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Government liabilities for disaster risk in industrialized countries: a case study of Australia

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ABSTRACT
This paper explores sovereign risk preferences against direct and indirect natural disasters losses in industrialized countries. Using Australia as a case study, the analysis compares expected disaster losses and government capacity to finance losses. Utilizing a national disaster loss dataset, extreme value theory is applied to estimate an all-hazard annual loss distribution. Unusually but critically, the dataset includes direct as well as indirect losses, allowing for the analysis to consider the oft-ignored issue of indirect losses. Expected annual losses (direct, and direct plus indirect) are overlaid with a risk-layer approach, to distinguish low, medium and extreme loss events. Each risk layer is compared to available fiscal resources for financing losses, grounded in the political reality of Australian disaster financing. When considering direct losses only, we find support for a risk-neutral preference on the part of the Australian government for low and medium loss levels, and a risk-averse preference in regard to extreme losses. When indirect losses are also estimated, we find that even medium loss levels are expected to overwhelm available fiscal resources, thereby violating the available resources assumption underlying arguments for sovereign risk neutrality. Our analysis provides empirical support for the assertion that indirect losses are a major, under-recognised concern for industrialized countries. A risk-averse preference in regard to medium and extreme loss events recommends enhanced investment in both corrective and prospective risk reduction in relation to these risks level, in particular to reduce indirect losses.

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KEYWORDS
Natural disasters; fiscal risk; direct and indirect losses; risk-layer; Australia

1. Introduction

The recent Global Assessment Reports on disaster risk (UNISDR, 2013, 2015a, 2017) issued a stark warning that economic losses linked to disasters will continue to escalate unless there is a significant increase in investment in risk reduction, and disaster risk management becomes a core part of investment strategies. Globally, the need to proactively redirect growth in asset exposure and plan for disaster events under differential vulnerability is increasingly prominent in the discussion on disaster risk management (IPCC, 2012;

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Welle & Birkmann, 2015). The recent Sendai Framework for risk reduction stated that countries should adopt a concise, focused and forward-looking framework for disaster risk reduction (UNISDR, 2015b). Similarly, the Global Risk Report published by the World Economic Forum (2014) concluded that better efforts are needed to understand, measure and foresee the evolution of interconnected risk, e.g. global trade and food networks (Centeno, Nag, Patterson, Shaver, & Jason Windawi, 2015). Part of this paradigm shift calling for a more proactive approach can be explained by the fact that disaster risk has increasingly been recognized as a major challenge to economic growth and overall societal well-being (Uitto & Shaw, 2016).

Key private sector stakeholders in disaster risk management include property owners, insurers and re-insurers, as well as the capital market (Grossi & Kunreuther, 2005). Especially in industrialized countries, the private sector (re)insurance system is a major source of funding for disaster recovery (Noy, Kusuma, & Nguyen, 2017). From the public-sector perspective, governments are now key players (Cardenas, Hochrainer, Mechler, Pflug, & Linnerooth-Bayer, 2007; IPCC, 2012). Governments are usually responsible for covering a significant part of public-sector total disaster losses due to their explicit (e.g. infrastructure restoration) or implicit (e.g. insurer of last resort) liabilities (Mitchell, Mechler, & Peters, 2014). As evidenced following the Christchurch, New Zealand earthquake in 2011, governments are also responsible for ensuring that affected economies make a full recovery. Different options exist for governments to finance disaster losses and they are usually grouped into ex-post, i.e. after the event, or ex-ante, i.e. proactive, instruments (Gurenko, 2004). For example, after an event the government may divert budget or take loans; use dedicated contingency reserves such as catastrophe funds; or activate insurance arrangements which are set up ex-ante to finance the losses (a comprehensive list of options can be found in Ghesquiere and Mahul (2007).

This paper focuses on national governments in industrialized countries, exploring the need for proactive investment in ex-ante risk reduction and contingency planning. Using Australia as a case study, we ask when and how governments should invest in ex-ante risk-financing measures. We show that the substantial fiscal and economic risks associated with disasters, and an absence of proactive risk management, are not only a concern for developing countries; wealthy and developed countries, such as Australia, are potentially subject to substantial and unacknowledged risk, which proposes a significant threat to government fiscal stability and medium to long-term economic growth. We conclude that instead of direct losses – which are of primary interest in the developing country context – for developed countries indirect losses pose a substantial risk and hence should be considered when determining the need of proactive investment. Furthermore, we suggest that a risk-layer approach may be helpful to group management instruments according to different risk levels a country is exposed to.

Government ex-ante risk-financing options each have advantages as well as disadvantages. Particularly pertinent to this discussion is sovereign risk preference, or how risk averse a government is. Governments who are risk averse are inclined to minimize risks to themselves and society even when such costs exceed the annual expected costs of disaster events. In the seminal paper by Arrow and Lind (1970) on the role of sovereign risk preference, the authors proposed that governments should behave risk-neutrally, as they are considered the entity best suited to deal with risk via efficiently pooling and spreading potential losses. Specifically, the argument did not favour neglecting risk, rather Arrow and

Lind suggested a fiscal management approach based on expected values only: '[…] the government should behave as an expected-value decision maker' (Arrow & Lind, 1970, p. 366). This means governments, because they can afford to refinance quickly, should only plan for and reserve for average costs incurred over a longer time horizon, and thus do not need to pay close attention to variability in costs.

Arrow and Lind (1970) themselves express many caveats to the government risk-neutrality assumption (for a general discussion on the Arrow-Lind Theorem, see Gopalakrishnan (2014)). Here we address the arguments in relation to extremes. Hochrainer and Pflug (2009) have shown that in theory, the Arrow-Lind Theorem fails in relation to extremes. Mechler (2004) analysed qualitatively which assumptions violated the Arrow-Lind Theorem for extremes and identified circumstances under which it is justifiable for governments to act as risk-averse agents; most important here are circumstances where there are constraints on resources for financing disaster losses and associated requirements. We are therefore interested in situations where expected damages might overwhelm resources for financing losses. To investigate this, Cardona, Ordaz, Reinoso, Yamín, and Barbat. (2012) and Hochrainer-Stigler, Mechler, and Mochizuki (2015) propose an approach which compares the financing resources available for the government with the risk (in terms of probability) of experiencing losses. The key motivator behind this approach is that disaster events which exceed financial coping capacity will cause additional and substantial indirect, long-term effects, e.g. business interruption. As the government cannot go bankrupt in the sense that it disappears (like businesses in markets) it should take these costs explicitly into account in its decision-making. In other words, a government should behave in a risk-averse manner for all risks (direct and indirect) it cannot cope with by utilizing all currently available resources.

Taking such a risk-based approach has several advantages, including that it can help identify sovereign risk preference by comparing available financing for disaster losses and expected annual loss. For example, while absolute direct losses (i.e. losses caused by the natural hazard event itself) may be high in industrialized countries, available financial resources are usually large enough to cope with losses. On the other hand, in developing countries direct losses may be small in absolute terms, but they are difficult to cope with due to lack of available financial resources. Consequently, in developing countries risk aversion can be expected even for very small risks (in terms of losses) while in industrialized countries risk aversion is very often recommended for events with very large direct losses (Hochrainer-Stigler et al., 2015).

When conceptualizing and estimating expected losses from disasters, the focus to date has been on direct losses. This is because direct losses are the most visible and straightforward to estimate, hence the vast majority of disaster loss data accounts for direct losses only. While a risk-based approach for direct losses can give important insights on sovereign risk preferences, we argue that for industrialized countries indirect losses from disasters have to be explicitly considered. Without the incorporation of indirect losses, the cumulative effects of potential disasters are missed and government fiscal risk is drastically underestimated. A comprehensive estimation of government fiscal risk is required for determining levels of sovereign risk aversion and subsequently the appropriate level of investment in proactive disaster risk management. We claim that this is especially relevant for industrialized countries as their relative availability of financial resources may bias the view towards a low financial vulnerability to disasters while in actuality, due to indirect consequences, they are highly vulnerable.

We estimate available financial resources and expected annual loss including both direct and indirect effects for Australia, gaining insight into the need for increased investment in ex-ante risk reduction. In this way we demonstrate our approach using Australia as a case study where (as in many other industrialized countries) there is an expectation that in the event of a disaster funds will be available for immediate humanitarian support, reconstruction and the ongoing costs to ensure affected communities and economies recover quickly and well. In other words, we assume that governments are responsible – via explicit or implicit liabilities – for all or part of the costs associated with direct and indirect impacts of the disaster.

The estimation of economic indirect effects due to natural disasters is still very challenging and far from resolved (see Hallegatte & Przyluski, 2010). Most studies dealing with this issue utilize macro-economic modelling approaches, which can only estimate average indirect effects, or effects under a limited number of scenarios (Cavallo & Noy, 2011). In this paper, instead of using a modelling approach we apply extreme value statistics (Embrechts, Klüppelberg, & Mikosch, 2013) to a recently produced dataset of direct and indirect losses for Australia. This enables a risk-based comparison of financing needs for all potential hazard events at the national level, considering both direct and indirect effects. We then apply a so-called risk-layer approach where we distinguish between different event probabilities. Our analysis finds that for the case of Australia there is a need for proactive, ex-ante risk management even for medium-level risks (50–100 year return periods), due to high indirect losses. We show that the substantial fiscal and economic risks associated with disasters, and an absence of proactive risk management, are not only a concern for developing countries; wealthy and developed countries, such as Australia, are potentially subject to substantial and unacknowledged risk, which proposes a significant threat to government fiscal stability and medium to long-term economic growth.

In the next section we first structure our discussion around the concept of contingent liabilities. We then introduce how we model the risk of extreme events, and ways to incorporate risk management instruments within a risk-layer approach. We then describe the database for the case study application. Section 3 presents our estimates of expected losses and government capacity to cover these losses, and compares them within the risk-layering framework. Section 4 discusses our findings and Section 5 concludes.

2. Theory, methods and data

2.1. Contingent liabilities

Identification of government liabilities exposed due to disaster events is the first step towards understanding possible consequences for government fiscal stability. Governments typically plan and budget for direct liabilities, that is, liabilities that manifest themselves through certain and annually recurrent expenditures. These liabilities can be termed explicit (as recognized by law or contract); however, implicit liabilities (e.g. due to moral obligations or public expectations) should also be assumed. In contrast to direct liabilities, costs associated with disaster event losses enter the balance sheet as contingent liabilities (marked in italics in Table 1), i.e. obligations that arise only when an event occurs. Here one

Table 1. Governments' explicit and implicit, direct and contingent liabilities.

Liabilities	Direct obligation in any event	Contingent obligation if a particular event occurs
Explicit Government liability recognized by law or contract	• Foreign and domestic sovereign borrowing, • Expenditures by budget law and budget expenditures	• State guarantees for non-sovereign borrowing and public and private sector entities • Reconstruction of *public assets*
Implicit A 'moral' obligation of the government	• Pension and health care expenditure • Future recurrent costs of public investment projects	• Default of subnational government or public or private entities, • Banking failure • *Disaster relief and recovery assistance* • *Ensuring that affected economies continue to function well*

Note: DRM relevant items in italics. Source: Modified after Polackova Brixi, and Mody (2002).

can also distinguish between explicit and implicit liabilities. Explicit contingent liabilities are those costs that deal with the reconstruction of infrastructure destroyed by events for which the government is explicitly responsible for. In contrast, disaster-related implicit contingent obligations are associated with providing relief and ensuring that affected communities and economies continue to function well – commonly considered as a moral liability for governments. We restrict our attention in this paper to explicit and implicit contingent liabilities (of national governments).

If a disaster event occurs the government can expect contingent explicit and implicit liabilities (either due to direct or indirect losses), which it needs to finance through ex-post measures such as budget diversion. However in contrast, for a proactive approach the contingent liabilities due to extremes need to change from contingent liabilities to direct ones, which requires that they can be properly defined so that they can be adequately quantified. In order to do this they must be assessed in a risk-based manner. In other words, potential future losses and their corresponding probabilities must be estimated, which we discuss next.

2.2. Assessing risks from extremes

There are two general approaches to a probabilistic assessment of risk from extreme events: (1) catastrophe modelling, and (2) applying extreme value theory (EVT) using data from past events. Within a catastrophe model, disaster risk is modelled as a function of the hazard, the exposed elements and their physical vulnerability (Woo, 2011). A catastrophe modelling approach is extremely data intensive; the hazard, exposure and vulnerability modules all require data which are not typically available for multiple hazards at the national scale – which is the scale of our analysis. Furthermore, the data availability problem is compounded by the fact that extreme risks are particularly difficult to model. This is because of the paucity of data points representing extreme events in the past, which are by definition rare.

The alternative to catastrophe models is to use data on past loss events and apply EVT and statistics to estimate extreme risk (Embrechts et al., 2013). It should be noted that the methods used in EVT for dealing with extreme risk are quite different from the usual assessment of frequent risks. In particular, much real-world data follow a normal distribution and the estimation of distributional parameters can be done based on the assumptions associated with such a distribution (Reiss & Thomas, 2007). However, for extremes, the tails are much fatter than classical distributions predict and while standard density estimation techniques fit well where data have the greatest density, they can be severely biased for estimating tail probabilities. As we use an EVT approach here we provide more detail about the estimation procedure below.

EVT deals with the stochastic behaviour of the maximum (or minimum) of independent and identically distributed (i.i.d.) random variables. The distributional properties of extremes (maximum or minimum) are determined by the upper (or lower) tails of the underlying distribution and can be evaluated by means of statistical procedures. Extreme value distributions are obtained as limiting distributions of (standardized) maximum values in random samples of increasing size. For example, Fisher and Tippett (1928) have shown that the distribution of the maximum (if not degenerate, i.e. a distribution which only takes a single value) can only be one of three types (the Gumbel, the Weibull or the Frechet distribution). Especially for the purposes of statistical estimation, a one-parameter representation of the three standard cases in one family is very useful. Jenkinson's (1955) introduction of the Generalized Extreme Value distribution given below is widely accepted in the literature as the standard representation for extreme risk.

Definition 1. (Jenkinson, 1955): The generalized extreme value (GEV) distribution is defined by

$$H_\xi(x) = \begin{cases} \exp\left(-(1+\xi x)^{1/\xi}\right) & \text{if } \xi \neq 0 \\ \exp(-\exp(-x)) & \text{if } \xi = 0 \end{cases},$$

where $1+\xi x > 0$ and ξ is called the shape parameter.

The classic statistical modelling approaches for estimating the extreme value parameters are the so-called 'Block Maxima' and the 'Peaks over Threshold' methods (Embrechts et al., 2013). The Block Maxima approach is usually applied for estimating the GEV as shown in Definition 1 above. The observation period is divided into non-overlapping time periods of equal size and attention is restricted to the maximum value within each period or block – hence 'block maxima' – e.g. days, months or even years. However, a key problem arises when using this approach: the total sample tends to be reduced considerably and estimations are then based on only a few data points. To avoid such problems the Peaks over Threshold approach can also be applied. For this method data points which are above some threshold level, say u, are examined. In the case where a non-degenerate distribution exists, a distributional approximation for the scaled excesses over the high threshold u can be formulated which gives rise to the following definition of a Generalized Pareto Distribution (GPD):

Definition 2. The generalized Pareto distribution (GPD) is defined as

$$G_\xi(x) = \begin{cases} 1-(1+\xi x)^{-1/\xi} & \text{if } \xi \neq 0, \\ 1-e^{-x} & \text{if } \xi = 0, \end{cases}$$

where $x \geq 0$ if $\xi \geq 0$ and $0 \leq x \leq -1/\xi$ if $\xi < 0$.

For more details about the theoretical background as well as statistical assumptions needed to apply the EVT or catastrophe modelling methodology, see Reiss and Thomas (2007), Woo (2011) and the seminal book by Embrechts et al. (2013). What is critical to note here is that the outputs of both catastrophe modelling and EVT approaches are analogous – they both are able to produce an annual loss distribution, i.e. the x-axis represents losses in monetary terms, while the y-axis represents the probability that losses do not exceed a given level of damage (therefore sometimes also called the 'event axis'). For example, a value of 0.98 on the event axis means that with a probability of 98% the annual losses will be smaller or equal to *x*. Or in other words, there is a probability of 1 in 50 per year that losses will exceed this level of damage (see as an example Figure 3). The same principle can be used for all other events. The loss distribution itself is tremendously important for risk management purposes because various risk measures can be calculated from it, e.g. average annual losses and losses for various return periods (see Pflug & Roemisch, 2007). Estimating a loss distribution enables the determination of the expected return on various risk reduction investments (Mechler et al., 2014). It also enables one to determine risk layers and possible associated risk reduction and management strategies, as discussed next.

2.3. Risk layering

A comprehensive disaster risk management strategy requires investment in reducing risks and risk financing, as well as investments in both ex-ante and ex-post disaster management. Finding the right balance between these investments is not a straightforward proposition. This is because the ideal mix depends on the wider costs and benefits of the different activities, their complex interactions (e.g. financial instruments, through incentives, can influence prevention activities) and their social acceptability. Costs and benefits, in turn, depend on the nature of the hazard, exposure and vulnerability. The risk-layering approach (Figure 1) has been proposed as one way to conceptualize the relationship between risk and the appropriateness of disaster risk management investment options (Linnerooth-Bayer & Hochrainer-Stigler, 2015).

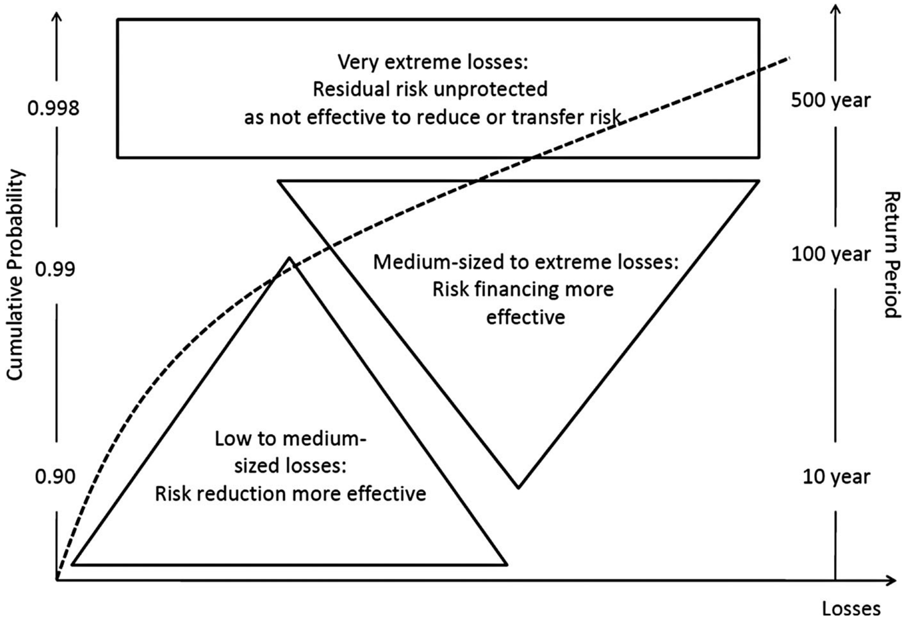

Figure 1. The layering approach for risk reduction and risk financing using a loss distribution. Source: Adapted after Mechler et al. (2014).

For the low- to medium-loss events that happen relatively frequently, risk reduction is likely to be cost-effective for reducing burdens. This is because the costs of risk reduction often increase disproportionately with the severity of the consequences. Moreover, individuals and governments are generally better able to finance the impacts from lower consequence disasters from their own means, such as savings or budget reserves, then utilizing risk-financing instruments for the middle- and high-risk layers were their own capacity to finance is limited. For this reason, it is generally advisable to reserve risk-financing instruments for lower probability/higher impact disasters that have debilitating consequences (catastrophes). Finally, as shown in the uppermost layer of Figure 1, individuals and governments will generally find it too costly to use even risk-financing instruments against very extreme risks occurring less frequently than, say, every 500 years.

To-date estimates of risk layers have primarily been derived from loss distributions which account for direct risk only (Figure 1). In other words, they account for losses which are caused by the disaster event itself, and do not include indirect and long-term consequences. We argue that the inclusion of these losses within a risk-layer approach may be beneficial for determining appropriate options. This is because they provide fuller information on levels of risk exposed and what additional options may be appropriate for mitigating these risks (e.g. increase of redundancies to decrease the risk of network effects such as cascading events). Relatedly, we argue that considering direct risks only vastly overestimates financing capacity. Hence, an inclusion of indirect losses within a risk-layer approach gives important additional details about which risks are estimated to overwhelm limited financing resources. We will demonstrate this through a case study example for Australia which is based on a recently produced unique dataset discussed next.

2.4. Country-level disaster data: the Australian disaster cost database

There is a strong demand for information on losses from natural disasters in Australia from policy-makers, researchers and the community to help estimate the current and potential risk (Ladds, Keating, Handmer, & Magee, 2017). This demand has been partly satisfied by the 2001 BTE (Bureau of Transport Economics) report: The Economic Costs of Natural Disasters in Australia. There is also a major proprietary dataset held by Risk Frontiers which is mainly concerned with insurance issues, a dataset from ICA (Insurance Council of Australia) on insurance losses from 1967–present (publicly available until mid 2014), and EM Knowledge (previously EMATrack). EM Knowledge is a long running dataset on disaster loss in Australia, but it is not suitable for trend analysis, and is largely dependent on media reports and the ICA database. In addition, many agencies hold time-series data on losses from fires (and others hazards), but these are usually neither continuous nor comprehensive records, nor available outside the agency concerned. Of these sources, the 2001 BTE report is the only publicly available consistent time-series of full disaster loss by hazard and by all Australian jurisdictions. The ICA dataset is consistent but deals only with insurance payouts and no metadata are available. This insurance dataset includes events with at least 10 million dollars in loss, and was used by BTE (2001).

However, the BTE report is very dated. To address this, an update project was funded by an NEMP (Australian National Emergency Management Projects) grant. The project updated the disaster loss data as well as the thinking underpinning the analysis presented in the 2001 report. The new database, called AUS-DIS (Ladds, Magee, & Handmer, 2015), covers reported Australian disaster losses from 1967 through to 2013. It drew on a number of local and international sources with clear metadata, explicit sourcing and reliability estimates for each data-point. Under the criteria of >$10 million or three fatalities, there are 313 disasters over the period covered by the dataset. The database is to be available on request. The loss estimates were normalized according to the consumer price indices and other dimensions including population and exposure (see Ladds et al., 2017 for more details). Loss estimates for each event include (1) insured losses; (2) reported losses; and (3) total losses.

Insured losses, as the name suggests, represent the value of insurance claims awarded as a result of the disaster. Insurance losses are typically considered a very limited subset of all losses since they only represent losses which have been insured; in the case of the AUS-DIS dataset, insured losses represent only insurance payments awarded to households, not businesses. Reported losses represent 'direct' economic losses, which arise from the destruction or damage of physical assets due to the hazard event. Total losses represent direct (reported) losses plus indirect losses, where indirect losses are changes to flows of goods and services, including business disruption, that are much more difficult to assess. These are made up of emergency response, disruption to households, disruption to business, disruption to public services, disruption to agriculture, road transport delays and disruption to other networks (e.g. ports, bridges, rail). We use all three loss variables for our analysis.

3. Results

Our analysis begins with a fiscal risk assessment of Australia by examining the current risk management practices of the Australian government. We then utilize EVT to estimate a loss distribution using the AUS-DIS database. Finally, the two are combined to identify potential risk management options within the risk-layer framework. All figures described below are estimated using Ladds et al.'s (2015) AUS-DIS database (see also Ladds et al., 2017).

3.1. Risk-financing instruments and liabilities in Australia

Losses due to natural disaster events in Australia are high, and this is true for the private as well as public-sector risk bearers. For example, from 1970 to 2013 (household) insured losses exceeded 21 billion USD, with an annual average loss rate around 500 million USD. While insurance usually only covers private-sector asset losses, government fiscal costs include a variety of expenditures at different levels of government and activities related to pre- and post-disaster management. As is typical around the world, pre-disaster investment in risk reduction is much lower than post-disaster expenditure on response and recovery. From 2002 to 2015, approximately 96% of Australian Government disaster-related expenditure was on post-disaster initiatives, amounting to more than 13 billion USD, with the National Disaster Relief and Recovery Arrangements (NDRRA) accounting for the bulk of the expenditure. However, at the state and territory level, the proportion of disaster-related expenditure spent on post-disaster initiatives varies considerably, ranging from 40 to over 90% (NDFA, 2014a). State and territory governments' NDRRA expenditure, which is not reimbursed by the national government, is shared among jurisdictions through a so-called process of horizontal fiscal equalization. For example, the high expenditures in Queensland in recent years are partially balanced out by receiving a higher amount of the nationally collected GST (Goods and Services Tax, collected and distributed by the Federal Government) redistribution in subsequent years (NDFA, 2014b). As Figure 2 indicates, different risk bearers at various scales, including households, business, governments at different levels and the broader community, have different responsibilities, and funding and financing options when it comes to risk reduction (mitigation) and recovery, including insurance, in Australia.

The NDRRA has undergone various changes over time as new policies have been added and determinations have been released, including its scope and eligibility (for more details, see Pikusa, 2015). Furthermore, the Australian Government Disaster Recovery Payment (AGDRP) provides immediate relief assistance to private-sector entities and therefore also takes some responsibility for the private sector (see Table 1), although it does so with very modest funds. For comparative purposes, between 2009 and 2013 relief and recovery expenditure was 5.9 billion USD for the NDRRA and 1.1 billion for the AGDRP (NDFA, 2014b). While the various state and territory governments in Australia have various financing options, including insurance facilities which transfer risk to the international financial system, our focus is on the national (federal) level which usually has to bear the largest burden and also responsibility (as insurer of last resort) in the event of large disasters.

Apart from the funding instruments, their use and resource availability in the past, the critical question for proactive risk management is what level of resources could be available in a most optimistic setting. Unfortunately, such information is difficult to gather, in part due to the lack of available estimation methodologies. To the authors' knowledge there is only one broad-brush approach available, by Hochrainer-Stigler, Mechler, Pflug, and Williges (2014), which presents one possible estimation procedure. The approach estimates available fiscal resources separated into diversion from budget, and the possibilities to gain loans. Applied to Australia, such an analysis indicates that currently a maximum of around 10 billion USD could be diverted from the budget, and around 16 billion USD could be taken in credit form, totalling around 26 billion USD annually. This is approximately twice the amount of Australian government disaster-related expenditure made available from 2002 till 2015. Hence, we find substantial fiscal capacity available, even if these are not reflected in past funding or may be politically unfeasible. We now turn to the question of whether this available fiscal capacity is adequate to meet the costs associated with national estimated disaster risk, especially when indirect effects are considered.

3.2. Estimates of disaster risk in Australia

Based on the AUS-DIS database we estimated extreme value distributions, both GEV (Definition 1) and GPD (Definition 2), for insured, direct, and total (direct and indirect) losses. As the government budget planning process is done on an annual basis, we estimated annual loss distributions, which include a sum of all losses from all-hazard loss events experienced in each year. Hence, the loss distributions are for multi-hazards; this is considered appropriate since our analysis is concerned with fiscal coping, irrespective of the specific hazard event causing the losses. The summed-up annual losses were used as the input data for the extreme value statistical analysis, which then generated the annual loss distributions.

Before applying EVT one first needs to test for the stationarity of the normalized data. This means one needs to investigate whether there was a trend in disaster losses over time, for instance, due to climate change. To test for stationarity an augmented Dickey Fuller Test was performed for the data; this produced some indications for non-stationarity (e.g. an upward trend in annual losses). However, the alternative non-parametric Phillips Perron tests suggested stationarity. Given the normalization procedure already applied to the data (see Ladds et al., 2017 for details), it may be the case that climate change effects indeed account for a possible non-stationarity trend in the time-series. However, the accumulation of the costs over a given year for various hazards makes it difficult to specify the drivers of the trend. Furthermore, the rather large events which have occurred in recent years, which contribute substantially to the upward trend, may still only be a coincidence. We therefore assume at least weak stationarity which allows us to apply EVT on the condition that we provide a lower bound estimate. We argue that this is adequate since climate change effects are predicted to increase the frequency and severity of climate hazards (and hence disaster losses) only in the future (IPCC, 2012). We see this as an important additional topic for analysis in the future but the focus in this paper is on losses and fiscal coping rather than changes in losses over time.

To estimate the model parameters for the GEV and GP loss distributions the usual maximum likelihood approaches were applied. Furthermore, as it is typical when applying EVT, the parameter estimates and diagnosis of model fits was largely based on graphical analysis of relevant plots including probability plots, quantile plots, return level plots, density plots as well as profile log-likelihood plots (for a discussion of these techniques see Embrechts et al., 2013). We then used the estimated parameters as starting values for an optimization algorithm which gradually adapted the parameters to the best fit with the empirical distribution, using the minimum distance to the empirical distribution as the objective function. This was performed to test the robustness of the parameter estimates, e.g. large deviations would indicate estimation problems using maximum likelihood. The results for this comparison are shown in Figure 3. The figure indicates that the differences between the empirical, maximum likelihood and GEV distributions are quite small. We therefore preceded with the GEV estimates as shown in Table 2.

As discussed above, the estimated extreme value loss distribution is required for risk management considerations. In addition to the distribution based on reported losses shown in Figure 3, annual loss distributions were estimated in the same way using insured and total losses data. With these distributions we were able to determine the probability of past annual loss levels. For example, according to our calculations, the reported loss events in 2011 with costs of around 13.4 billion USD are rather a frequent occurrence, with an annual return period of 30 years. Annual total losses in the magnitude of 2011 (26.5 billion USD) would happen on average every 24 years. It should be noted that these estimates include all natural hazard events and therefore these figures represent the multi-hazard situation. Having these losses in a probabilistic sense, it is now possible to combine these loss estimates with the information of possible resources to finance them within a risk-layer approach, as discussed next.

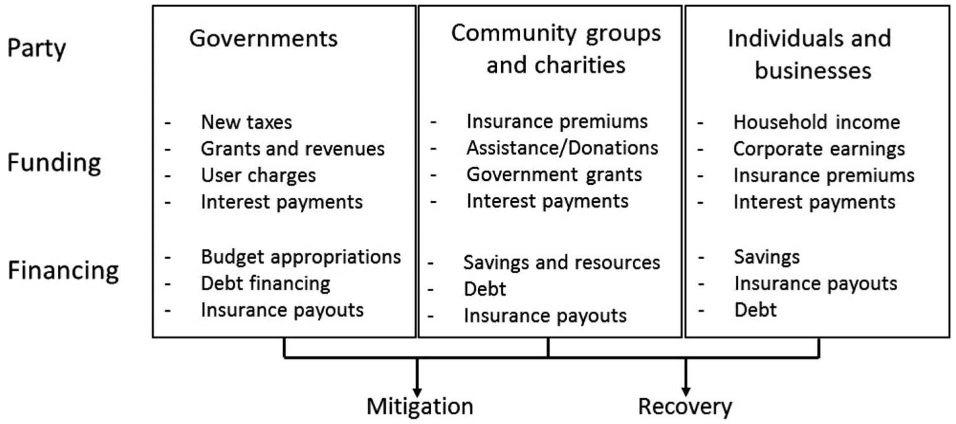

Figure 2. Responsibilities and financing natural disaster for Australia. Source: Adapted after NDFA (2014a, 2014b).

3.3. Risk layers for Australia

Given the estimates of available fiscal resources outlined in Section 3.1, together with the annual loss distributions estimated above, we are now able to estimate Australia's fiscal coping capacity within the context of risk layers. Based on all three loss distributions (reported, insured and total losses), we find that the large losses seen in 2011 due to

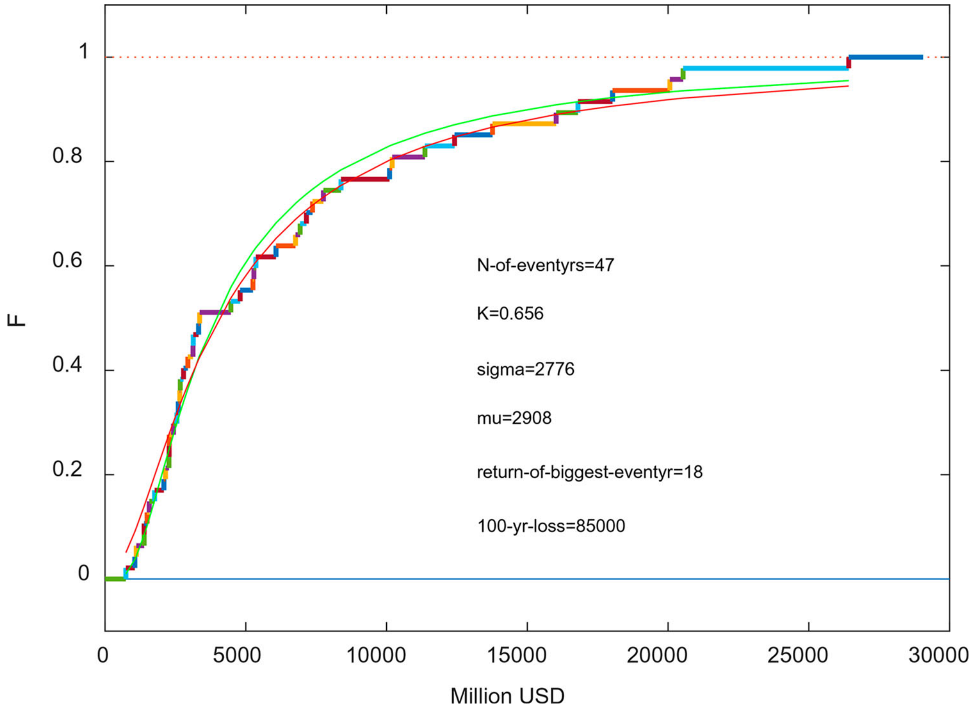

Figure 3. Empirical distribution (blue), estimated GEV distribution based on ML (green) and GEV distribution based on minimum distance to the empirical distribution in red. Data: total losses.

widespread flooding across the country, are all within the 20 to 30 year risk layer, which is quite low and therefore can be expected quite frequently. More extreme events, such as a 100-year annual loss event would incur much higher losses, for example, reported losses of around 24.8 billion USD and total losses in excess of 80 billion USD.

Recall that above we estimated that under an optimistic scenario the government could raise 26 billion USD in a given year. If we assume that only half of the losses would be financed by the government (an assumption which may not be too far from reality, see Lugeri, Kundzewicz, Genovese, Hochrainer, & Radziejewski, 2010), we find Australia able to finance direct losses up to the 400 year event. However, it is well known that taking loans for financing disasters in Australia is not currently seen as politically acceptable, therefore when we considering only the 10 billion USD from budget diversion a different picture emerges. In more detail, again assuming for illustration purposes the government takes half of the reported losses and uses only budget diversion, the 80 year loss return period instead of the at least 400 year event would be the threshold level for having budgetary problems as a result of disasters.

When we conduct the analysis again using the loss distributions derived from total cost data (both direct and indirect effects), the results change considerably. Even under the assumption of an optimistic finance scenario, when indirect costs are taken into account we find that the government would only be able to finance losses up to approximately the 15 year loss event level. In other words, while for direct risk the government is estimated to be exposed only to medium or high risk, if indirect losses are included financing problems emerge even at the low risk layers. Therefore, when indirect effects are taken into account we find justification for sovereign risk aversion, even for lower risk layers.

Let us now take a closer look again at the Arrow-Lind perspective. Instead of estimating financial resources to cope with an event for different risk layers, another approach is to look at the ability of governments to spread risk over the whole population, therefore rendering individual risk negligible. This is the current implicit approach for Australia, which is focusing on possible increases in tax revenue to finance losses (see NDFA, 2014a, 2014b). How effective would this instrument be for the estimated risk? One way to explore this question is to compare the estimated annual losses to the annual gross domestic product (GPD), tax revenue or gross domestic savings (GDS). The current Australian GDP is around 1,454,000 million USD, and tax revenue and GDS are around 309,846 and 349,122 million USD, respectively (World Bank, 2016). Table 2 shows what percentage of GDP/tax revenue/GDS losses represent, for different loss return periods. Percentages are shown for both reported losses and total losses estimates.

Table 2. Loss return periods and comparison to macro-economic performance measures.

Return period	20	50	100	250	400	500
Reported losses						
Loss/GDP	0.36	0.59	0.85	1.38	1.76	1.98
Loss/tax	1.68	2.78	4.01	6.48	8.27	9.28
Loss/savings	1.49	2.46	3.56	5.75	7.34	8.24
Total/direct and indirect losses						
Loss/GDP	1.69	3.16	5.04	9.32	12.75	14.80
Loss/tax	7.91	14.83	23.68	43.75	59.86	69.46
Loss/savings	7.02	13.17	21.02	38.83	53.13	61.65

Examining the ratio of GDP/tax revenue/GDS and reported losses, it appears that Australia is well equipped to handle direct losses, at least from a risk-spreading perspective. Even for the 500 year loss event, estimated direct losses are still below 2% of GDP and loss to savings and taxes are still below or around 5% for the middle-layer risk. When indirect effects are included by utilizing total loss estimates, the situation worsens considerably. For example, the loss to GDP ratio climbs to nearly 15% for the 500-year event, with a considerable amount of taxes and savings required to finance the loss. As we saw in Section 3.1 when looking at past financing of disaster losses via NDRRA and AGDRP, even the high losses experienced to date are rather low in comparison to actual risk exposed.

In order to investigate these results further and to test the robustness of our findings, we took a closer look at the fiscal risk side of the estimates using the loss distribution based on the insured loss data. In the Australian government productivity commission report on national disaster funding arrangements (NDFA, 2014a) a regression type of approach linking insurance losses with fiscal requirements is presented. They estimate the following relationship (NDFA, 2014b):

$$\text{Fiscal costs}(t) = -\$712\text{million} + 0.502\text{insurance losses}(t) + 0.670\text{insurance losses }(t-1).$$

Insured losses in the same period and up to two lags (in years) of insured losses were mainly used because after a natural disaster insurance payouts generally occur relatively quickly, while government expenditure can happen over several years. While the overall fit was good the relationship should be treated with caution. Nevertheless, we used this equation and our loss distribution to estimate fiscal risk. To set up this analysis we needed to sample from our estimated insured losses distribution for year t and year $t-1$, which was performed with a Monte–Carlo sampling technique using the inverse transformation method (a sampling method based on the distribution function estimated, see Klugman, Panjer, & Willmot, 2008). A total of 1,00,000 sample points were generated in this way and again used to estimate a fiscal cost distribution (again using a GEV). The results were found to be in line with the original analysis and findings above.

4. Discussion

The analysis presented here is based on the assumption that national governments are responsible – via explicit or implicit liabilities – for all or part of the costs associated with direct and indirect impacts of possible disaster events. Our analysis finds substantial fiscal and economic risks associated with disasters in Australia. Australia is subject to substantial and unacknowledged risk, which poses a significant threat to government fiscal stability and medium to long-term economic growth. Instead of using a modelling approach for calculating the indirect risk, we applied extreme value statistics to a recently produced dataset of direct and indirect losses for Australia. This enabled us to apply a risk-based comparison of financing needs for all potential hazard events on the country level, for direct and indirect risks. With a so-called risk-layer approach we were able to distinguish between different probabilities of events and corresponding losses, and loss financing resources. Our analysis finds that it is indirect impacts which are the key concern for Australia. Hence, there is a clear need for investment in the reduction of indirect risks, not only direct ones, and indirect risks are already a concern for the more frequent events (or low risk layers).

From a risk-layer perspective one could argue that direct risks, while having the potential to be colossal, both from an Arrow-Lind perspective as well as financing perspective, for Australia only the high risk layer is seen as problematic. However, when indirect losses are included, while the low risk layer may still be seen as unproblematic, in the cases of both the middle- and high-risk layers we find serious challenges in terms of loss spreading abilities as well as loss financing possibilities. Therefore, Australia may be financially prepared to deal with the direct costs of disasters; however, it will have problems with indirect losses (measured through total losses) that occur for the medium and high-risk layers, e.g. above the 20-year annual loss event scenarios. Consequently, there should be some reflection and focus on how to decrease these indirect losses in the future through appropriate risk management measures tackling this specific issue.

It is important to note that government measures to mitigate indirect losses may not necessarily be constrained by financial constraints or fiscal losses, but instead by economic aspects. These include economic resource constraints (e.g. limited number of tradespersons and/or materials in case of a disaster), redundancies in the economic system (e.g. number of independent businesses and communication channels within a sector), the degree of slack resources due to economic cycles (e.g. a disaster during a recession will have different impacts compared when it happens during a growth period) or more generally on the economic resilience of the country (Rose, 2007). Recent events such as the Tohoku earthquake in Japan as well as the Christchurch event in New Zealand have shown the importance of not only the magnitude of direct losses and financing resources available, but also of the economic situation in which they occur (Cavallo & Noy, 2009; Noy et al., 2017).

5. Conclusions

Our analysis concludes that indirect effects are potentially a game changer for risk analysis and risk management decision-making. It has long been hypothesized that direct effects are a primary concern for developing countries, with indirect effects being more prominent in developed countries. Until now expected annual loss distributions have not included indirect effects because of a lack of data. The AUS-DIS database allowed us to undertake this analysis for Australia considering indirect effects, and found support for the hypothesis that indirect effects, while typically ignored, are a more prominent concern for risk management in a developed country context. We find this despite the fact that the AUS-DIS database has only partial coverage of indirect effects – with no coverage of heatwaves – so our analysis presents a very conservative scenario.

Australia, and presumably many similar developed countries, are unaware of their level of risk relative to their capacity to finance expected losses. Our analysis finds support for a more risk-averse approach, in particular, for the rarer and more extreme events, and for targeted increased investment in (a) risk reduction to reduce current existing risks (corrective risk reduction), and (b) avoiding the creation of new or increased risk (prospective risk reduction). In particular we suggest increased investment in understanding and preventing the occurrence of indirect losses. Using a risk-layering approach, we were able to distinguish sovereign risk preference (risk-averse or risk-neutral) for Australia for each risk layer. When considering direct risk only, we found that Australia should behave risk neutrally for frequent and medium-term risks, and risk averse for extreme risk. When we included indirect impacts, we found Australia should behave risk averse even for low and for medium risks. The more risk-averse approach advocated for by our analysis stands in contrast to the sovereign preference for risk neutrality put forward by the Arrow-Lind Theorem. This is due to the reality of constraints on resources for financing disaster losses faced by Australia, which violates the assumptions underpinning Arrow-Lind in the case of inclusion of indirect effects.

The application of EVT along with the risk-layering approach for indirect risk is a new contribution to the field. Using this approach, we were able to use a country-level dataset, as opposed to the extremely data intensive catastrophe modelling approach, to estimate national-level risk. This kind of analysis may be especially useful for industrialized countries who are often interested in direct and indirect national-level risks, and can typically cope with direct risk, while the potentially more problematic indirect risks are either largely ignored or unable to be calculated. By taking a risk-layering perspective, the approach supports a risk-based approach to investment in disaster risk management (considered best-practice in the field), by aiding in the understanding of coping potential and optimal risk preference for different levels of risks.

Disclosure statement

No potential conflict of interest was reported by the authors.

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