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PROPAGATION OF LOSSES FROM EARTHQUAKES THROUGH THE ECONOMY BY USING THE SPATIAL CGE MODEL

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Abstract

This study aims to develop a novel probabilistic approach to estimating economic losses caused by the propagation of catastrophe-induced disruptions through the economy of a country or a region. Our proposal connects a probabilistic model for seismic risk assessment with a Computable General Equilibrium model (CGE), both robust and well-known models, used worldwide in their respective fields. To the authors' knowledge, this work constitutes the first effort ever made to join the probabilistic seismic risk and the CGE modeling frameworks. We use a spatial CGE model to describe economic relations that consider the geographic location of the economic components. The seismic risk model is used to probabilistically estimate the physical loss of all economic components during a seismic event and the frequency with which it occurs. We estimate physical losses for a vast collection of seismic scenarios, which are considered mutually exclusive and collectively exhaustive. Our assumption is that physical losses are directly proportional to the reduction of capital stocks that make up the assets inventory of an economy. We propagate the impact of the physical losses, and the associated capital stocks reduction, across the economy using the spatial CGE model, in order to assess higher-order regional economic effects. For each seismic scenario, we can compute different economic outputs, such as the expected value of the production loss and its standard deviation, for a wide range of economic variables, with the particularity that each loss is the result of the interaction among all the components of the economic system. Likewise, we can also compute the total average annual income loss (AAL) and the exceedance rate of different values of production loss, that is, the loss exceedance curve of production, for the complete region. Besides dealing with the business interruption aspects, our model goes beyond the estimation of production losses, allowing a complete probabilistic glance of the consequences of the earthquake disturbance into the full economy, incorporating what economists refer to as general equilibrium effects. We are able to estimate, for instance, the standard risk metrics for different components of the economy, such as employment, GDP, GRP, consumer prices index, export volume, etc. To illustrate the approach, we present an example, developed for Chile, whose results constitute the first of its type.

Keywords: seismic risk, CGE modelling, economic loss propagation, disaster risk management.

1. Introduction

There is evidence that economic production losses caused by disasters, sometimes called *indirect losses*, can be much larger than those produced by physical damage (DaLa database, Global Facility for Disaster Recovery and Reduction, GFDRR - World Bank). The importance of accounting for indirect losses in risk estimation is well-recognized [1,2,3,4,5]. However, it is not easy to account for the economic consequences of earthquakes with historical information alone, because these catastrophic events are infrequent, so relevant information is scarce, and it is not always easy to distinguish between direct and indirect losses.

Catastrophe modeling of physical damage caused by earthquakes is today a well-developed technique, to the point that it is possible to estimate, in a probabilistic manner, the seismic risk of each individual asset (buildings, contents, machinery, equipment, etc.). Modeling of indirect losses, in comparison, lags far behind, mainly due to the difficulties in empirically translating property damage into indirect losses and due to the lack of adequate models that relate these two kinds of losses. Usually, indirect losses are estimated roughly as a percentage of physical losses, stablishing this percent with empirical information obtained from a very limited historic database of events occurred around the world; this is clearly unsatisfactory.

Construction of models for the indirect losses is considerably more complicated since, in addition to the physical damage, several players enter into the game: production interaction between agents, public and private decisions during recovery, capacity to input substitution, use of remaining resources more efficiently to maintain business operational, etc.

However, there is a well-developed literature on the economic impact of natural and man-made disasters, whose most recent advances have been compiled by Okuyama and Rose [6]. On one hand, efforts have been focused on improving and extending the quantitative models used for disaster impact analysis. The basic input-output (I-O) model has been extended to cover multiple regions and/or the time dimension of disaster impacts. Furthermore, by way of integrating multiregional and non-linear programing models, research has extended the I-O framework allowing for supply shocks and spatial substitution effects [7], which allows not only to catch negative impacts but also shows positive impacts in some regions. In the case of CGE models, the effects of resilience in production processes have been incorporated and are further analyzed from various perspectives, such as a portfolio theory or under a financial crisis. Multi-regional CGE tools have been applied to examine several disasters; for instance, the economic impact of the Great East Japan Earthquake and Tsunami in 2011 [8]. Efforts have also been made to improve and expand CGE and I-O models to analyze the economic consequences of cyber-attacks, extreme weather events, earthquakes, flooding, climate change, and terrorist attacks, amongst others. On the other hand, researchers have devised tools to directly estimate economic damages and/or losses based on some physical data of natural hazards [9,10], or to evaluate, for instance, the changes in economic activities with a set of satellite data on annual difference in nighttime light intensity [11]. Additionally, new frameworks have been proposed to assess disaster-related consumption losses or to integrate models of transportation, critical supply chains, and community demand.

In spite of the existence of this large and rich analytical framework to study the impact of disasters, including earthquakes, into the economy, efforts have concentrated in the analysis of individual events, without appropriate consideration of their frequency of occurrence. But frequency of occurrence matters. Clearly, decisions and policy would be very different if one knew that the economic impacts of a certain event are to be expected, on average, once every 100 years or once every 1000 years. Further, it would seem that little attention has been given to linking physical damage to infrastructure or economic components with higher-order economic losses.

In view of this, we would like to present a probabilistic approach to the estimation of higher-order losses that takes into account that: 1) natural events –earthquakes in our case- take place as a stochastic process in time; 2) frequency of occurrence of events matters for measuring risk; and 3) there are links between the level of physical damage to economic components and the reduction of capital stock. In our approach, we start with a Computable General Equilibrium (CGE) model of the economy specified as a fully integrated interregional system. This model describes the economic interactions among regions and industrial sectors, and is in equilibrium under a certain level of inputs, outputs and prices. Then, an earthquake happens, and produces physical damage (direct losses) to the economic components associated with the available capital stock (e.g. building, factories and infrastructure) of the affected portion of the region; these losses are estimated with conventional seismic risk techniques. Direct losses, in turn, produce partial reductions in some inputs to the CGE model, namely regional-sectorial capital stocks, which attains a new equilibrium after proper adjustments, reaching new levels of outputs and prices. The result is that the occurrence of the earthquake produces direct losses plus other types of indirect losses that result from the propagation of the reduction of available primary factors through the economy described by our CGE model. As in the case of conventional seismic risk models, the analysis is then repeated for a vast set of earthquakes with known occurrence frequencies, that collectively describe the hazard of the region under study. Results for all earthquakes allow for various probabilistic risk metrics to be computed, now including the effect of indirect losses as well.

To the authors' knowledge, this work is the first effort ever made to join the probabilistic seismic risk and the CGE modeling frameworks, both robust and well-known models used worldwide in their respective fields, in

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a systematic probabilistic way. CGE models are used widely for studying and simulating economic effects within an economy, given the occurrence of different types of shocks, such as economic policies, taxes, financial crises, terrorist attacks, etc. We make use of a special type of CGE models, known as spatial CGE models, which have the ability to take into account the geographic location of economic agents and endowments.

Our modeling approach is fully probabilistic on the earthquake occurrence side, but is deterministic on the CGE side. We assume that the physical damage produces a proportional reduction on the value of the capital stock of components hit by the earthquake, which initially causes a direct reduction on production and later propagates into the economy in ways dictated by interactions contained in the CGE model.

Besides dealing with the estimation of indirect monetary losses, our approach allows for a better glance of the likely consequences of the earthquake occurrence into the full economy. As we will see, the richness of the CGE modelling allows to carry out risk assessment referred to different economic variables, such as employment, GDP, GRP, wages, tariff revenue, consumer price index, export volume, and so on.

In the following sections, we will present the general structure and some details of our approach and, at the end, we will present results from a pilot study carried out for Chile.

2. Seismic risk model

As we mentioned before, we start our modelling process with an economy that is in equilibrium with a certain levels of inputs, outputs, prices and other economic variables; we will describe our economic model of choice in Section 3.

First, the seismic risk model contains an *exposure database* that includes all assets at risk that are relevant for the analysis. In our case, the relevant assets are buildings, factories, infrastructure and, in general, all assets that provide input of some kind to the economic model. In other words, all assets whose damage might have a potential impact in the economic flows. Each asset must be identified by its location, seismic vulnerability characteristics and, particularly relevant for our present purposes, the economic sector to which it belongs.

At random instants, with all assets intact, and following a Poisson process, the economic equilibrium is perturbed by the occurrence of an earthquake with known focal characteristics (magnitude, hypocentral location, orientation of the rupture plane), which in turn will produce a spatial random field of intensities (peak ground acceleration, spectral values). In contemporary seismic risk models, this information is provided by its *hazard component* [12,13,14,15]. This component provides a potentially very large event set, each one associated to an annual frequency of occurrence and to one or more intensity random fields. Therefore, the hazard component provides information about how frequently different kinds of earthquakes take place and gives probabilistic indications of the intensities it produces. In principle, the hazard component should contain information about occurrence frequencies and intensity distributions of all earthquakes that could take place in the future. In other words, the event set must be collectively exhaustive.

Once a hypothetical earthquake has taken place and its intensities are known –or, more precisely, the probability distributions of the intensities are known-, the seismic risk model provides tools to assess in probabilistic terms the level of direct losses suffered by each one of the assets contained in the exposure database; this part of the model is usually referred to as the *loss component*. The level of damage sustained by an asset depends on its location, the size of the intensity at its location and its vulnerability characteristics. Thus, once a hypothetical event has taken place, we have means to determine the probability distribution of the losses sustained by each one of the assets at risk.

In general, and in view of the lower geographical resolution of the CGE models compared to that of the seismic risk models, a loss aggregation is required in order to sum all the losses that correspond to the same economic sector at the same economic region. Since the losses at the various assets are not numbers but correlated random variables, the aggregation process is not trivial, because of the correlation among losses for the same event.

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We will not discuss in detail how this aggregation process is handled; we just call the readers' attention to this complexity.

Therefore, as it can be noticed, the seismic risk model is used in our approach to determine two important pieces of information for each one of the members of the event set: 1) the probability distributions of the losses incurred by assets belonging to all economic sectors and regions, that is, the severity of the direct losses; and 2) the annual frequency with which that particular loss scenario takes place. We will see later how this information is used in the overall risk calculations.

So far, the use of the seismic risk model is not at all different from its classic use in risk assessment. However, in the following section we will see how these results from the classic risk model are used as inputs to the economic modelling.

3. The economic model

From the economic point of view, our initial conditions are the equilibrium among economic variables according to a Computed General Equilibrium (CGE) model. In particular, we will be using a *spatial* CGE model, a type of model that has the ability to take into account the location of the economic components.

We use the BMCH model, a fully operational spatial CGE model for Chile. The model uses an approach similar to [16,17,18] to incorporate the interregional economic structure. We use an absorption matrix as the basis to calibrate the CGE model, together with a set of elasticities borrowed from the econometric literature applied for Chile. This database allows capturing economy-wide effects through an intricate plot of input-output relations.

The current version of the BMCH model recognizes the economic structures of the 15 Chilean regions. Results are based on a bottom-up approach – i.e. national results are obtained from the aggregation of regional results. The model identifies 12 production/investment sectors in each region producing 12 commodities, a representative household in each region, regional governments and a Central government, and a single foreign area that trades with each domestic region. Two local primary factors are used in the production process, according to regional endowments (capital and labor). Special groups of equations define government finances, accumulation relations, and regional labor markets. The BMCH model qualifies as a Johansen-type model in that the solutions are obtained by solving the system of linearized equations of the model, following the Australian tradition. A typical result shows the percentage change in the set of endogenous variables, after a policy is carried out, compared to their values in the absence of such policy, in a given environment. Interregional linkages play an important role in the functioning mechanisms of the model. These linkages are driven by trade relations (commodity flows), and factor mobility (capital and labor migration). In the first case, interregional trade flows are incorporated; interregional input-output relations are required to calibrate the model, and interregional trade elasticities play an important role [19]. Table 1 shows the regions and economic sectors that constitute the model.

Table 1 – Regions and economic sectors used for Chile

Code	Name of the region	Code	Name of the economic sector
R1	Region of Arica and Parinacota	S1	Agricultural-forestry and fishing
R2	Region of Tarapacá	S2	Mining
R3	Region of Antofagasta	S3	Manufacturing industry
R4	Region of Atacama	S4	Electricity, gas and waste management
R5	Region of Coquimbo	S5	Construction
R6	Region of Valparaiso	S6	Commerce, hotels and restaurants
R7	Metropolitan Region of Santiago	S7	Transport, communications and information services
R8	Region of Libertador General Bernardo O'Higgins	S8	Financial intermediation
R9	Region of Maule	S9	Real state and housing services
R10	Region of Biobío	S10	Business services
R11	Region of La Araucanía	S11	Personal services
R12	Region of Los Ríos	S12	Public administration
R13	Region of Los Lagos		
R14	Region of Aysén Del General Carlos Ibánez del Campo		
R15	Region of Magallanes and Chilean Antarctic		

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As mentioned before, our economy is initially in equilibrium as dictated by the CGE. Then, an earthquake takes place, and it produces direct losses whose probability distributions are determined with the seismic risk model described succinctly in Section 2. The relevant losses here are those aggregated by economic sector and region. Clearly, an individual earthquake will inflict different damages to different regions – the region closest to the earthquake would very likely be more damaged- and different sectors.

Once aggregated, the direct losses by sector and by region are entered into the CGE model by means of “shocks” to the capital stock component of the sector/region combination. These shocks are nothing more that capital stock reductions, which are usually calculated as the ratio between physical loss and the total cost of the capital stock. When entering the set of shocks to the CGE model, the equilibrium conditions of the model are lost, so that we need to run the CGE model again in order to reach a new equilibrium that reflects how the economy adjusts to the received shock. The new equilibrium condition is obtained with a new value-set of the endogenous variables, which are the results of the model.

A CGE model can be made of hundreds or even thousands of variables (exogenous and endogenous); each one of them can provide us with a different type of result, either of economic or social interest. The richness of the CGE model in terms of the amount of results is extraordinary, allowing the possibility to develop a broad range of analyses. Initially, we will focus on the variables that quantify the total production of the industries; later, however, we will go back to other, non-economic types of losses.

We will define the *production loss* of sector i in the spatial region j, Lp_{ij}, as the difference between the production before and after the earthquake, for the same sector/region. In other words, as a consequence of the decreased capital stock in certain sectors and regions, hit by the earthquake, the economy attains a new equilibrium in which the production at that sector/region is smaller (or higher…) after the earthquake than before. We regard this difference as a production loss, and this will be our initial measure of indirect losses, although we will later explore the use of results related to other variables.

At this initial phase of our research, the behavioral parameters and structural coefficients of the CGE model, that is, the parameters and coefficients required to establish the relations between exogenous and endogenous economic variables, are considered deterministic. In spite of this, the outputs of the CGE model – the indirect losses – are not numbers, but random variables, because some of the inputs were also random variables. We do not want to distract the attention of the reader with details on how the probability distributions of the CGE model outputs are determined. For the time being, it suffices to say that it is possible – although computationally challenging – to obtain the probability distributions of all relevant CGE model outputs, either at the sector/region level or for any required aggregation.

At this point, we are able to compute, for each event of the event set, probabilistic direct and indirect losses. In the following section we will illustrate the way in which the most common risk measures can be obtained with the results presented so far.

4. Risk measures

4.1 Usual risk measures

The most common risk measures, both in the disaster risk management world as well as in the insurance sector, are: 1) the average annual loss; and 2) the loss exceedance curve, which indicates the average frequency with which given values of loss would be exceeded. We will focus here, only for illustration purposes, on the total direct and indirect losses. The total losses are, of course, the sum of the losses for all assets, in the case of the direct losses, and for all sectors and regions, for the case of the indirect losses.

Say, for instance, that the k-th event of the event set produces probabilistic direct and indirect losses Ld_k and Lp_k, respectively. Then, the corresponding average annual losses, AAL_d and AAL_p would be given by:

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$$AAL_d = \sum_{k=1}^{Events} \mathrm{E}(Ld_k)\, F_k \tag{1}$$

$$AAL_p = \sum_{k=1}^{Events} \mathrm{E}(Lp_k)\, F_k \tag{2}$$

where $\mathrm{E}(.)$ denotes expected value and F_k is the annual frequency of occurrence of event k. AAL_d is a quantity that is routinely computed in conventional risk analyses; AAL_{dp} is introduced in this paper.

The loss exceedance curves, $\nu_d(.)$ and $\nu_p(.)$ of direct and indirect loss, respectively, are computed with the following expressions:

$$\nu_d(l) = \sum_{k=1}^{Events} \Pr(Ld_k > l)\, F_k \tag{3}$$

$$\nu_p(l) = \sum_{k=1}^{Events} \Pr(Lp_k > l)\, F_k \tag{4}$$

where $\Pr(Ld_k > l)$ and $\Pr(Ld_k > l)$ are, respectively, the probabilities of direct and indirect losses exceeding a given value, l.

4.2 New complementary risk indicators

The richness of CGE modelling regarding the amount of interesting output variables, each one of them reflecting a different aspect of the economy, allows for the computation of many interesting and useful risk measures. For instance, besides calculating the risk measures in terms of production loss, it is possible to compute risk measures for losses of employment, GDP, GRP, tariff revenue, consumer price index, export volume, among others. The procedure for the computation is exactly the same but for the corresponding economic variable instead of the production one. These novel indicators can be very useful metrics for seismic risk management, as they provide a way to measure the losses and variation in all components of an economy facing earthquake hazard. As it will be shown below in the hands-on case study, the range of possibilities for new useful risk indicators is very broad.

5. Case study

The new methodology is applied to the Chilean case, a country that is frequently affected by large earthquakes. From an economic point of view, the Chilean economy is considered one of the most dynamic in Latin America, showing remarkable competitiveness, economic freedom and financial development. Chile is also a country with remarkable regional disparities. These characteristics make Chile an ideal place to exemplify our approach.

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As we have mentioned before, this is the first time in which a more robust and systematic connection between seismic and large-scale economic models has been attempted. Therefore, we have not been able to collect all data required to carry out a full joint calibration of the models. In this sense, our example should be considered a proof-of-concept rather than a final product. In spite of this, we believe that the results obtained in this example are quite reasonable and can be used to gauge the power of the approach, within, of course, its assumptions and limitations. In what follows we will present the main results of our example, highlighting some of the most interesting findings.

5.1 General results

The exposure database of our example is made up exclusively of non-residential buildings. The reason for this restriction is that we are trying to model damages only in capital stocks used in the production process, in the sense that their physical disruption is susceptible of being propagated in the economy of the country. The total value of these assets is given in Table 2, where we also present some general descriptors of the Chilean economy and some of the more aggregated results of our analysis.

Table 2 – General values of the Chilean economy (2014) and main aggregated results

Item	Value	Average annual loss
Total value of assets	90,030 million USD	262 million USD
Total value of yearly production	219,340 million USD	277 million USD
GDP	251,020 million USD	305 million USD
Total employment in Chile	6,671,072 workers	7,786 workers
Total export volume	83,102 million USD	62 million USD

We will express seismic risk, due to direct or indirect losses, in terms of standard risk metrics. We will use the average annual loss (see Eqs. 1 and 2) and the loss exceedance curve (see Eqs. 3-4). Let us start presenting the results at the country level.

Fig.1 shows the loss exceedance curve of Chile's direct and production losses. It must be noted that we are representing the loss exceedance curve with the return period (the inverse of the exceedance rate) in the horizontal axis and the loss values in the vertical axis.

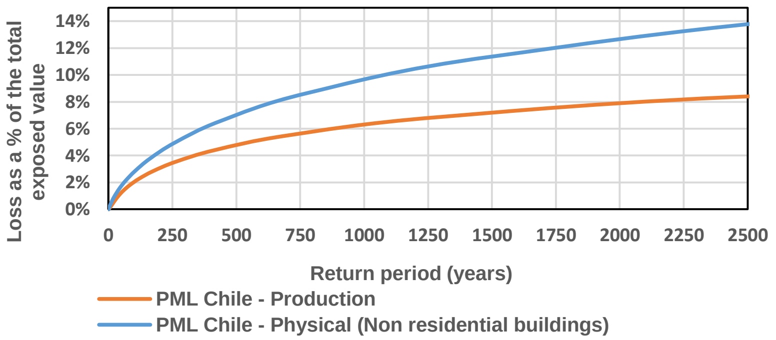

Fig. 1 – Loss Exceedance Curves of direct and indirect (production) losses

The AAL of direct losses has been estimated as 302 million dollars, which is 0.29% of the total value of the exposed assets. In turn, the AAL of production losses reaches 277 million dollars, that is, 0.126% of the total yearly production of the country, valued at 219,340 million dollars.

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Fig.2 shows the AAL by economic sector, both for direct and production losses. Similarly, Fig.3 depicts the AAL by region of the country for both types of losses, together with an indication of the seismic hazard level, expressed in terms of the peak ground acceleration (PGA) associated to a return period of 475 years. In the case of Fig.4, it presents loss exceedance curves of production losses, by region and by economic sector.

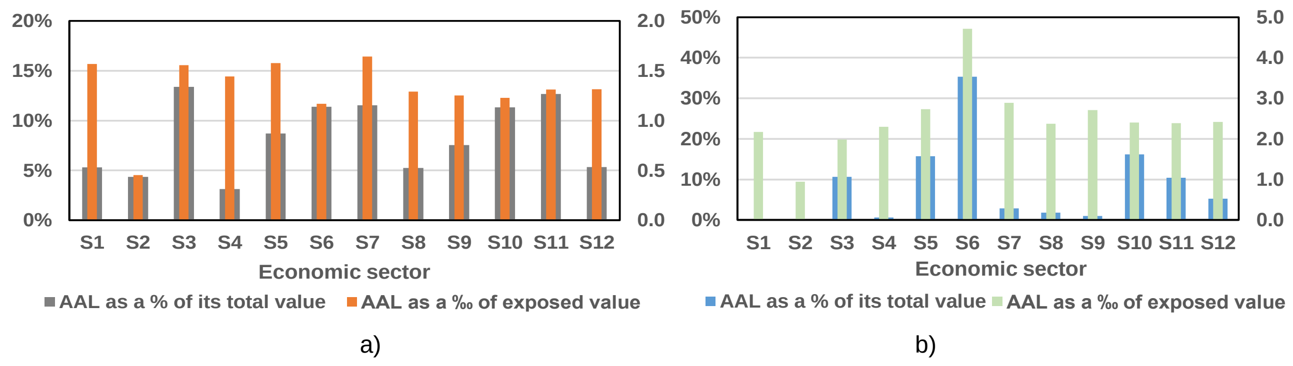

Fig. 2 – Average annual loss by economic sector as a percentage of its total value (gray and blue) and as a fraction (per mile) of its exposed value (orange and green): a) production losses, b) physical losses.

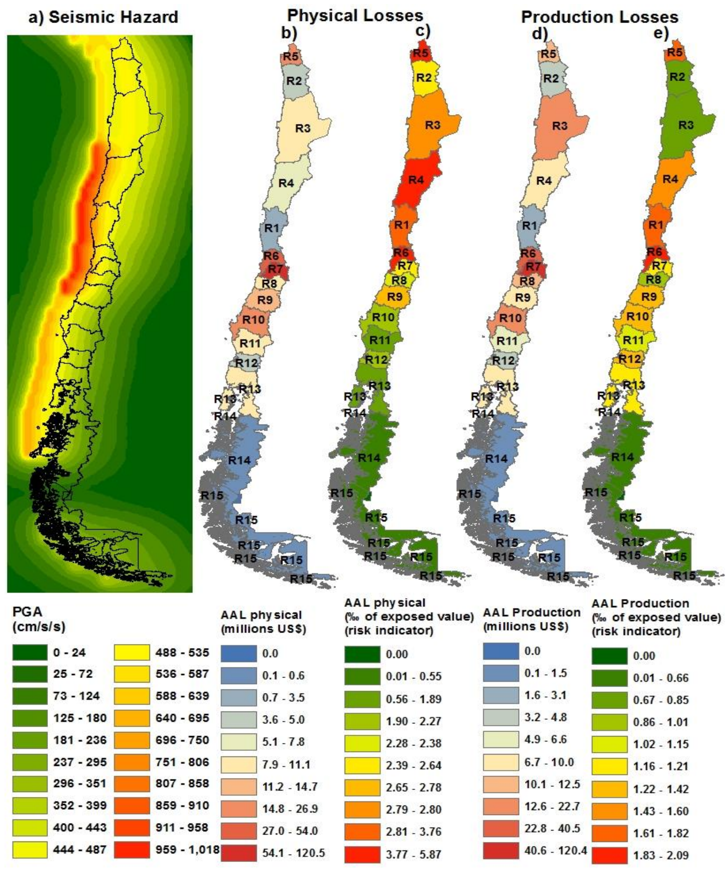

Fig. 3 – a) Seismic Hazard for Chile, expressed in terms of the peak ground acceleration (PGA) associated to 475 years of return period. Average annual loss due to physical damage of assets by region: b) in millions of US$ and c) as a fraction (per mile) of its exposed value (risk indicator). Average annual loss in production by region: d) in millions of US$ and e) as a fraction (per mile) of the total annual production (risk indicator). Physical losses account exclusively for non-residential buildings.

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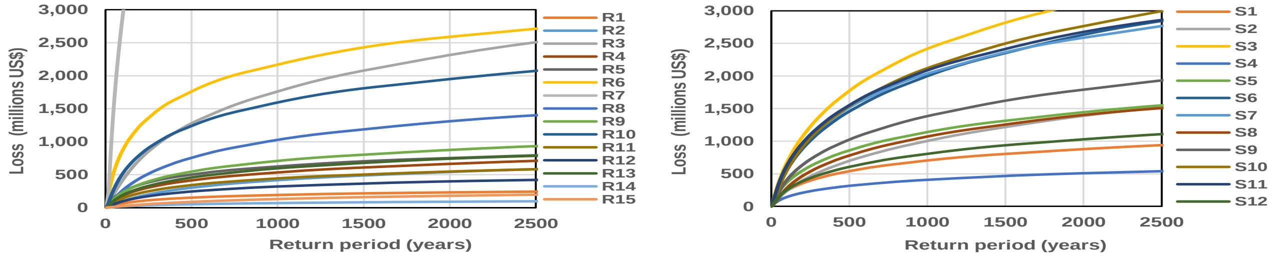


Fig. 4 – Production loss exceedance curves by region (left) and by economic sector (right).

We can also compute risk results at the regional level as shown in Fig.5, which presents loss exceedance curves of production losses and AAL, by economic sector, for two regions of Chile, located in the economic core of the country.

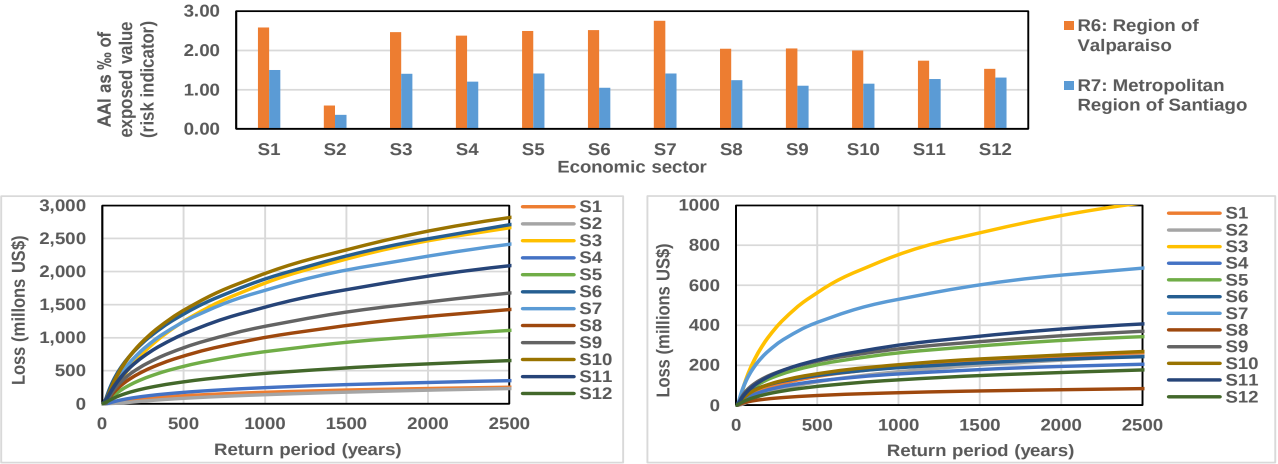
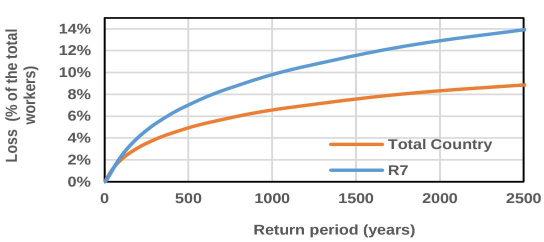


Fig. 5 – Top: Average annual loss by economic sector as a fraction (per mile) of its exposed value (risk indicator) for Metropolitan region of Santiago (blue bars) and for region of Valparaiso (orange bars). Bottom: Production loss exceedance curves by economic sector for Metropolitan region of Santiago (left) and for Region of Valparaiso (right).

5.2 New risk indicators

Employment: the average annual loss of employment due to seismic hazard is 7,786 workers, or 0.115% of the total employment in the country. Fig.6 shows the employment loss-exceedance curves, while Fig.8 shows AAL of employment by region of the country.

Gross domestic product (GDP): the average annual loss in the GDP for Chile due to seismic hazard has been estimated in 305 million dollars, that is, 0.122% of the total GDP of the Country. Fig.7 shows the GDP loss exceedance curves, while Fig.8 shows AAL of Gross Regional Product (GRP) by region.



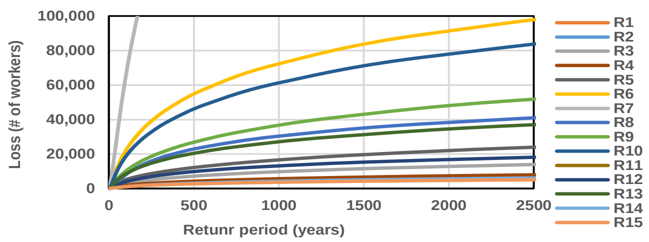


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Fig. 6 –Employment loss exceedance curves. Left: for the whole country and region 7 (Metropolitan Region of Santiago). Right: by region of the country.

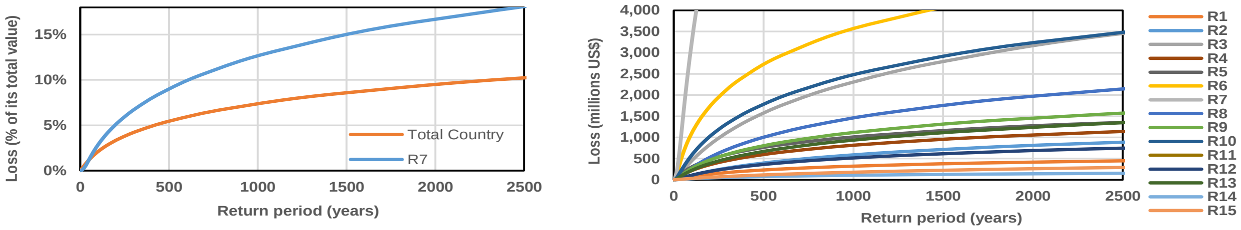

Fig. 7 –Left: gross domestic product loss exceedance curves for the whole country and region 7 (Metropolitan Region of Santiago). Right: loss exceedance curves of each gross regional product.

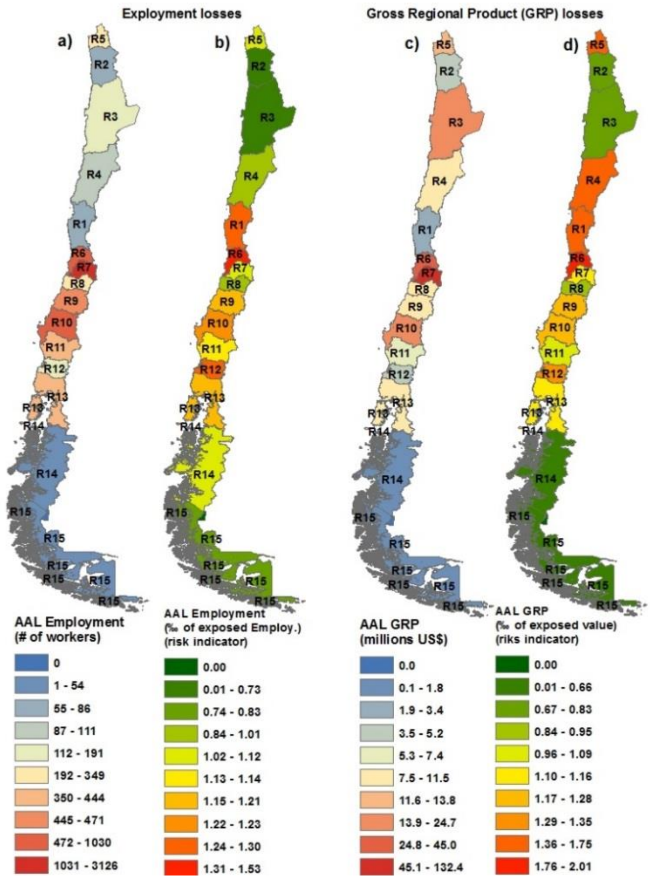

Fig. 8 –Average annual loss of employment by region: a) in terms of number of workers and b) as a fraction (per mile) of total employment (risk indicator of employment). Average annual loss in the gross regional product (GRP): c) in millions of US$ and d) as a fraction (per mile) of the total GRP of the region (GRP risk indicator).

Consumer price index (CPI): more than a quantitative measure, it is an example of a qualitative indicator of risk than can be used to see the effect of earthquakes on inflation either at the country level or at regional level. Fig.9 illustrates these indicators.

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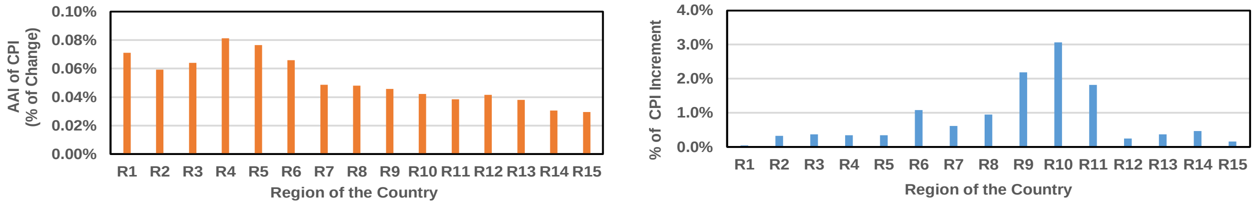

Fig. 9 – Left: average annual increment of the CPI by region of the country. Right: Increment of CPI by region given the occurrence of a simulated event (Mw8.8 Maule earthquake 2010)

Export volume: the average annual loss in the export volume of Chile caused by the seismic hazard has been estimated in 62 million dollars, that is, 0.75% of the total export volume of the country. Fig.10 shows the loss exceedance curves of export volume computed for Chile.

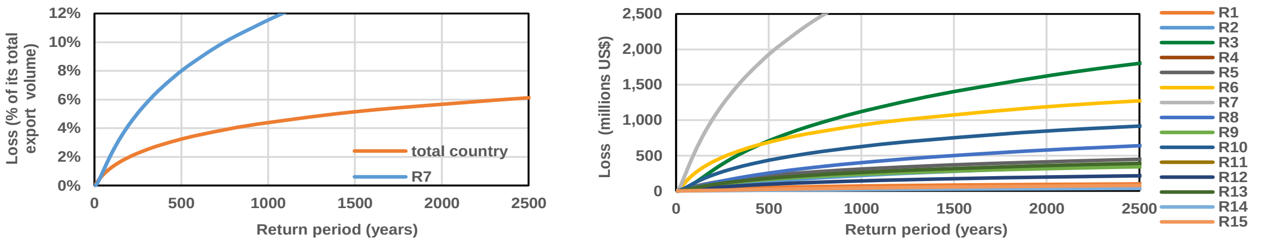

Fig. 10–Loss exceedance curves of export volume. Left: for the whole country and region 7 (Metropolitan Region of Santiago). Right: by region of the country.

6. Conclusions

With the approach presented here, we have shown how the Computable General Equilibrium (CGE) model and the probabilistic model for seismic risk assessment are able to work together allowing a complete probabilistic glance of the consequences of the earthquake disturbance into the full economy. We were able to successfully deal with the business interruption matter, exemplifying our methodology with the computation of the standard risk metrics respect to production loss, that is, the average annual production loss (AAL) and the loss exceedance curve of production losses for Chile. We also have shown how our approach can go beyond of business interruption aspects and harnessing the richness of the CGE modelling, we have computed the standard risk metrics for different economic variables, for example regarding to losses of employment, GDP, GRP, export volume and consumer price index. We are inclined to believe that these new metrics would be positioned in the future as useful and complementary risk indicators in the field of catastrophe modelling.

The production AAL and the production loss associated to 250 years return period for Chile were 0.126% and 3.5% of its total yearly production. From the authors' experience, these results look reasonable in comparison with the direct economic losses obtained. The production losses, on annual average, are about 43% of the direct losses, in relative terms to their corresponding exposed values (AAL of physical loss was 0.29% of the total value of exposed assets). Furthermore, we saw that for less severe events with low return periods (up to 50 years), the economic losses on the production follows a positive proportional relation with direct losses, which goes from almost zero up to reach a maximum value (around 70% of the direct impact, in relative terms to their corresponding exposed values). For earthquakes with return periods between 50 to 400 years, we observed that the economic impact on the production maintains its maximum value respect to direct impacts. In a third stretch, as soon as the earthquakes become less probable and more severe (return periods higher than 400 years), the production losses present a very soft negative proportional relation with direct losses. For instance, for a return period of 10,000 years, the production losses were 55% of the direct losses and for 100,000 years, 50% of the direct losses (in relative terms to their corresponding exposed values).

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