsurer SCOR in 2009, covers Japan earthquake and European Windstorm. The structure involved an index-based transaction for Japan earthquake based on the exposure based weighting of strong ground motions recorded at K-Net stations in Japan using the Shake-Map interpolation procedure employed in Montana Re.

The Muteki Catastrophe Bond, issued in May 2008 and running for three years on behalf of Munich Re had a value of \$300M and covered earthquake risk in Japan using an index formula calculated from the simple sum of the measured peak ground acceleration PGA cubed across a set of designated K-Net stations in Japan.

The three year Successor X Cat Bond issued for \$305M by Swiss Re in February 2011 employs an index based on values derived from the USGS ShakeMap output (1sec peak spectral acceleration) for California earthquake risk.

A.4 The Strong motion recording network for Chile

At the time of the Feb 27th 2010 earthquake there were only around 30 strong motion recorders in the central region of Chile. This number would not have been sufficient to be able to support the development

of a second generation index based trigger risk transfer mechanism. Also questions of data ownership meant that information from these strong motion recorders was not made generally available.

Going forward, the Government of Chile is strongly advised to ensure one legacy of the 2010 earthquake is that a strong motion recording instrumentation network is created whose results can be transmitted to a central location and used in real time. This same data should then be made available (for a fee) to support catastrophe securitization transactions.

In terms of what is now required in terms of strong motion data capture for Chile:

- what are the characteristics of an institution best able to run the network of strong motion recorders?

The institution that runs the strong motion network in Chile needs to be considered of the highest scientific caliber and completely independent and reliable in the timely provision of recorded strong motion data. When employed for catastrophe risk transfer the outcome of specific strong motion readings may determine whether a Cat bond worth \$100M or more is, or is not, triggered. Investors and issuers will only have confidence to invest in such a bond structure if they perceive the organization generating the underlying strong motion data is of the highest probity. Organisations that enjoy this status include the US Geological Survey and the Japanese NIED. The organization in Chile tasked with running the network and distributing the results should be government funded but otherwise completely independent of government in its operations. It should also be independent of a University insofar as that ensures it has professional 24/7 operation and maintenance.

- how should the network be configured geographically?

There will be a range of factors under consideration when siting recording stations in the strong motion network for Chile, including: station accessibility, absence of other non-seismic sources of disturbance, proximity to likely earthquake sources onshore and onland, proximity to critical facilities such as dams etc. However a key consideration should be that the network of recorders is distributed around the principal concentrations of people and property at risk. This means that every town and city above some threshold should have two or three strong motion recorders in its vicinity, while a major city such as Santiago should have as many as 20 strong motion recorders at an approximately even density throughout the city.

- how should the instrumentation and power supplies be designed to ensure the instruments function in an emergency?

Every strong motion recorder needs to have a back up battery power supply. These batteries need to be inspected and changed regularly. (A number of past earthquake have highlighted situations where strong motion recorders fail because batteries have not been maintained.)

- how should information from the network be telemetered to one or more central locations so the data can be guaranteed to be available in real time?

Given that mobile data transfer networks can be expected to cease to function (generally through lack of offsite power) in a major earthquake, thought should be given to having recorded ground motion data telemetered via a satellite system to ensure data can be sent to a central location immediately following a major earthquake. However the recording will also be stored at the equipment itself where it can be retrieved later, or downloaded once the mobile network has been restored.

- how should data from the network be made generally available and employed for identifying the real time impacts of any earthquake in Chile?

The data obtained from the strong motion network should be available to all approved users immediately following the earthquake over the internet. Where detailed data is provided to the calculation agent responsible for determining whether, or not, a particular risk transfer structure has been triggered this should be provided (for a fee) typically after a few days, once the data has itself been carefully checked for any errors.

A.5 Conclusions

In order to facilitate new forms of risk transfer for Chile, the Chilean Government is advised to ensure that the strong motion data recording network for Chile is designed and managed in such a way that data from the network can be employed for second generation parametric index based structures. Facilitating such structures can provide an alternative to the reinsurance market for transferring earthquake risk in Chile and the competition introduced between risk securitization and reinsurance should be good for maintaining competitive pressure on risk transfer costs.

There are two regions of the world that have taken a lead in the operation and use of real-time strong motion data – Japan and California. The Chilean government and relevant Disaster management agencies are advised to study the systems in both these regions (in particular the role of the USGS and NIED) to learn best practice in designing and managing such a network in Chile. A key stakeholder in such a network is the community of issuers and investors involved in catastrophe risk transfer.

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