ECONADAPT

The Economics of Adaptation

Funded by the European Union

Pan-European Assessment of Fiscal Consequence of Climate Extremes

Junko Mochizuki, Reinhard Mechler, Stefan Hochrainer-Stigler, Thomas Schinko

Deliverable number	5.2
Work Package Number	5
Submission date	March 2016
Type of Activity	RTD
Nature	R = Report
Dissemination level	Public

Document information

Title:	Pan-European Assessment of Fiscal Consequence of Climate Extremes
Authors:	Junko Mochizuki, Reinhard Mechler, Stefan Hochrainer-Stigler, Thomas Schinko
Other Contributors	
Date:	31 March 2016
Contact details	
Work Package Number	WP 5
Deliverable number	D5.2
Filename:	.doc
Document history:	
Type of Activity	RTD
Nature	R = Report, O = Other
Dissemination / distribution level	PU = Public
Citation:	
Copyright:	

The ECONADAPT project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 603906.

To find out more about the ECONADAPT project, please visit the web-site: www.econadapt.eu

For further information on the ECONADAPT project contact Alistair Hunt at: ecsasph@bath.ac.uk.

Executive Summary

While it remains debatable whether extreme hazard events can be attributable to climate change, disaster events at the European and global scales have already begun to impose significant costs on the public and private sectors. In light of these concerns, work package 5 of the ECONADAPT project comprises a case study of climate risk management, providing comparative analysis of adaptation and disaster risk management for EU member countries. The present analysis focuses on both short- to longer-term changes in the frequency, severity and duration of extreme weather events resulting from climate change.

Building on the recommendations outlined in D 5.1, the aim of report D5.2 is to provide further analytical bases for climate risk analysis, within an iterative risk management framework. In particular, this study focuses on the domain of public finance and fiscal planning, and illustrates how climate risk concerns could be 'mainstreamed' into decision-making processes. Through the pan-European assessment of the fiscal consequences of extreme weather events in the EU, this deliverable (1) **quantifies extreme event risks** (in terms of potential capital stock losses) across an illustrative range of climate scenarios (with a time horizon of 2030 in the short-term and 2050 in the long-term); (2) **identifies the fiscal repercussions in terms of public debt trajectories** and, (3) **identifies options for better stochastic planning** to reduce and finance fiscal risks.

Two distinct approaches - **fiscal risk scorecard** and **stochastic debt-assessment**- are used to gain both a broader understanding of fiscal and climate risks facing the EU28 member states and a more-in-depth understanding of Austria (the focus of our case study). The results of our analysis (which focuses on increased flood risk), indicate that the economic risk of climate extremes (relative to the size of economic and public finance resources) are estimated to be high in countries such as Hungary, Slovenia Latvia, Lithuania and Slovakia. Furthermore, these countries also have significant need for fiscal consolidation in the medium to long-term, thus proactive fiscal risk management is especially important.

The fact that many EU member states are still in the early stages of designing and implementing their climate change adaptation strategies means that there are ample opportunities to consider an iterative risk management process, where state-of-the art scientific information on risk (hazard, exposure and vulnerability) is mainstreamed into economic and fiscal decision-making. Looking ahead, while EU member states strive for fiscal consolidation, sustainable growth and climate risk management, the mainstreaming of climate risk into fiscal planning will become all the more important. The new methodologies developed and presented in this deliverable will be useful in informing these discussions.

Table of Contents

Contents

1 Introduction

Climate change has already begun to have a significant impact on biological, physical and human systems, and in many cases early warning signs are visible across the globe. Based on the latest projections, climate impacts are expected to increase, though whether extreme weather events—such as heavy rainfall, drought spells, severe storms and extreme temperatures—are attributable to climate change is still being debated (Bouwer 2011; Mechler and Bouwer, 2015; IPCC, 2012). Together with longer-term changes in socioeconomic drivers—such as the continued expansion of exposed assets in risk-prone areas and increased vulnerability— these combined forces are likely to lead to higher climate-extreme risks in the foreseeable future. In Europe, a variety of climate change risks are predicted to increase, including, but not limited to, rising coastal and riverine flooding, heat waves, and water scarcity. The impact of climate change is expected to become most severe under a high-emissions, no-adaptation scenario: deaths due to heat-related events, for example, are expected to rise to approximately 200,000 per annum, damages due to riverine flooding to over 20 billion euro per annum (Jongman et al., 2014), and areas at risk of forest fires to beyond 800,000 ha (European Environment Agency 2015).

There is significant uncertainty regarding the future trajectories of greenhouse gas emissions, socioeconomic development and potential adaptation policies; this makes the ex-ante management of climate extreme risk particularly challenging. Faced with the uncertainty of longer-term societal trajectories, the potential implications of, and any trade-offs between, policy actions and inactions must be identified and deliberated openly so that communities may choose the optimal courses of action. Ideally, these deliberations should take place in an iterative manner, as recommended in the report D5.1, to allow for additional flexibility and adaptability in complex decision-making.

As many EU member states are in the early stages of deliberating and designing future policy mixes for their countries' climate change adaptation strategies, there are still ample opportunities to incorporate these kind of iterative risk management procedures into planned adaptation policy-making. Moreover, given the ongoing societal debate over what might be the most favourable course of action in terms of adaption and risk management, cost-benefits and any other implications of adaptation policies should be evaluated within the context of other pressing longer-term structural issues, such as the 'greening' of tax and investment, population ageing and longer-term sustainable growth at the regional and global level. This necessitates the development of novel economic appraisal tools, which is the primary goal of this report D5.2.

Across the globe, various stakeholders are engaged in developing and implementing adaptation policies. To support climate change adaptation efforts, the European Commission released a communication titled 'an EU strategy on adaptation to climate change'; this policy document emphasized the need to mainstream adaptation concerns into sectoral policies, and to enhance ex-ante and ex-post capacities to anticipate, adopt and cope with the potential extreme consequences of climate change in the foreseeable future. Currently, approximately 20 member states have officially adopted a national adaption strategy (as of June 2014), 17 of which have also defined a national action plan (European Environment Agency 2015).

At the EU level, climate risks are increasingly being evaluated in an adaptive and iterative manner: for example, the Delta Programme in the Netherlands has incorporated the notion of ‘dynamic adaptation pathways’, whereby measures are adopted to increase both the flexibility and robustness of existing risk management options (OECD 2015). The Thames Estuary 2100 project in the UK has adopted a similar approach, incorporating an iterative decision-making process. In this process, major milestones have been pre-determined up to 2050 in order to take account of new scientific information and learning, thereby enhancing the overall robustness of policy across multiple possible future developments (Watkiss 2013). At the same time other countries, such as Austria and Czech Republic, are also addressing the risks of extremes by periodically updating the estimates of extreme event risk when new information on potential risks becomes available (see Schinko et al., *forthcoming*).

The ECONADAPT D5.1 examined how European countries currently make decisions regarding the selection and design of risk management options at different scales. The report proposed how climate change, and the uncertainty that goes with it, could be integrated into DRM strategies. The analysis demonstrated that investment into flood-risk management has the potential to yield tangible and high economic returns across Europe. Currently, the level of sophistication in methodological approaches to disaster risk appraisal varies significantly, from simple updates of protection design standards (based on a ‘most-likely’ scenario of future climate changes), to complex applications of alternative climate and development pathways analysis. The evidence gathered in D5.1 suggests that policy and scientific discussions are ongoing, with government officials, academic researchers and stakeholders deliberating different aspects of iterative decision-making. The report also highlighted the complexity of decision-making and the interplay of local, regional and national actors.

Building on the recommendations outlined in D 5.1 of this project, the aim of D5.2 is to provide further methodologies for facilitating climate risk analysis. In particular, this report focuses on the domain of public finance and fiscal planning, and how climate risk concerns could be ‘mainstreamed’ into decision-making processes. This deliverable (1) **assesses extreme event risks** (in terms of potential capital stock losses) across an illustrative range of climate scenarios (with a short-term time horizon of 2030); (2) **identifies the resulting fiscal repercussions** and, (3) **identifies options for better stochastic planning**, thereby reducing and financing fiscal risks. The following sections describe relevant background literature, modelling methodology, results and conclusions.

2 Fiscal Consequences of Climate Extremes in EU

Debates over the probable fiscal cost of mitigation and adaptation policies (CEPS 2010a b ; Osberghaus D. and Reif C 2010 ; Ranci et al. 2011; Springmann 2012), the potential for revenue recycling and double dividends (Conrad and Schmidt 1999; Vaze and Sunderland 2014; Pereira and Pereira (2014)), and the costs of climate adaptation in different sectors (Mechler et al., 2010) are some of the most frequently analysed topics in this context, where a variety of modelling approaches have been taken to answer the 'what if' questions of future climate policy. More often than not, modelling exercises such as these have employed a non-probabilistic approach, and policies are evaluated under 'most likely' GDP and population growth scenarios.

An approach such as this offers insights into potential consequences under 'normal' or 'average' conditions; however, it gives little insight as to how societal trajectories might deviate from average projections, should extreme events occur in these alternative future scenarios. Neither does this approach give us any information with regard to how a society might manage such risks using alternative policy instruments. When policy questions must address the potential for climate extremes, therefore it is evident that an alternative— probabilistic approach—is more desirable. This section briefly reviews existing studies of climate extreme risk in the context of the EU adaptation policy discussions and outlines key research questions identified regarding the evaluation and management of fiscal consequences due to climate extremes.

2.1 Overview of existing studies at the European Scale

Recent extreme weather events such as the heatwaves of 2003 and the Central European Floods of 2013, have triggered the need for major domestic and regional debates over appropriate policy to manage and reduce climate extremes. In a EU wide survey conducted in 2014, 28 out of 30 country respondents identified extreme weather events as being a primary trigger for national adaptation policy planning and action, ranking them as the most important driver, followed by other factors such as EU level policy guidance, scientific research, and estimates of climate damage costs (European Environment Agency 2014).

In response to this build-up in momentum towards policy change, a growing number of biophysical studies have been conducted on the potential impacts of climate change and extreme events. The most recent IPCC report outlines the current state-of-knowledge regarding scientific consensus on this topic. Increasing economic loss and damages arising from extreme events are considered to be one of the key drivers of risk in Europe. For example, there is *high* and *medium confidence* respectively in "increased economic losses and people affected by flooding in river basins and coasts, driven by increasing urbanization, increasing se levels, costal erosion and peak river discharges (IPCC 2014 p. 23)" and "extreme heat waves, impacts on health and well-being, labour productivity, crop production, air quality and increased risk of wildfire in southern Europe (ibid).” Adaptation potentials to reduce and manage such extreme risks are still presumed to be high, with actions such as structural and non-structural flood mitigation, early warning systems and development of risk transfer instruments, such as insurance, being considered as potential policy options (Table 1).

While downscaling efforts are ongoing to understand potential impacts of climate extreme events at finer resolutions, a number of economic studies are also being conducted to understand options for and feasibility of risk management measures. Availability of such cost benefit information is, however, highly variable across EU member states: in a recent survey, 11 out of 30 country respondents (including those from Cyprus, Czech Republic, Estonia, Hungary, Ireland, Lithuania, Romania and Slovenia) indicated that they lacked estimates regarding the costs and benefits of adaptation policy options at the country level. Only France, Greece, Slovakia and the United Kingdom responded that these costs were available at the national level, while the remainder of countries responded that only partial information was available. In terms of hazards, relatively comprehensive costs and benefit estimates are available for coastal flooding, coastal storm surges and erosion; sound evidence has also been gathered on riverine and alluvial flooding. Evidence regarding costs and benefits of management options for climate extremes such as drought, storm, avalanches, and health related mortality and morbidity, however, remain limited.

Table 1: Summary of Projected Climate Change Impact

Sector Risk	Summary of projected climate change impact
Coastal flooding	Coastal flooding is estimated to affect an additional 775,000 (B2 scenario) and 5.5 million (A2 scenario) people across 27 EU countries, with the Atlantic, and Northern and Southern Europe being the most seriously affected.
Riverine Flooding	Climate change impacts are intricately linked to future population and economic growth; some regions are projected to have increased risk while others may have little change or a decrease in risk.
Drought	An increase in intensity and duration of droughts is projected for Central and Southern Europe as well as Mediterranean to UK.
Storm	An increase in storms is projected for Northwest Europe but natural variations are high and thus evidence is inconclusive.
Avalanches	Mass movement and avalanches in general are estimated to be more frequent, though natural response may be complex, making precise prediction difficult.
Heat-related mortality and morbidity	Heat-related mortality and morbidity in general is expected to rise (though the effects of adaptation are often excluded in the existing estimates).

Wildfire	An increase in wildfire risk is projected for Southern Europe, whereas risk may decrease in Northern Europe.

Source: IPCC (2014)

The fiscal costs of climate extreme events is becoming an increasingly important topic within the EU context. For example, the European Policy Commission (EPC) has established an internal working group on energy and climate change at the EU level, exploring aspects such as the macroeconomic impacts of 2020 GHG targets, green growth strategy and transition pathways to a low-carbon economy. [1] Bio-physical simulations provide crucial analytical input into many of the integrated assessments used in these analysis, as seen in recent assessments, such as PESETA II (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) (Martinez et al. 2014). In these studies, quantitative projections of how economic productivity may respond, for example, to changes in average temperatures and availability of water resources over time offer critical starting points for the assessment of future sector outputs and demands under alternative radiative forcing and socioeconomic scenarios.

In general, existing studies on the fiscal implications of climate adaptation may be categorised into i) those estimating the direct budgetary costs of public investment needs and ii) those estimating the indirect budgetary costs, including the effect of autonomous adaptation using general equilibrium modelling. These two strands of research have offered different insights.

For the former, Mechler et al. (2010), for example, used the CATSIM model to assess the fiscal consequences of weather extreme events, quantifying weather-related disaster contingent liabilities in the key flood hot-spots of Austria, Romania, and Hungary. Their analysis indicated that substantial disaster-related contingent liabilities (or hidden disaster deficits) may have the potential to put significant stress on government balance sheets. Osberghaus and Reif (2010) also estimated the direct budgetary costs of adaptation needs in European countries in agriculture, forestry, flood protection, water supply, health, energy supply and demand, and transport sectors, and concluded that the public costs of adaptation for flood protection alone could increase to 4 billion Euro by 2060 in Western Europe alone. Compiling detailed bottom-up estimates of climate-proofing options in energy, transport, urban areas and agriculture, Altvater et al. (2012) estimated the costs of climate adaptation and public and private contributions towards the investment needs of EU countries.

For the latter, Delpiazzon et al. (2015) evaluated the fiscal and macroeconomic implications of sea level risk (SLR) in five Mediterranean countries of France, Italy, Spain, Portugal and Greece using ICES CGE modelling calibrated to the GTAP 8 and Dynamic Interactive Vulnerability Assessment (DIVA) model. Incorporating the potential impacts of climate change

[1] More details can be found at: http://europa.eu/epc/working_groups/eccwg_en.htm.

on 12 categories - agriculture, forestry, ecosystem services, health, electricity, buildings, transport, manufacturing, cities, flooding and tourism- Steininger et al. (2015) estimated that as a result of climate change the average annual public budget in Austria may be decreased by 0.15 % (in 2030) and 0.24 % (in 2050).

These studies provide important scientific bases for the evaluation of alternative courses of action with regard to climate change adaptation; however, many of them tend to focus on average longer-term changes as opposed to evaluations of climate extreme events (represented by tails of distribution functions). Consequently, any changes in the occurrence of, and implications from, catastrophic extreme events are often neglected. This lack of concern for climate extreme risk is potentially problematic as public concern for extreme weather events is already high, demonstrated by recent evidence that such concern ranks as the most important policy drivers for climate change adaptation for many EU countries (European Environment Agency 2014). Another limitation is that the studies available do not take into account potential interactions of additional fiscal pressures, such as the risks associated with ageing societies and the ongoing fiscal and debt crisis that may be becoming increasingly relevant in the context of public finance discussions.

2.2 Key research questions

The following section therefore focuses on advancing probabilistic assessment of climate extreme risk, outlining how climate risk concerns may be mainstreamed into public budget and fiscal planning at the EU level. This study develops two analytical approaches—climate and fiscal risk scorecard and stochastic debt assessment. We focus on the assessment of the fiscal and budgetary implications of climate extreme risk facing the EU member states in the medium (2030) to longer-term (2050).

The methods provided are applicable to a number of different hazard scenarios; however, in this study we focus on riverine floods for an illustrative application given that relatively reliable scientific projections of future hazards and cost and benefits of risk management options are available. By focusing on flood risk, this study illustrates how probabilistic longer-term fiscal costs may be projected within existing fiscal risk assessment, thereby improving the budgetary readiness of 28 EU member states. Like Obserghaus and Reif (2010), this study uses the term ‘fiscal consequences’ of climate extreme to imply ‘budgetary effect’ – i.e. projected changes in expenditure and revenues and fiscal positions in terms of their impact on variables such as primary balance and external borrowing. In particular, it addresses question such as:

- What are the levels of contingent liability due to future climate extremes (flooding in particular) and their primary drivers for EU member countries?
- How do these risks compare with a country’s ability to finance reconstruction and recovery—through means such as reserve funds, budget diversion, private sector insurance and domestic and foreign credit?

3 Methodology and Data

3.1 CATSIM Assessment

This report builds on the CATSIM framework to model the fiscal and economic risk of extreme events. The CATSIM framework assists policymakers to quantify public sector risk of extreme events and develop pre- and post- disaster risk management strategies. The CATSIM calculates the estimates of a country's direct monetary risk and evaluates their risk tolerance relative to the fiscal resources available (Mechler, 2004; Hochrainer, 2007; Hochrainer-Stigler et al. 2014; Mochizuki et al. 2015). The framework has been applied in regional and national level exercises, and more recently, globally. The latest database extends to 172 countries, including the advanced economies of the European Union.

Public and private sector losses due to flood events are estimated and compared to the financial resources available, such as reserve fund, budget diversion and international and domestic borrowing (Figure 1). The CATSIM framework helps policy-makers to understand a government's fiscal position to take on its explicit and implicit contingent disaster liabilities. Explicit liabilities may, for example, include the rebuilding of damaged public infrastructure, whereas implicit liabilities include providing relief and support to both the private sector and households in order to cover estimated losses.

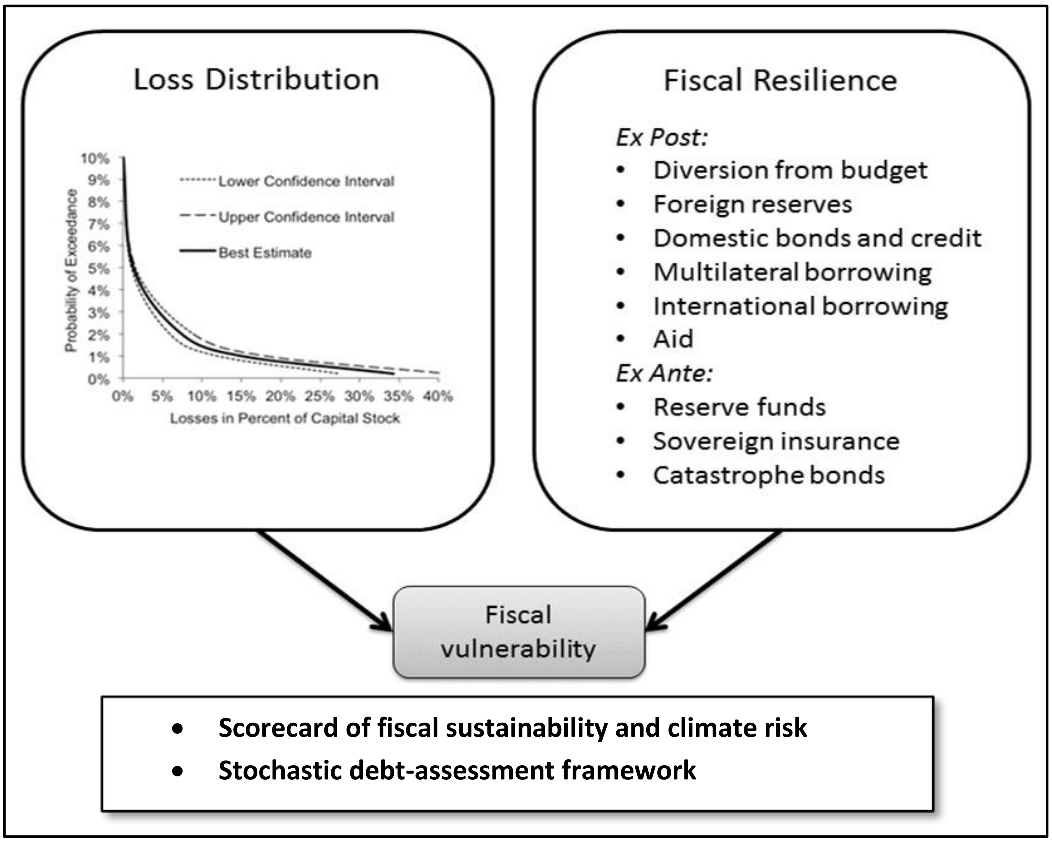


Figure 1: CATSIM Framework

Source: The authors

In this study, we extend this methodology using a climate risk scorecard and stochastic debt assessment to take account of the future risk of climate extreme events (focusing on the projected impacts of extreme riverine flooding). In the pan-European assessment using a risk scorecard, we examine both the structural drivers of fiscal pressure (such as baseline population projections, growth potential and fiscal consolidation needs), as well as the cyclical and stochastic fiscal pressure arising from macroeconomic and climate variability (i.e. flood risks).

Whereas the scorecard gives us a broad, birds-eye-view of inter-related issues such as longer-term fiscal sustainability, ageing and climate risk facing EU member states, the stochastic assessment allows for a more detailed assessment of climate risk management options at the national level. Both approaches demonstrate how future contingent liability due to climate extremes may, without much difficulty, be mainstreamed into existing fiscal risk and sustainability assessments for EU member countries.

Individual countries wishing to mainstream climate change contingent liability into long-term budgetary planning may be able to do so by adopting and/or modifying the approaches presented here. Following the general policy recommendations of Deliverable 5.1, budgetary risk assessments should be conducted in an iterative manner at the appropriate administrative levels (national, subnational, local levels, etc.) according to the existing decision-making structures and process of each EU member state.

3.2 CATSIM extension based on SSP scenarios

In this study, we use the Shared Socioeconomic Pathway (SSP) scenarios to extend the CATSIM approach. SSPs are “reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a century timescale, in the absence of climate change or climate policies (O’Neill et al. 2013, p.387),” which allow for the standardization of assumptions and storylines used in integrated assessments. There are currently five different SSPs that are used in the integrated assessment community, namely SSP1- Sustainable Pathway; SSP2-Moderate Pathway; SSP3-Rocky Road; SSP4-Regional Pathways and SSP5-Taking the Fast Road (IPCC 2007; Cuaresma 2015).

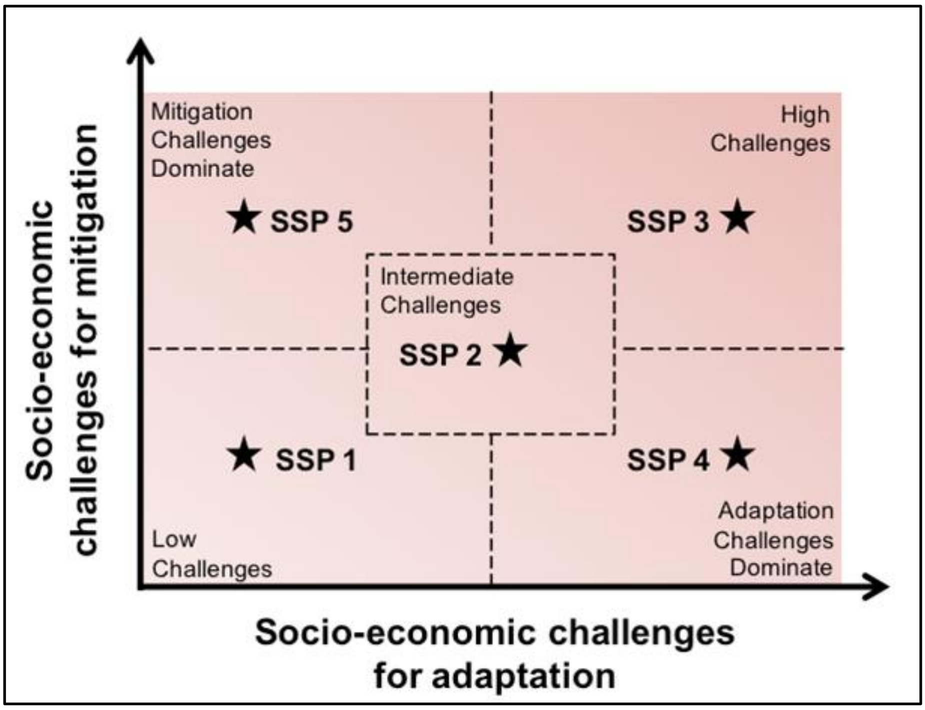


Figure 2: Shared Socioeconomic Pathways

Source: O'Neill et al. (2013)

The development of common scenarios with quantitative and qualitative descriptions followed two steps: in the first step, basic indicators with a minimum set of information on mitigation and adaptation challenges were described across the spectrum of low to high challenge situations (Figure 2). Minimum assumptions included future trends of demography, economic growth, and the degree of economic integration. In the second step, extended SSPs were built using finer geographical and temporal resolutions, describing key aspects such as urban versus rural populations, patterns of international trade, environmental quality, technological progress, governance and institutional development, etc. In the current analysis, we have used projected GDP and demographic composition in Shared Socioeconomic Pathway 2 as an illustrative example, showing how the CASTIM approach can be extended to assess future risks for EU member states.

3.3 Estimating monetary risk (direct risk)

Direct economic risk due to flooding for countries in the EU is estimated in the following way: We applied a structured coupling of probability loss distributions on the basin scale (derived from LISFLOOD; see van der Knijff et al. 2010; Rojas et al. 2012) using the method discussed in Jongman et al. (2014), and more recently in Timonina et al. (2015). Dependencies between river basins are estimated based on maximum river discharges for the period 1990-2011, using different copulas (e.g. Clayton, Frank or Gumbel).

The loss distributions from each basin are then coupled using the copulas and a minimax ordering approach in order to derive a loss distribution at the national level. Details of the copula methodology (which avoids underestimating extreme risk (Jongman et al. 2014)) and a general algorithm to perform coupling can be found in Timonina et al. (2015). [2]

As in most flood models, our flood loss estimates do not incorporate current protection standards for each basin and therefore they are likely to overestimate losses (especially for more frequent events). Ideally, one should use detailed information at a finer scale to conduct bottom-up estimates of flood risk. However, this is not possible at the national level, as this kind of information is not available. To circumvent this problem, we use protection levels estimated in Jongman et al. (2014), where protection standards are defined as the minimum probability of discharge leading to flooding. To estimate the size of losses the government is liable for, we assumed that it is liable for half of the total losses (and including help to private sector entities). For the stochastic assessment we sampled loss events using a Monte Carlo simulation approach.

3.4 CATSIM-Scorecard

A policy scorecard is a common approach used in EU wide assessments in a variety of policy domains, including, more recently, its development for use in climate change adaptation (European Commissions n.d). In this study the scorecard is developed to show data from the following three domains, capturing:

- Underlying fiscal pressure
- Macroeconomic & fiscal variability
- Climate change extreme risk (DRM Fiscal Capacity)

For underlying fiscal pressure, the scorecard shows four variables: current debt-to-GDP, the primary balance needed to stabilize debt at 60% in year 2030 (also known as the S1 indicator), the projected increase in fiscal burden due to demography-related costs (ageing, health, longer-term care, education), and projected changes in the fiscal burden as a result of climate change mitigation. This set of indicators illustrate the current fiscal health and consolidation requirements of each EU member country, along with the additional longer-term challenges posed by both climate and socioeconomic changes under the SSP 2 scenario.

For macroeconomic and fiscal variability, the scorecard shows the historical variability of three variables: growth adjusted interest rate, exchange rate and semi-budget elasticity parameters (describing how budgetary expense and revenue responded to a percentage change in the

[2] To the authors' knowledge the only other model currently available for Europe which employs a copula approach is the aforementioned one, discussed in Prettenthaler et al. (2015), which, however, falls short in comprehensively including all exposed assets.

output gap). This set of indicators show how future debt burden may deviate from baseline projections (assuming past variability is indicative of the future variability of these variables). These variables are also used in the stochastic-debt assessment, described in the next section.

For climate change extreme risk, the scorecard shows five variables: annual average loss (AAL) calculated for 2015, AAL projected for 2050 (relative to the size of projected government expenditure), current availability of reserve fund and budgetary allocation, historical observations of average insured losses, and availability of other budgetary mechanisms. This set of indicators show both direct risk posed by current and future risk of extreme weather events, together with the availability of fiscal and economic resources to cope with these kind of risks. To gather information on governments' ability to cope financially with current extreme weather events, this study sent out email surveys to relevant ministries (e.g. ministries of finance and disaster management agencies) in each EU member state. From the 28 member states, we received 11 responses, thus limiting the availability of indicators on this aspect.

3.5 Stochastic Debt Evaluation-Application in Austria

In addition to the policy scorecard, this study builds a stochastic debt assessment based on future projections of flood risks and historical variance covariance matrix of macroeconomic fluctuations. A stochastic debt assessment is a common fiscal risk analysis method applied in various countries and contexts, where debt dynamics equations are built based on baseline projections of macroeconomic variables, and the impacts of financial shocks to debt trajectories are evaluated (IMF 2006; Medeiro 2012; Ellor and Urvova 2012; IMF 2012).Unlike previous studies that have focused solely on macroeconomic variabilities and longer-term non-stochastic costs of ageing, this study incorporates the additional stochasticity due to the future contingency of climate extreme events. Model building and implementations were performed using Matlab R2013a.

Following Berti (2013), stochastic debt dynamics may take the following form, including a new stochastic variable of reconstruction needs due to climate extremes (J_t), as introduced by this study.[3] Furthermore, the baseline potential output (g_t) refers to the future GDP projections calculated according to five alternative demographic projections of SSP1- Sustainable Pathway; SSP2-Moderate Pathway; SSP3-Rocky Road; SSP4-Regional Pathways and SSP5-Taking the Fast Road (IPCC 2007; Cuaresma 2015).

[3] While this is a general framework applicable to all EU member countries, as the majority of debt in Austria is denominated in EURO, the share of debt denominated in foreign currency is not applicable in the Austrian application shown in section 4.2.

Using the production function approach employed in Cuaresma (2015), economic output is estimated based on baseline projections of population, and disaggregated according to age-brackets and educational status for each scenario; this allows for the existing ageing-related cost-estimates to be recalibrated according to the new IPCC scenarios. The use of IPCC scenarios also ensures that climate change mitigation and adaptation costs are examined in a manner consistent with each socioeconomic scenario. The variable (J_t) was projected up to 2050 based on the new IPCC scenario using an integrated assessment of stochastic extremes of flood events:

$$d_t = a^n d_{t-1}\frac{1+i_t}{1+g_t} + a^f d_{t-1}\frac{1+i_t}{1+g_t}\frac{e_t}{e_{t-1}} - b_t + c_t + J_t + f_t$$

d_t	=	Debt to GDP ratio in year t
a^n	=	Share of total debt denominated in national currency
a^f	=	Share of total debt denominated in foreign currency
i_t	=	Nominal implicit interest rate at year t
g_t	=	Nominal GDP growth rate at year t
e_t	=	Nominal exchange rate at year t
b_t	=	Structural primary balance over GDP in year t
c_t	=	Change in age-related costs over GDP in year t relative to base year
J_t	=	Reconstruction needs due to disasters over GDP.
f_t	=	Stock flow adjustment over GDP in year t

To simulate flood risks and macroeconomic variabilities simultaneously, we first evaluated the empirical relationships between quarterly flood damages (both insured and uninsured) and macroeconomic variables to determine whether these two sources of variabilities could be statistically related (and should therefore be treated as dependent risk). As Figures A1 and A2 in appendix 1 show, Wilcoxon signed-rank and median tests indicate there were not statistically significant differences across medians of macroeconomic variables in non-flood and flood quarters; this study proceeded, therefore, in treating these two risks as independent sources of risks.

Based on the quarterly macroeconomic variables available from public databases, we have constructed historical variance-covariance matrix of economic variables, assuming a joint normal distribution. This historical variance-covariance matrix was then used to generate future quarterly shocks on economic variables, which were aggregated as annual shocks and entered into stochastic debt equations (see appendix 2 for details of these steps).

To further align the modelling framework to alternative scenario assumptions adopted under the IPCC shared socioeconomic pathways, projected costs of population ageing were also adjusted to reflect the alternative demographic trajectories assumed in current EU level assessment and IPCC scenarios. Following the work of the European Commissions’ ageing working group (EC 2014a and EC 2015), this study adjusted the projections of pension, health care, longer-term care, education reflecting the differences in both GDP and demographic projections assumed (see appendix 3 for details of this step).

3.6 Data

This study gathered various economic and climate related variables based on publically available sources at the EU level and our own calculations based on probabilistic flood risk modelling. In addition, we accessed NatCat Service data, maintained by Munich Re, for further information relating to historical insured and non-insured flood damage for all EU member states. Table 2 shows both the data sources and baseline assumptions adopted for this study. To ensure the results from this study were comparable to those of existing fiscal risk assessments conducted at the EU scale, we adopted, wherever possible, similar baseline assumptions for future projections of the main economic variables used in longer-term fiscal sustainability by the European Commission (EC 2014b).

It is important to note that detailed economic cost estimates of flood risk under new IPCC scenarios were not available at the time of writing. Although current ongoing efforts, such as the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) estimate hazard risk (i.e. probability and inundation depth) under new climate scenarios[4]; combining this information with asset exposure and physical vulnerability data was beyond the scope of this study. We have therefore combined the socioeconomic pathway scenario with that of the old IPCC scenario of A1B in order to illustrate how climate extreme risk can be incorporated into longer-term fiscal assessments at the EU level. The methods used can easily be adapted to incorporate new estimates of the economic costs of flood risk based on Representative Concentration Pathways (RCPs), as and when this data becomes available.

Table 2: Data and Baseline assumptions used in this study

Item	**Descriptions**	**Sources**
Baseline GDP Growth	Production function approach using age and education disaggregated labors (SSP2)	Cuaresma (2015)
Baseline Population Growth	Projected population (SSP)	Samir and Lutz (2014)
Baseline long-run interest	Assumed to converge to 3% in T+10	European Commission (2014b)
Baseline GDP deflator	Assumed to converge to 2% in T+5	European Commission 2014b

[4] Further information regarding ISI-MIP can be accessed at: https://www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/research/rd2-cross-cutting-activities/isi-mip.

Average maturity of debt	Assumed to be 8 years	EUROSTAT[5]
Semi-elasticity parameter of budget balance	Assumed to remain constant at 0.58.	Mourre et al. (2014)
Historical macroeconomic variables	Quarterly data on GDP growth, interest rates, and price indices	EUROSTAT
Historical observations of flood losses	Quarterly data on insured and uninsured losses	NatCat Service data[6]
Forecasted flood risk	Estimated based on A1B for illustration	Schinko et al. forthcoming
DRM policy parameters	Sources and allocation of disaster fund	Schinko et al. forthcoming
Baseline projections of ageing cost	Pension, health, longer-term care, education and unemployment	European Commission (2015)

4 Results

4.1 CATSIM Fiscal Risk Scorecard

The results of the fiscal risk scorecard exercise indicate a variety of challenges facing EU member states with regard to longer-term costs as a result of climate extreme events. Figure 3 shows the estimates of fiscal pressure, variability and climate extreme costs, ranked according to 25th (Green), 50th (Yellow), 75th (Orange) and 100th (Red) percentiles respectively. For example, the first indicator, government debt as a percentage of GDP, illustrates the wide range of fiscal consolidation needs that these countries face in coming years. This ranges from 10.6 % in Estonia to 177.1% in Greece.

In many countries, public debt increased sharply following the financial crisis of 2008-2009 due both to structural elements (decline in revenue and an increase in the growth-interest rate differential) and expansionary spending. A cluster of countries, including Croatia, Cyprus, Portugal, Slovenia, France, Ireland, Greece, Spain, and the UK, are under Excessive Deficit Procedures (EDP), and promoting sustainable growth is a major challenge for these countries. For those countries with closed excessive debt procedures –Austria, Belgium, Bulgaria, Czech Republic, Denmark, Germany, Hungary, Italy, Finland, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Romania, and Slovakia—it is important that fiscal stance and

[5] http://ec.europa.eu/eurostat.

[6] http://www.munichre.com/en/reinsurance/business/non-life/natcatservice/index.html.

structural factors continue to be monitored, and that longer-term planning takes sufficient account of future direct and contingent liabilities.

The second indicator S1 (adjusted for SSP2 scenario) ranks countries' need for fiscal consolidation: in order to achieve convergence criteria (debt-to-GDP ratio of 60%) countries including the United Kingdom, Ireland, and Croatia, must adjust the primary balance by approximately 0.3 - 0.4% annually over the next 15 years under the demographic and GDP trajectories assumed in the SSP 2 scenario. Figure 4 shows the relationship between estimated flood risk and S1 indicators, showing which countries may face the twin challenge of fiscal consolidation and management of flood risk. Assuming the observed average insured rate remains constant and there are no major changes in flood mitigation measures, a cluster of countries, such as Hungary, Slovenia, Bulgaria, Slovakia, Latvia, Czech, Romania and Lithuania for example, will likely face the combined challenge of fiscal consolidation and management of climate extreme events due to flooding.

The third indicator shows the relative contribution of an increase in ageing-related costs. These are highest in countries such as Belgium, Germany, Lithuania and Slovenia, where age-related expenditure could add approximately 9-12% of additional expense to the public budget from now until 2050. At the moment, collective efforts are ongoing to estimate and share information related to the future cost of ageing across EU member states.[7] Under SSP 2 scenarios, countries such as Greece, Spain and Italy are likely have a demographic composition where more than 35% is aged 65 and above. The demographic dependency ratio (the ratio of dependents to working age population) is highest in countries such as Greece, Spain, and Italy, where it is estimated to be above 70%. Improving quality of life for these dependent populations while also reducing their exposure to the risk relating to climate extreme events (such as heat-waves) will therefore be high on the agenda in the future.

The fourth indicator shows short-term costs of climate change mitigation for the period leading up to 2020 derived from the available cost calculation of net budgetary impact. The cost of achieving the mitigation goals could be high for countries such as Latvia (0.97% of GDP) and Romania (0.47% of GDP) and lower, or indeed negative, for countries such as Bulgaria, Latvia, Greece, Malta and Finland (Ranci et al. 2011).

The fifth and sixth indicators derived from past variability in output growth, interest rate and fiscal response to output gaps indicate that these are highest in countries such as Greece, Hungary, Poland and Sweden for the former variables, and Denmark, Czech Republic, France and Netherlands for the latter. Figure 5 shows the relationship between direct economic risk

---

[7] European Policy Committee (EPC) has set up Working Group on Ageing Populations and Sustainability (AWG) consisting of experts representing Member States, Commission services, the European Central Bank, and other relevant institutions such as IMF, WB and OECD. The group meets periodically to carry out harmonized budgetary projections based on common scenario assumptions.

due to flooding and macroeconomic variability. Based on past variability of macroeconomic indicators, countries such as Hungary, Slovakia, Bulgaria and Czech Republic will likely face highly volatility stemming from both macroeconomic variability and flood risk. While this indicator shows the overall trends in past years, the potential impact of macroeconomic volatility and climate extreme costs on debt trajectory is investigated further using stochastic debt-assessment with case illustration in Austria.

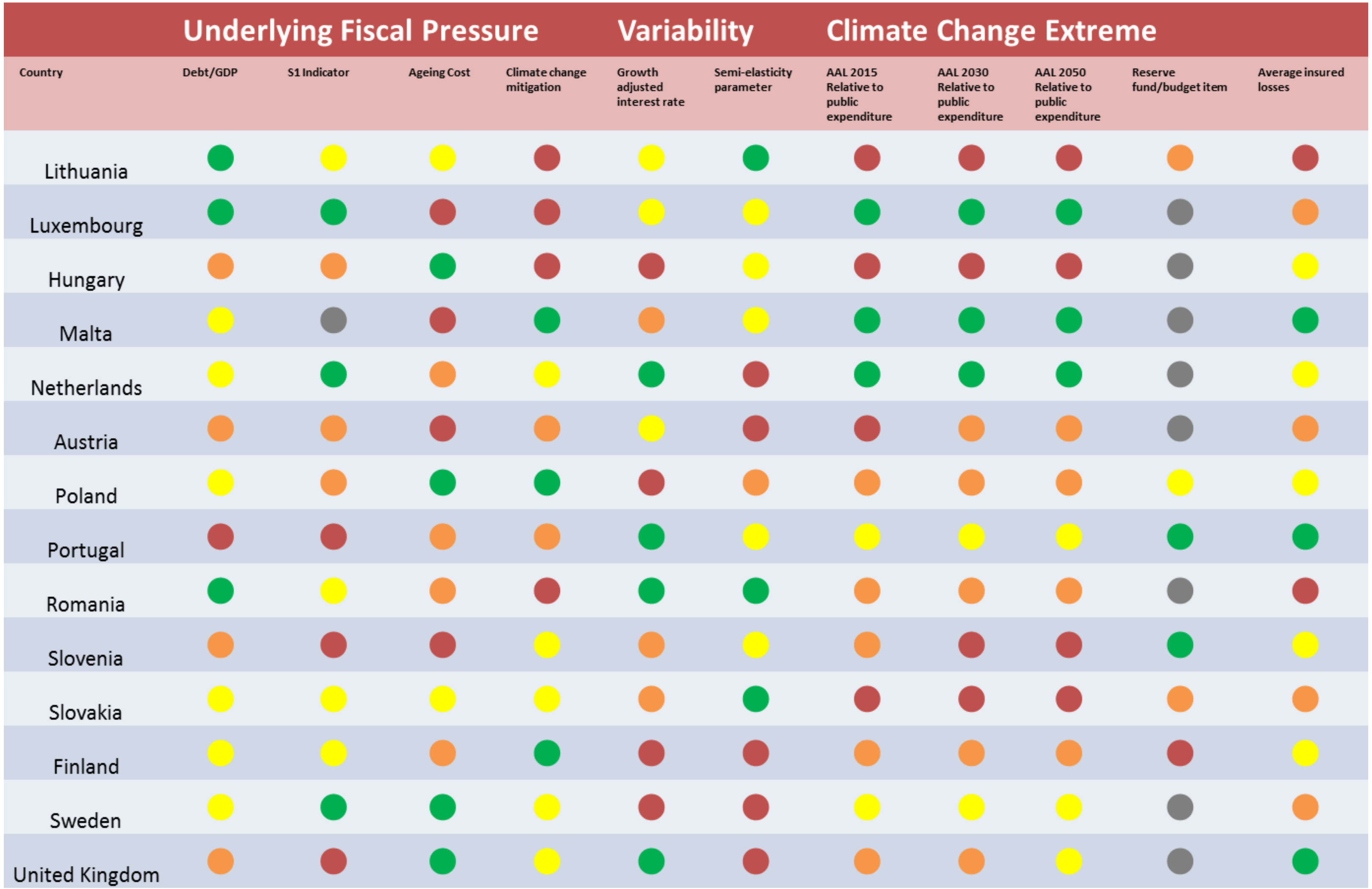
The economic costs of extreme flood events are expected to increase. In absolute terms, countries such as Bulgaria, Czech Republic, Estonia, Hungary, Poland, Romania, Slovenia and Slovakia are expected to have a large increase in AAL, exceeding 200%, in the period 2015 - 2050. The difference in growth relative to public budget is expected to be substantial in countries such as Latvia, Lithuania, Hungary and Slovakia, where a 100 flood event accounting for 3.5%, 2.8%, 6.2%, and 2.9% of public expenditure may grow to 11.6 %, 10.5%, 18.7%, and 12.1% by 2050 respectively. Given that the coverage of private insurance and the use of options such as reserve funds is relatively low in these countries, proactive management of flood risk through a portfolio of risk management options will play an important part in managing the additional fiscal burden arising from future costs of flood risk.

Figure 3: Fiscal Risk Scorecard

	Underlying Fiscal Pressure				Variability		Climate Change Extreme				
Country	Debt/GDP	S1 Indicator	Ageing Cost	Climate change mitigation	Growth adjusted interest rate	Semi-elasticity parameter	AAL 2015 Relative to public expenditure	AAL 2030 Relative to public expenditure	AAL 2050 Relative to public expenditure	Reserve fund/budget item	Average insured losses
Belgium	Red	Red	Red	Orange	Orange	Red	Orange	Orange	Orange	Orange	Green
Bulgaria	Green	Orange	Yellow	Green	Orange	Green	Orange	Orange	Orange	Orange	Red
Czech Republic	Green	Yellow	Orange	Red	Red	Green	Red	Red	Red	Red	Green
Denmark	Yellow	Green	Green	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Grey	Green
Germany	Orange	Green	Red	Green	Green	Orange	Green	Green	Yellow	Grey	Orange
Estonia	Green	Green	Green	Green	Yellow	Yellow	Red	Red	Red	Orange	Red
Ireland	Red	Red	Red	Red	Green	Orange	Orange	Orange	Yellow	Grey	Green
Greece	Red	Yellow	Yellow	Green	Red	Yellow	Yellow	Yellow	Yellow	Grey	Red
Spain	Red	Red	Orange	Orange	Orange	Orange	Green	Green	Green	Grey	Orange
France	Red	Red	Yellow	Orange	Green	Red	Yellow	Yellow	Yellow	Grey	Green
Croatia	Orange	Red	Green	Grey	Orange	Yellow	Green	Green	Green	Grey	Red
Italy	Red	Orange	Orange	Yellow	Yellow	Orange	Yellow	Yellow	Yellow	Grey	Yellow
Cyprus	Red	Grey	Green	Orange	Orange	Orange	Grey	Grey	Grey	Grey	Orange
Latvia	Green	Yellow	Yellow	Red	Yellow	Green	Red	Red	Red	Orange	Red

Note: Percentile thresholds for each indicators (expressed as Indicator [25th: Green, 50th: Yellow, 75th: Orange, 100th: Red]) are as follows: Debt/GDP (%) [43, 72, 92,177] S1 Indicator [1.1, 2.1, 3.3, 6.2] Increase in ageing related expenditure (% of GDP) [1.4, 4.1, 6.8, 12.6] Increase in climate mitigation cost (% of GDP) [0.02, 0.1, 0.2, 1] Growth adjusted interested rate (%) [17, 22, 37, 85] Budget semi-elasticity [0.44, 0.52, 0.56, 0.65] 100 year flood in 2015 relative to public expenditure (%) [0.4, 0.8, 2.4, 6] 100 year flood in 2030 relative to public expenditure (%) [0.3, 0.7, 3.7, 11] 100 year flood in 2050 relative to public expenditure (%) [0.3, 0.7, 7.4, 19] Reserve fund or budget item relative to AAL (%) [160, 360, 209, 660] Average insured damage (%) [2.6, 10.4, 24.8, 69].

Figure 3 continued.



Note: Percentile thresholds for each indicators (expressed as Indicator [25th: Green, 50th: Yellow, 75th: Orange, 100th: Red]) are as follows: Debt/GDP (%) [43, 72, 92,177] S1 Indicator [1.1, 2.1, 3.3, 6.2] Increase in ageing related expenditure (% of GDP) [1.4, 4.1, 6.8, 12.6] Increase in climate mitigation cost (% of GDP) [0.02, 0.1, 0.2, 1] Growth adjusted interested rate (%) [17, 22, 37, 85] Budget semi-elasticity [0.44, 0.52, 0.56, 0.65] 100 year flood in 2015 relative to public expenditure (%) [0.4, 0.8, 2.4, 6] 100 year flood in 2030 relative to public expenditure (%) [0.3, 0.7, 3.7, 11] 100 year flood in 2050 relative to public expenditure (%) [0.3, 0.7, 7.4, 19] Reserve fund or budget item relative to AAL (%) [160, 360, 209, 660] Average insured damage (%) [2.6, 10.4, 24.8, 69].

Figure 4: S1 indicator and direct economic risk under a 100 year flood (uninsured)

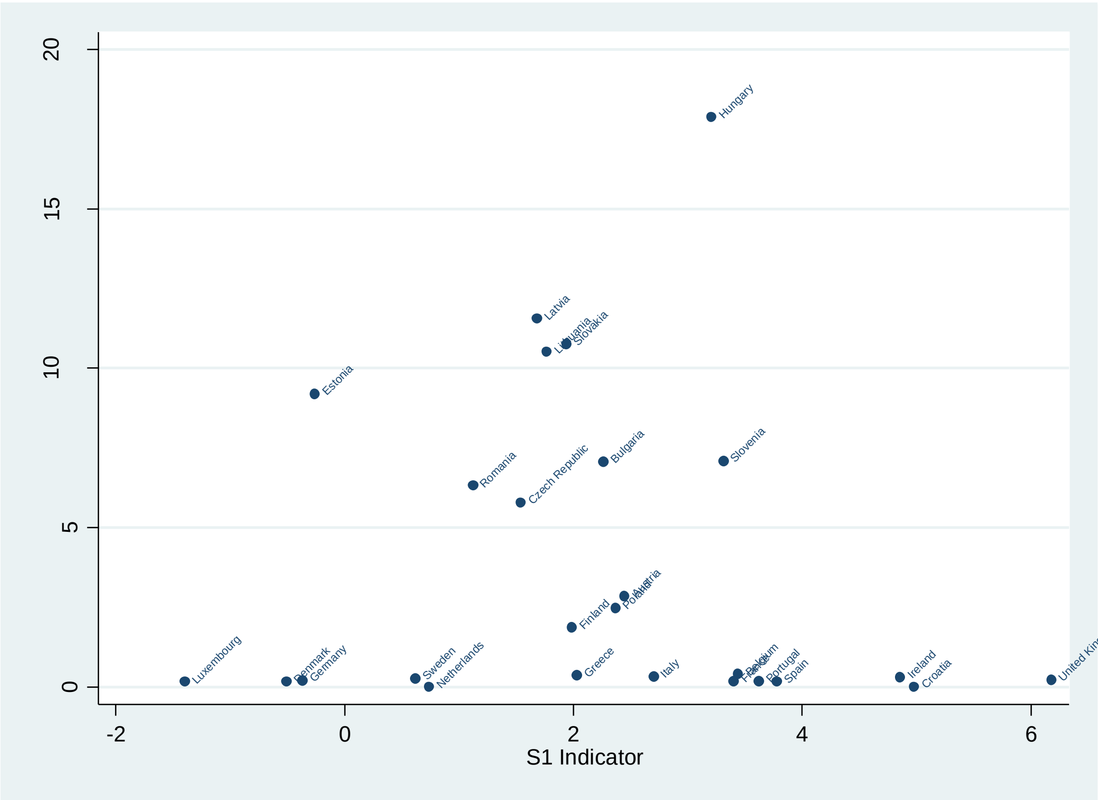
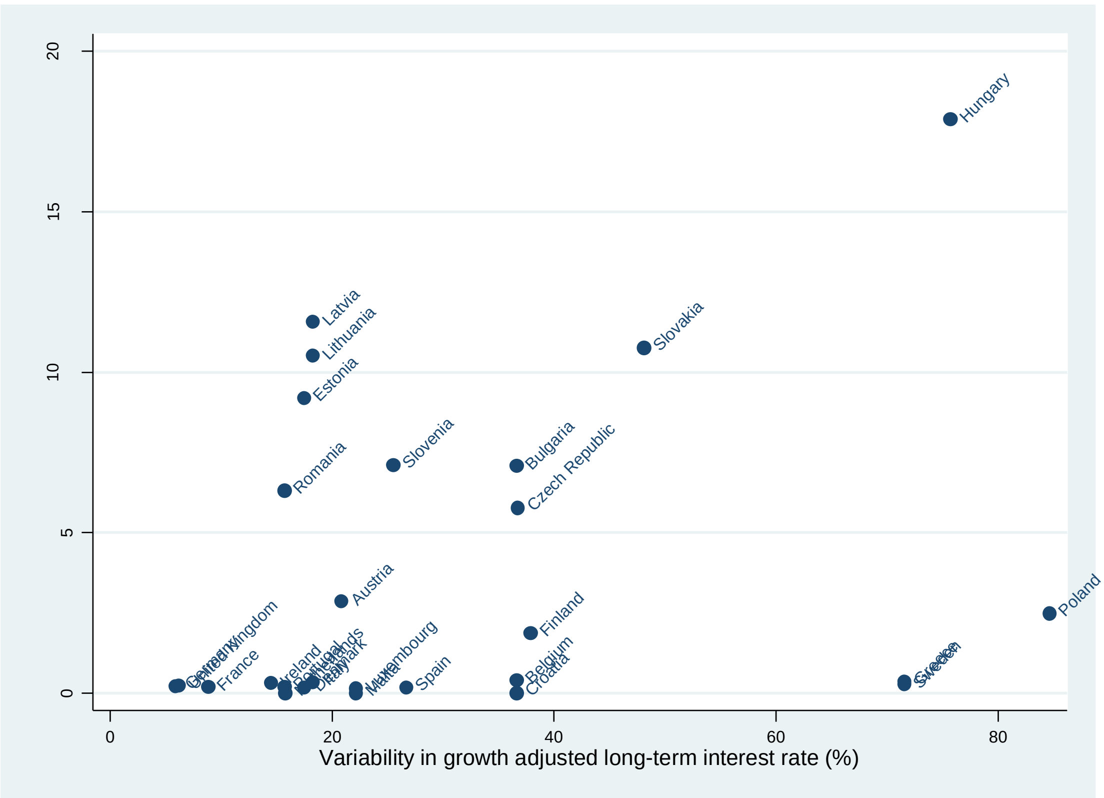


Figure 5: Direct economic risk under a 100 year flood and macroeconomic variability.



4.2 Stochastic Debt-Sustainability—case study of flood risk in Austria

Stochastic fiscal impact of flood risk is explored further using Austria as a case study. Under SSP2 scenario, the total population of Austria is expected to increase from its current level of 9.7 million to 11 million in 2050; this comprises a dependent population of 27.3 %, a working age population of 53.9 % and a youth population of 18.8 %. Based on the educational level and demographic composition assumed under this scenario, the country's GDP is expected to increase by approximately 1% per annum up to 2050. Combining population and demographic trends, ageing related costs are estimated to increase by 8.2 % of GDP by 2050.

As of 2015, public debt stands at 84.5% of GDP; this is made up of approximately 5% short-term (less than 1 year) and 95% longer-term debt (more than 1 year) respectively. Weighted average matury of debt stands at approximately 8 years. In recent years we have seen both a sharp increase in public debt and a steady decline in interest rates in response to the global financial crisis and its repercussions (see Annex 1 for variables used in this study). The variance and covariance of macroeconomic indicators show that their co-movement has been highly volatile in recent years.

The estimates of correlation between floods and macroeconomic variables detected no stastically significant relationships, indicating that past flood events had no major impact on macroeconomic variables. Austria experienced large flood events in August 2002, August 2005 and June 2013, leading to approximately 2,445 Million Euro, 515 Million Euro and 866 Million Euro in economic damage respectively (Thieken et al. 2014).Under the A1B scenario, flood risk in Austria is expected to increase substantially. AAL is estimated at 0.29 billion in 2015, 0.39 billion in 2030 and 0.56 billion in 2050. The extreme tails of flood risk are also projected to increase, and, a 100 year flood event, for example, would cause approximately 7.84 billion (2.5 % of public expenditure) in damages in 2015, 10.7 billion (3 % of public expenditure) in 2030 and 15.45 billion (3 % of public expenditure) in 2050.

In Austria, fiscal resources for disaster prevention, response and recovery are managed thourgh the disaster fund (in German "Katastrophenfonds") administed by the Federal Ministry of Finance (BMF). [8] Currently, resources are allocated for preventive measures (73,27%) remedying of damages due to exceptional catastrophic events (17.84%) and equipment for fire departments (8.89%). The majority of the funds are financed though percentage share (currently 1.1%) of the federal income tax, wage tax, capital yield tax (on dividends), and corporate income tax revenues. Further resources for disaster funds are drawn from investments and repayments by the Austrian hail insurance. Additionally, until 2013 the fund accrued interest yields from the invested disaster fund reserves (Schinko et al. Forthcoming).

---

[8] While the Federal Ministry of Finance administers the resources of the disaster fund, two other federal ministries – the Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) and the Federal Ministry for Transport, Innovation and Technology (bmvit) – as well as the nine Austrian federal states are responsible for the implementation of measures relating to natural hazards protection.

The private insurance coverage of flood risk remains low in Austria for a number of reasons. Private insurance is available for various hazards in an unregulated market, including floods, however, the coverage of flood risk is limited to approximately 3500-5000 Euro, thus limiting its protection against higher damages. In addition, the availability of public compensation through the Disaster Fund serves as a major disincentive to private insurance uptake. Based on past flood data obtained from NatCat Service, average insured losses versus uninsured losses over the past decade is estimated to be below 20%.

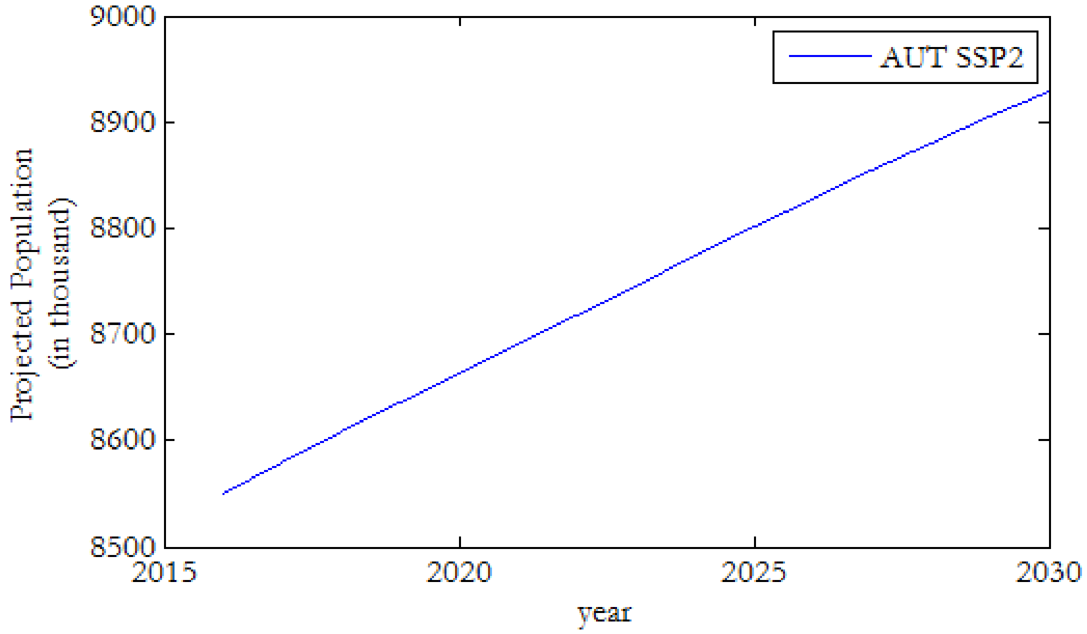
Using baseline assumptions of macroeconomic, demographic projections, public debt under a business as usual scenario (i.e. no fiscal consolidation) is estimated to increase from 84.5 % in 2015 to 123% in 2030. Under the same assumptions, the total disaster fund is expected to increase from its current level of 292 million/year to 330 million/year in 2030. While continuation of no fiscal consolidation is unlikely beyond the medium term, baseline assumptions suggest that the total disaster fund will increase to 410 million/year by 2050.

The results of the Monte-Carlo simulation shows how the Austrian fiscal position may deviate from the baseline debt-projections due both to macroeconomic variability and climate extreme events. The results indicate that variability due to macroeconomic variability is much higher than that of the direct risk of climate extremes, suggesting that climate extreme events in themselves are unlikely to pose significant fiscal pressure on Austria. What is important, however, is the combined effect of macreoconomic- and climate-derived fiscal pressure on the Austrian fiscal stance: under increased pressure due to longer-term fiscal consolidation and macroeconomic variability, ad-hoc and ex-post oriented management of climate extreme events is likely to become increasingly difficult. In the mid-term, up to 2030, the annual probability of disaster fund depletion is estimated at 12 % (2015-2030) and this is estimated to increase to 14 % in (2031-2050). [9]

Under the same set of assumptions, we have further simulated the potential benefits of ex-ante risk reduction worth 50 million/year and 100 million/year respectively on flood risk reduction in Austria. We assumed that an average benefit cost ratio is 4:1, a project life-span is 20 years and DRR investment is effective at reducing risks up to a 100 year event. Under these assumptions, annual DRR investment of 50 million will likely reduce the probability of funding depletion to 9%(2015-2030) and 10%(2031- 2050). An annual DRR investment of 100 million will reduce the probability of disaster fund depletion to 5% (2015-2030) and 3% (2031-2050). Of course, the benefit cost ratio of different DRR investments varies widely, as do the effects of different risk; this illustrative analysis must therefore be interpreted with caution. Further studies are certainly useful in collecting more informaiton on DRR investment effectiveness in Austria and how it may change as a result of anticipated climate change. The

[9] It is important to note that current stochastic assessment excludes longer-term costs of climate mitigation and adaptation due to limited data availability. Incorporation of such costs will likely shift the projection of baseline public debt upwards.

stochastic model developed in this work package will be useful in incorporating new information into fiscal planning, as and when it becomes available.



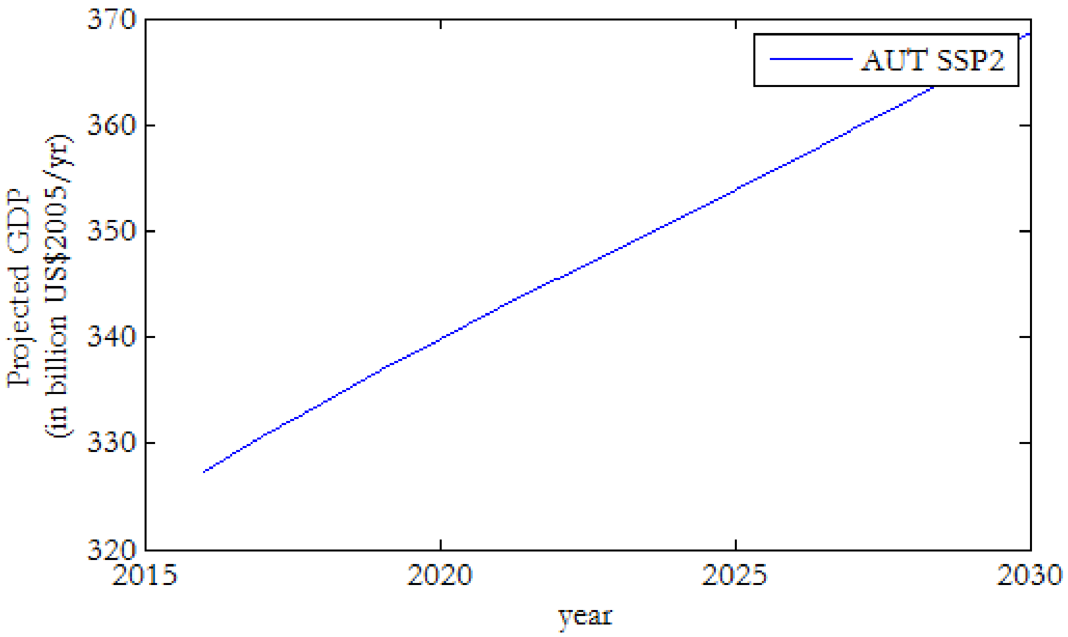


Figure 6 and 7: Baseline assumption population (above) and GDP (below) for Austria under SSP2 scenario.

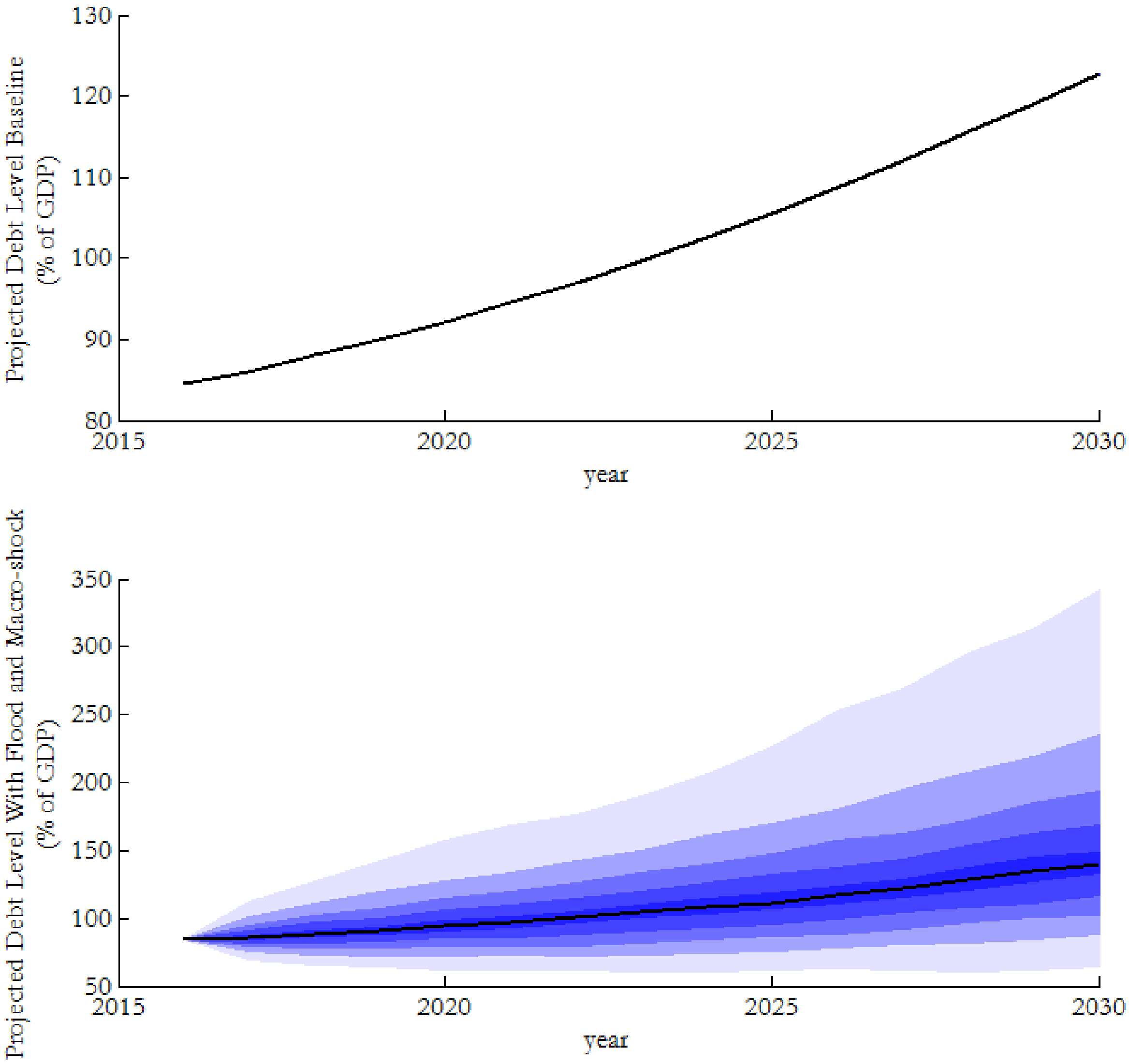
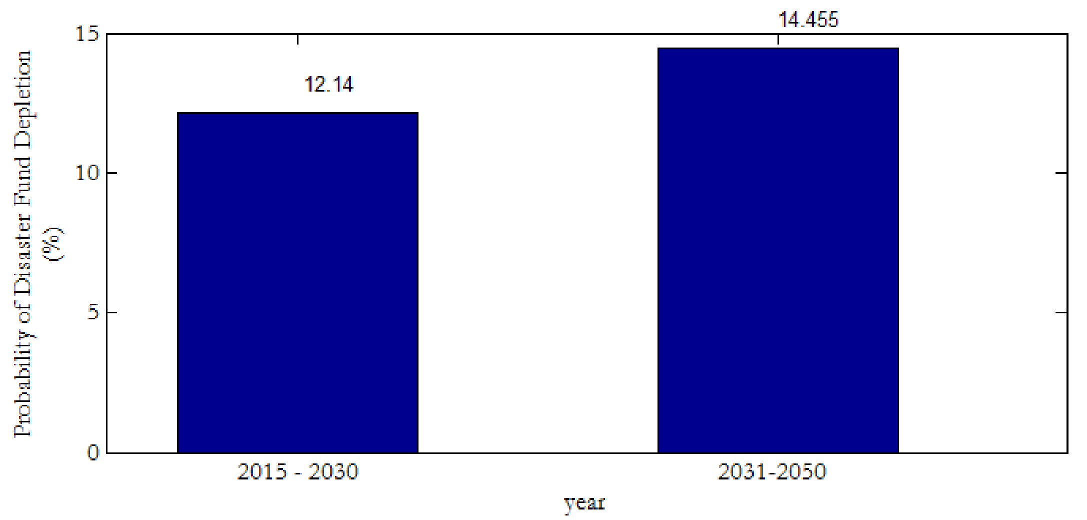


Figure 8 and 9: Baseline (above) and stochastic (Below) debt trajectories for Austria under SSP2 scenario up to 2030. Showing 5th to 95th percenties.



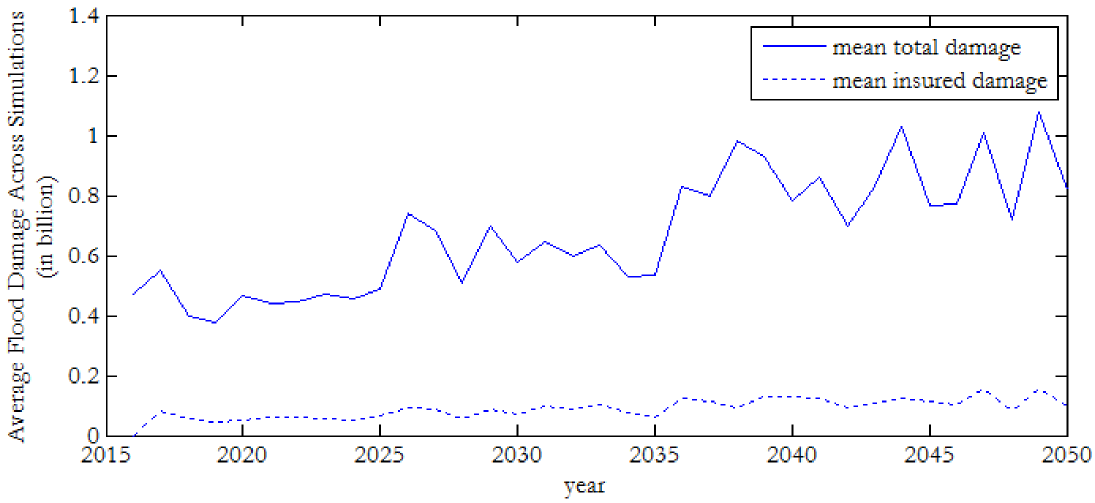


Figure 10 and 11: Baseline mean estimates of probability of disaster fund depletion (above) and mean estimates of insured versus uninsured damage (below) across 1000 scenarios.

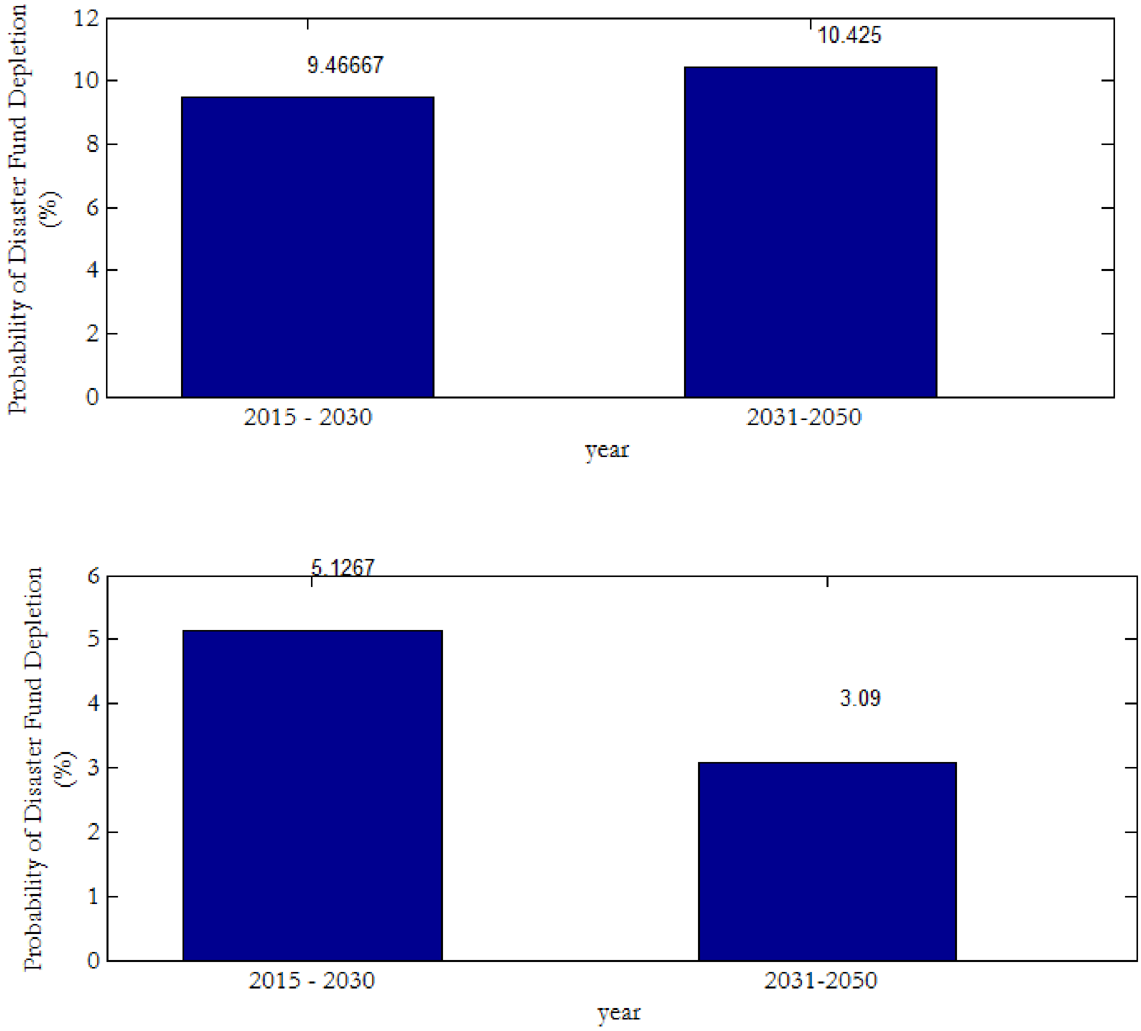


Figure 11 and 12: Mean estimates of probability of disaster fund depletion with annual DRR investment of 50 million Euro (above) and 100 million Euro (below) across 1000 scenarios.

5 Discussions and Conclusions

The climate risk scorecard and stochastic debt-assessment illustrate the importance of fiscal mainstreaming of climate risk in EU member countries. Focusing on increased flood risk in EU countries, economic risk of climate extreme events, relative to the size of economic and public finance resources available, is estimated to be high in countries such as Hungary, Slovenia Latvia, Lithuania and Slovakia. At the same time, these countries also face the need for fiscal consolidation in the medium to longer-term, thus making proactive risk management especially important for these countries.

At the EU level, longer-term fiscal planning has thus far focused on incorporating the increased cost of ageing-related expenditure, whereas climate-related costs are only just beginning to be analysed. Unlike ageing cost estimates, which are projected using common underlying assumptions and shared widely with public and relevant institutions, climate related fiscal cost considerations still lack such harmonized estimation methodology. As this report illustrates, shared socioeconomic pathways scenarios (SSPs) provide a useful framework for linking inter-related dimensions of demography, climate change and other socioeconomic trajectories, and this kind of approach will likely be effective in linking various fiscal policy concerns and designing appropriate fiscal risk managing policies under changing climate and socioeconomic trends.

As EU member states strive for fiscal consolidation, sustainable growth and climate risk management in coming years, mainstreaming of climate risk into fiscal planning is becoming increasingly important. This kind of fiscal mainstreaming not only involves probabilistic estimates of climate-related economic damage and losses, but also should create a common deliberative process though which climate risk may be managed in a proactive manner. As many EU member states are still at the early stages of designing future policy mixes for their country's climate change adaptation strategies, there are ample opportunities to incorporate an iterative style of risk management where state-of-the art scientific information on risk (hazard, exposure and vulnerability) can be mainstreamed. Taking proper stock of public expenditure allocation in prevention, response and recovery, clarifying the responsibility of multiple institutions(thereby avoiding institutional overlap and confusion), and identifying key decision-making mechanisms through which risk information can be incorporated into every-day planning, are important entry points for this type of iterative risk management.

In the case of fiscal risk management at the EU level, the mainstreaming of climate risk into existing fiscal sustainability assessment seem to be a natural entry point. This type of mainstreaming can link climate concerns to wider socioeconomic concerns, such as rising demography-related public expenditure. Members of existing working groups set up at the EPC, such as the Ageing Working Group and the Climate Working Group, will be some of the key audience for such fiscal mainstreaming exercise. In the case of Austria, monitoring and reform of disaster funds provides additional opportunities for fiscal mainstreaming, as well as the existing platform for longer-term macroeconomic planning of public debt and fiscal resources. Given the high uncertainty of climate change related issues, fostering open discussions will be key to creating the institutional culture of learning, and the wider involvement of stakeholders across public, private and civil society will be necessary.

6 References

Altvater, S. et al. (2012): Adaptation Measures in the EU: Policies, Costs, and Economic Assessment. Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2460266.

Berti,K (2013) Stochastic Public Debt Projections Using the Historical Variance-Covariance Matric Approach For EU Countries, Economic Paper 480, European Commission.

Bouwer, L.M. (2011). Have disaster losses increased due to anthropogenic climate change? *Bulletin of the American Meteorological Society* 92: 39-46.

CEPS [Center for European Policy Studies] (2010a) *The fiscal implications of climate change adaptation.* No. ECFIN/E/2008/008. Part I.

CEPS [Center for European Policy Studies] (2010b) *The fiscal implications of climate change adaptation*. No. ECFIN/E/2008/008. Part II.

Conrad, K. and Schmidt, T.F.(1999) Double Dividend of Climate Protection and the Role of International Policy Coordination in the EU — An Applied General Equilibrium Analysis with the GEM-E3 Model. *Man-Made Climate Change. V*olume 1 of the series ZEW Economic Studies pp 180-215.

Cuaresma,J. (2015) Income Projections for Climate Change Research: A Framework Based on Human Capital Dynamics. *Global Environmental Change*. Article in press.

Delpiazzo, E. Standardi, G. and Parrado, R. (2015) Fiscal implications of climate change impacts and adaptation policies in EU Mediterranean countries: an application to sea level risk. Green knowledge platform (GGKP) Third Annual Conference, *Fiscal Policies and the Green Economy Transition: Generating Knowledge*—Creating Impact 29-30 January 2015. University of Venice Italy.

Eller, M. and Urvova, J. (2012) How Sustainable are Public Debt Levels in Emerging Europe? Evidence for Selected CESEE countries from a Stochastic Debt Sustainability, *Focus on European Economic Integration* Q4/12.

European Commission (n.d.) *EU Strategy on Adaptation to Climate Change*. Available at: http://ec.europa.eu/clima/publications/docs/eu_strategy_en.pdf.

European Commission (2012) *Fiscal Sustainability Report: European Economy* 8/2012. . Available at: http://ec.europa.eu/economy_finance/publications/european_economy/2012/pdf/ee-2012-8_en.pdf.

European Commission (2014a) *The 2015 Ageing Report: Underlying Assumptions and Projection Methodologies.* European Economy 8/2014. Available at: http://ec.europa.eu/economy_finance/publications/european_economy/2014/ee8_en.htm

European Commission (2014b) *Assessing Public Debt Sustainability in EU Member States: A Guide*. Occasional Papers 200. September. Available at: http://ec.europa.eu/economy_finance/publications/occasional_paper/2014/pdf/ocp200_en.pdf

European Commission (2015) *The 2015 Ageing Report: Economic and Budgetary Projections for the 28 EU Member States (2013-2060).* European Economy 3/2015. Available at: http://europa.eu/epc/pdf/ageing_report_2015_en.pdf

European Environment Agency (2014) *National Adaptation Policy Processes in European Countries* EEA Report No. 4 2014.

European Environment Agency (2015) Climate change impacts and adaptation http://www.eea.europa.eu/soer-2015/europe/climate-change-impacts-and-adaptation

Hochrainer-Stigler, S. (2007) *Macroeconomic risk management against natural disasters*: Analysis focused on governments in developing countries. Berlin: Springer.

Hochrainer-Stigler, S., Mechler,R. Pflug,G and Williges, K. (2014) Funding public adaptation to climate-related disasters. Estimates for a global fund. *Global Environmental Change* 25: 87–96.

Martinez et al. (2014) Climate Impacts in Europe*. The JRC PESETA II Project.* Available at: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/climate-impacts-europe-jrc-peseta-ii-project.

IMF (2006) Probabilistic Sustainability of Public Debt: A Vector Auto-regression Approach for Brazil, Mexico, and Turkey, *IMF Staff Report* 55(1), International Monetary Fund. Washington D.C.

IMF (2012) A Toolkit for Assessing Fiscal Vulnerabilities and Risks in Advanced Economies, *Working Paper* No. 12/11, International Monetary Fund, Washington D.C.

IPCC (2007) *Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts and Response Strategies: IPCC Expert Meeting Report* 12-21 September. Available at: http://www.ipcc.ch/pdf/supporting-material/expert-meeting-ts-scenarios.pdf.

IPCC (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (eds Field, C. B. et al.). Cambridge Univ. Press.

IPCC (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132pp.

Jongman, B., Hochrainer-Stigler, S., Feyen, L., Aerts J.C.J.H., Mechler, R., Botzen, W.J.W., Bouwer, L.M., Pflug, G.C., Rojas, R., Ward, P.J. (2014). Increasing Stress on Disaster-Risk Finance Due to Large Floods, *Nature Climate Change*, 4:264-268.

Mechler, R. (2004) *Natural disaster risk management and financing disaster losses in developing countries,* vol. 1. Verlag Versicherungswirtsch.

Mechler, R. Hochrainer, S. Aaheim, A. Salen, H. and Wreford, A. (2010). Modelling economic impacts and adaptation to extreme events: Insights from European case studies. *Mitigation and Adaptation Strategies for Global Change* 15 (7): 737-762

Mechler R. and Bouwer, L. (2015). Reviewing trends and projections of global disaster losses and climate change: Is vulnerability the missing link? *Climatic Change* 33 (1) : 23-35

Medeiro,J (2012) Stochastic Debt Simulation Using VAR Models and a Panel fiscal Reaction Function: Results for a Selected Number of Countries, *Economic Papers* 459, European Commission.

Mochizuki J. Vitoontus S. Wickramarachchi B, Hochrainer-Stigler S, Williges K. Mechler R and Sovann R. (2015) Operationalizing Iterative Risk Management under Limited Information: Fiscal and Economic Risks Due to Natural Disasters in Cambodia. *International Journal of Disaster Risk Science* 6(4):321-334.

Mourre G, Astarita C and prince (2014) Adjusting the budget balance for the business cycle: the EU methodology. *European Economy. Economic Papers* 536. November. Available at: http://ec.europa.eu/economy_finance/publications/economic_paper/2014/pdf/ecp536_en.pdf.

OECD (2015) Climate Change Risks and Adaptation: Linking Policy and Economics. OECD Publishing, Paris. Available at: http://www.oecd-ilibrary.org/environment/climate-change-risks-and-adaptation_9789264234611-en

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., Vuuren, D.P. van, (2013) A new scenario framework for climate change research: the concept of shared socioeconomic pathways. *Climatic Change* 122, 387–400.

Osberghaus, D. and Reif, C (2010) Total costs and budgetary effects of adaptation to climate change: an assessment for the European Union. *Center for European Economic Research. Discussion Paper* No. 10-046.

Pereira, A.M. and Pereira, R.M. (2014) Environmental Fiscal Reform and Fiscal Consolidation: The Quest for the Third Divident in Portugal. *Public Finance Review* 42(2) 222-253.

Prettenthaler F, Kortschak D, Hochrainer-Stigler S,Mechler R, Urban H, Steininger KW (2015) Catastrophe management: riverine flooding. In *Economic Evaluation of Climate Change Impacts.* Springer

Ranci P, Olmos L, Pazienza M, Ruester S, Sartori M. Galeotti M and Glachant JM (2011) The Impact of Climate and Energy Policies on the Public Budget of EU Member States. *THINK project.* Available at: http://www.eui.eu/Projects/THINK/Documents/Thinktopic/THINKTOPIC4.pdf.

Rojas. R. Feyen, L. Bianchi, A. and Dosio, A. (2012) Assessment of future flood hazard in Europe using a large ensemble of bias-corrected regional climate simulations. *Journal of Geophysical Research* 117(D17).

Samir, K.C. and Lutz, W. (2014) The Human Core of the Shared Socioeconomic Pathways: Population Scenarios by Age, Sex and Leevl of Education for All Countries to 2100. *Global Environmental Change.* In press.

Schaechter A, Emre Alper C, Arbatli E, Caceres C. Callegari G, Gerard M, Jonas J, Kinda T, Shabunina A, Webter A. (2012) A Toolkit to assessing fiscal vulnerabilities and risks in advanced economies. *IMF WorkingPaper* WP/12/11 Available at: https://www.imf.org/external/pubs/ft/wp/2012/wp1211.pdf.

Schinko, T. Mechler, R. and Hochrainer-Stigler, S. A methodological framework to operationalize Climate Risk Management: Managing sovereign climate-related extreme event risk in Austria, under review

Springmann, M (2012) The costs of climate-change adaptation in Europe: a review. *EIB Working Papers.* Available at: http://www.eib.org/attachments/efs/economics_working_paper_2012_05_en.pdf.

Steininger et al. (2015) *Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria*, Springer.

Thieken AH, Cammerre H, Dobler C, Lammel J and Schoberl F (2014) Estimating changes in flood risks and benefits of non-structural adapation strategies- a case study from Tyrol, Austria. *Mitigation and Adaptation Strategies for Global Change* pp. 1-34.

Timonina, A., Hochrainer-Stigler, S., Pflug, G., Jongman, B. and Rojas, R. (2015) Structured Coupling of Crobability Loss Distributions: Assessing Joint Flood Risk in Multiple River Basins: *Risk Analysis*, article in press.

van derKnijff, J., J. Younis, and A. deRoo (2010) LISFLOOD: A GIS-based distributed model for river basin scale water balance and flood simulation, International *Journal of Geographical Information Science* 24(2): 189–212.

Vaze P. and Sunderland L. (2014) The economic case for recycling carbon tax revenues into energy efficiency. Available at: http://www.e3g.org/docs/The_case_for_recyling_carbon_tax_Feb2014_Final.pdf.

Watkiss P (2013) Iterative Risk Management. weAdapt 21st May. Available at: https://www.weadapt.org/knowledge-base/climate-adaptation-training/module-iterative-risk-management.

7 Appendices

Appendix 1. Empirical observations of insured and uninsured flood losses and macroeconomic variables in Austria.

Historical data obtained regarding past flood losses (Insured vs. Uninsured) and other economic variables show high inter-quarter variability as shown in Figure A1. Over the past years, there has been continued decline in both longer-term and shorter-term interest while varaibility of GDP growth and price index remained volatile. Austria experienced large flood events in both 2002 and 2013, where the majority of losses were uninsured.

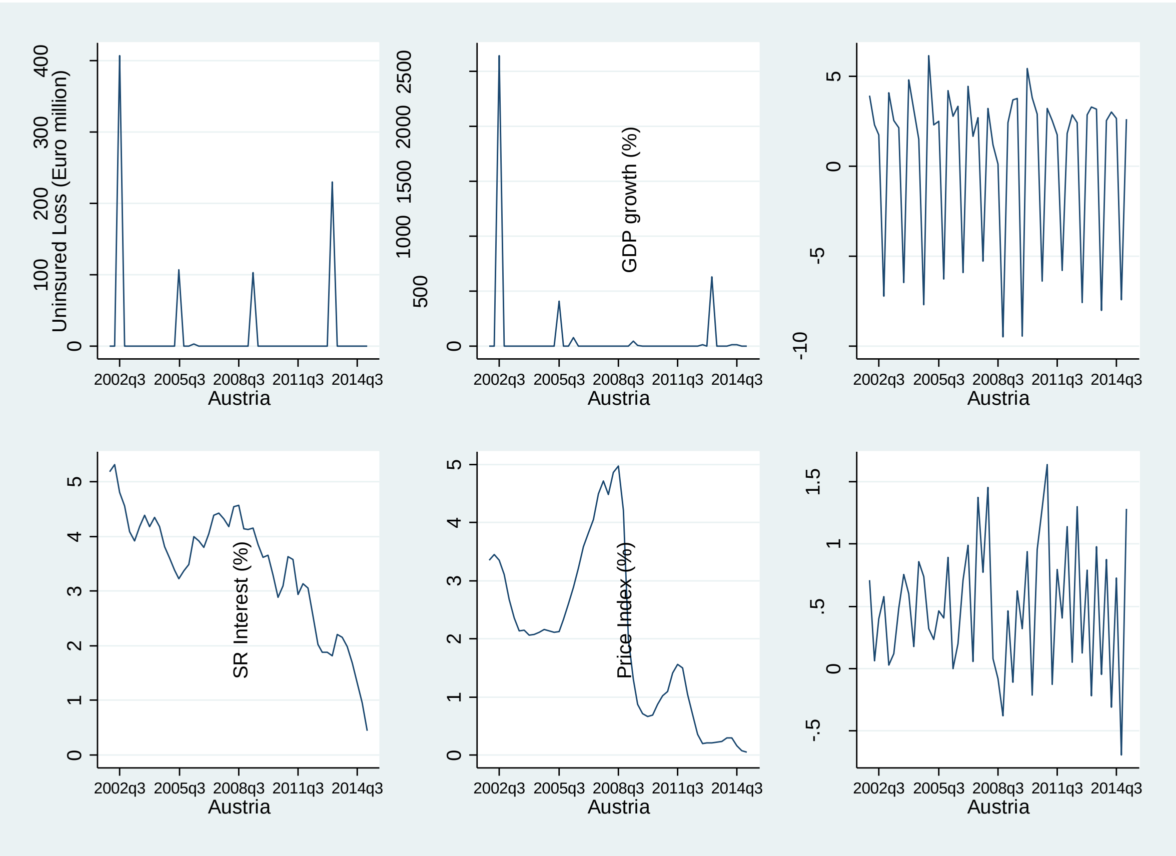


Figure A1: Historical Inter-Quarter Variabilities of Variables Used in This Study

Sources: EUROSTAT, NatCatService

To statistically test whether past observations of economic variables are related to the occurrence of floods in Austria, we have conducted visual inspection (Figure A2) and non-parametric tests (Wilcoxon signed-rank and median tests) which indicated there is no statistically significant differences in medians observed in flooded versus non-flood quarters for Austrian data.

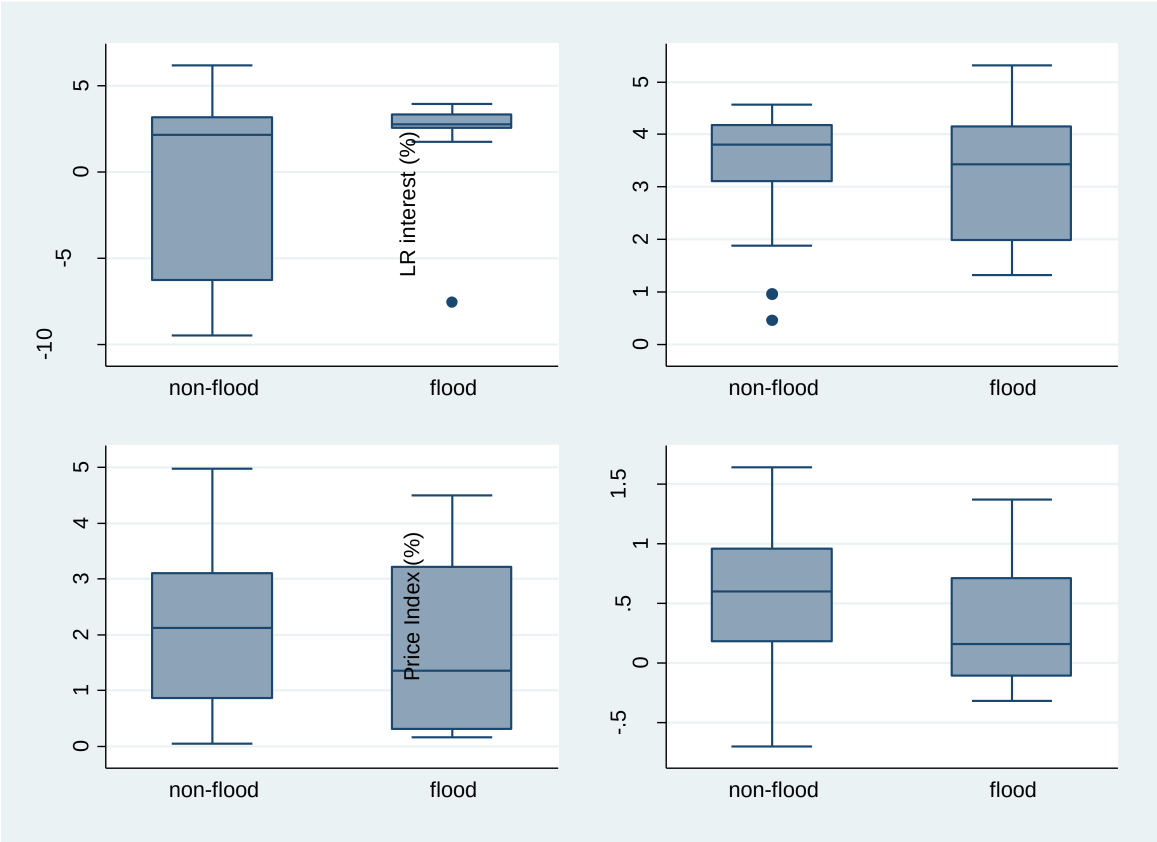


Figure A2: Medians of Economic Variables in Flooded versus Non-Flooded Quarters.

Source: Own calculation based on EUROSTAT and NatCat Service

Appendix 2:Detailed methodologies for stochastic debt asssessment used in the present study.

Following Berti (2013), this study simulates future quarterly macroeconomic shocks based on an estimated historical variance co-variance matrix. Using time-series data of quartly economic variables reported in 2002 q1- 2015 q1, historical shocks (φ_q^k) are extracted as:

$$\varphi_q^k = k_q - k_{q-1}$$

Where k_q is a variable reported at quarter q and k_{q-1} and at quarter q-1 respectively. Historical variance co-variance matrix was then constructed based on these historical shocks.

Table A1 shows historical variance co-variance matrix estimated for this study. Very high variance of GDP growth rates reflects historical volatility in macroeconomic output observed in the recent past.

Table A1: shows historical variance co-variance matrix used this study.

	GDP growth	**LR interest**	**SR interest**
GDP growth	55.34	0.07	0.58
LR interest	0.07	0.08	0.03
SR interest	-0.58	0.03	0.16

Sources: Authors' own estimation based on EUROSTAT Database

Based on this matrix, and assuming a joint normal distribution of variables, this study performed Monte Carlo simulations to generate random vectors of quarterly economic shocks for the projected period (2015-2050). The generated quarterly shocks are then aggregated into annual shocks in the following manner.

For GDP growth, randomly generated quarterly shocks (ω_q^{GDP}) are simply aggregated into an annual shocks at time t(ω_t^{GDP}).

$$\omega_t^{GDP} = \sum_{q=1}^{4} \omega_q^{GDP}$$

In a similar manner, randomly generated quarterly shocks to short-term interest rates (ω_q^{ST}) are simply aggregated to an annual shock at time t (ω_t^{ST}) as,

$$\omega_t^{ST} = \sum_{q=1}^{4} \omega_q^{ST}$$

This simple aggregation indicates that random shocks to short-term interest rates will not have longer-term implications beyond year t.

For longer-term interest rate shocks, however, this study assumes that the impacts of initial shocks are carried over beyond year t up to the year of debt manurity (T) calcuated based on the weighted average maturity of debt (i.e. 8 years for Austria).

Further, annual shocks to implicit rates (ω_t^{IMP}) are calcuated as weighted averages of shortern and longer term interest rates where δ^L and $\delta^S$are shares of long-term and short-term debt respectively.

$$\omega_t^{IMP} = \delta^L * \omega_t^{LT} + \delta^S * \omega_t^{ST}$$

Finally, it is assumed that stochastic variability in GDP growth (ω_t^{GDP}) translates to changes in fiscal balance based on budget semi-elasticity parameter.

Appendix 3: Ageing, education and unemployment cost adjustment

To align the present modelling framework with scenario assumptions adopted under the IPCC shared socioeconomic pathways, projected costs of population ageing according the European Commission Ageing Working Group were adjusted based on both baseline GDP and demographic projections (European Commission 2015). Given the full evaluations regarding different trajectories of ageing related costs (based on alternative policy assumptions, etc.) are beyond the scope of the present analysis, ageing related costs are adjusted simply based on assumed elasticity of unit cost and changes in beneficiaries. The assumptions taken are similar to those of 'demography scenario' as described in European Commission (2015). The unit costs of pension, health, longer-term care, and education are assumed to change proportional to the per capita GDP projections. In other words, given a percentage increase in per capita GDP, a unit cost of health expenditure for example is assumed to increase by a percentage point (due for example to an increasing quality of health care made possible by a rise in standards of living (using per capita as a proxy). In addition, these costs are also adjusted based on future trajectories of potential beneficiaries and this study simply assumed that costs of pension, health and long-term care will change based on the size of dependent population, while those of education will change based on school age populations.

Table A2. Adjustment factors used for demographic-related costs

Cost Categories	Unit Cost Adjustment	Demography Adjustment
Pension	Unit elastic	Dependency (65+)
Health	Unit elastic	Dependency(65+)
Long-Term Care	Unit elastic	Dependency(65+)
Education	Unit elastic	School age (5-19)

Further calibrations based on a more detailed analysis of demographic and economic projections will certainly be useful; however, we have adopted these simplistic assumptions as a way of illustration only, to demonstrate how an incorporation of ageing costs into a stochastic debt assessment may be performed in a manner consistent with the IPCC shared socioeconomic pathways scenarios.

Appendix 4: S1 indicator calculation

The S1 indicator used by the European Commission (European Commission 2012) to illustrate the amount, and duration of, fiscal consolidation efforts needed to achieve medium-term debt sustainability by EU member countries. Assuming that the fiscal consolidation efforts must increase annually at a constant rate (c>0) between t_{0+1} andt_1. Changes in primary balance (PB) may be expressed as:

$$\Delta PB_i \equiv PB_i - PB_{t_0} = c(i - t_0) - \Delta A_i \quad for t_0 < i \leq t_1$$

$$\Delta PB_i \equiv PB_i - PB_{t_0} = c(t_t - t_0) - \Delta A_i \quad for t_2 \geq i > it_1$$

Where (ΔA) change in demography related costs.

Then the debt ratio target(D_{t_2}), (assumed as 60% of GDP in year 2030 in this study) can be written as:

$$D_{t_2} = D_{t_0} \alpha_{t_{t0:t2}} - \sum_{i=t_0+1}^{t_2} \left(PB_i \alpha_{t_{i:t2}} \right)$$

Where $\alpha_{t_{t0:t2}}$ accumulation factor of differential between nominal interest rate and growth rate.

Substituting the first two equations into the above, we have:

$$D_{t_2} = D_{t_0} \alpha_{t_{t0:t2}} - \sum_{i=t_0+1}^{t_1} (PB_{t0} + c(i - t_0)) \ \alpha_{t_{i:t2}} - \sum_{i=t_1+1}^{t_2} \left(PB_{t0} + c(t_1 - t_0) \right) \ \alpha_{t_{i:t2}} + \sum_{i=t_0+1}^{t_2} (\Delta A_i \ \alpha_{t_{i:t2}})$$

By rearranging, we obtain S1 indicator as:

$$s_1 \equiv c(t_1 - t_0) = \frac{D_{t_0} \left(\alpha_{t_{t0:t2}} - 1 \right)}{\sum_{i=t_0+1}^{t_2} (\ \alpha_{t_{i:t2}})} - PB_{t0} + c \frac{\sum_{i=t_0+1}^{t_1} \left((t_i - i) \ \alpha_{t_{i:t2}} \right)}{\sum_{i=t_0+1}^{t_2} (\ \alpha_{t_{i:t2}})} + \frac{D_{t_0} - D_{t_2}}{\sum_{i=t_0+1}^{t_2} (\ \alpha_{t_{i:t2}})} + \frac{\sum_{i=t_0+1}^{t_2} (\Delta A_i \ \alpha_{t_{i:t2}})}{\sum_{i=t_0+1}^{t_2} (\ \alpha_{t_{i:t2}})}$$

Appendix 5: Flood Risk Estimates (in billion Euro)

	2015				2030				2050			
	5	**100**	**500**	**1000**	**5**	**100**	**500**	**1000**	**5**	**100**	**500**	**1000**
Austria (AT, 1)	0.00	7.84	16.50	17.50	0.00	10.73	22.49	23.94	0.00	15.45	32.58	34.05
Belgium (BE, 2)	0.00	3.51	11.73	14.09	0.00	4.77	14.75	18.51	0.00	7.70	23.71	27.20
Bulgaria (BG, 3)	0.08	0.84	1.10	1.30	0.20	2.03	2.71	3.11	0.45	4.75	6.21	7.21
Switzerland (CH, 4)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Czech Rep. (CZ, 6)	0.00	3.84	5.79	7.12	0.00	9.31	13.65	16.70	0.00	20.02	30.35	37.36
Germany (DE, 7)	0.55	4.99	8.13	9.64	0.72	6.69	11.31	13.47	0.97	8.85	14.18	17.31
Denmark (DK, 8)	0.00	1.07	1.76	1.88	0.00	1.45	2.39	2.52	0.00	1.96	3.26	3.43
Estonia (EE, 9)	0.00	0.53	0.90	1.06	0.01	1.30	2.23	2.63	0.02	2.69	4.52	5.31
Greece (EL, 10)	0.05	0.76	1.14	1.19	0.06	1.04	1.57	1.62	0.08	1.50	2.30	2.37
Spain (ES, 11)	0.48	2.33	2.94	3.25	0.66	3.20	4.09	4.57	0.95	4.76	6.01	6.81
Finland (FI, 12)	0.39	3.98	5.51	5.73	0.53	5.51	7.47	7.79	0.75	7.44	10.56	10.93
France (FR, 13)	1.17	10.79	17.79	20.44	1.59	14.45	24.67	28.44	2.18	19.43	32.76	38.02
Croatia (HR, 14)	0.00	0.03	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hungary (HU, 15)	0.00	6.03	12.84	15.28	0.00	14.44	29.95	35.28	0.01	31.48	69.66	83.09
Ireland (IE, 16)	0.01	1.36	2.18	2.51	0.02	1.91	3.13	3.57	0.03	2.58	4.41	4.96
Iceland (IS, 17)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Italy (IT, 18)	0.30	6.38	11.68	13.00	0.41	9.21	15.88	18.16	0.61	13.34	24.19	28.08
Liechtenstein (LI, 19)	0.00	0.18	0.22	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Lithuania (LT, 20)	0.03	0.97	1.50	1.60	0.07	2.21	3.57	3.73	0.16	5.04	7.84	8.38
Luxemburg (LU, 21)	0.00	0.10	0.78	0.78	0.00	0.10	1.05	1.05	0.00	0.22	1.45	1.45
Latvia (LV, 22)	0.03	0.82	1.34	1.60	0.08	1.95	3.26	3.92	0.17	4.42	7.23	8.48
Montenegro (ME, 23)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macedonia (MK, 24)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Malta (MT, 25)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Netherlands (NL, 26)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Norway (NO, 27)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poland (PL, 28)	0.33	4.02	7.06	7.57	0.78	9.49	16.87	18.49	1.63	18.18	34.00	36.42
Portugal (PT, 29)	0.02	0.64	0.85	0.89	0.03	0.89	1.18	1.26	0.04	1.29	1.68	1.79
Romania (RO, 30)	0.29	3.03	7.35	8.83	0.71	7.20	17.93	21.15	1.68	18.13	41.19	50.53
Sweden (SE, 31)	0.36	1.71	2.23	2.42	0.48	2.33	3.04	3.31	0.68	3.28	4.37	4.71
Slovenia (SL, 32)	0.00	0.56	2.57	2.62	0.00	1.39	6.28	6.40	0.00	3.48	16.92	17.21
Slovakia (SK, 33)	0.00	2.08	7.02	8.27	0.00	5.24	17.05	19.86	0.00	12.36	40.55	47.34
Turkey (TR, 34)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UK (UK, 35)	0.00	15.38	45.54	48.79	0.00	20.88	63.08	66.25	0.00	30.63	94.14	100.63

Appendix 6: scenario assumption

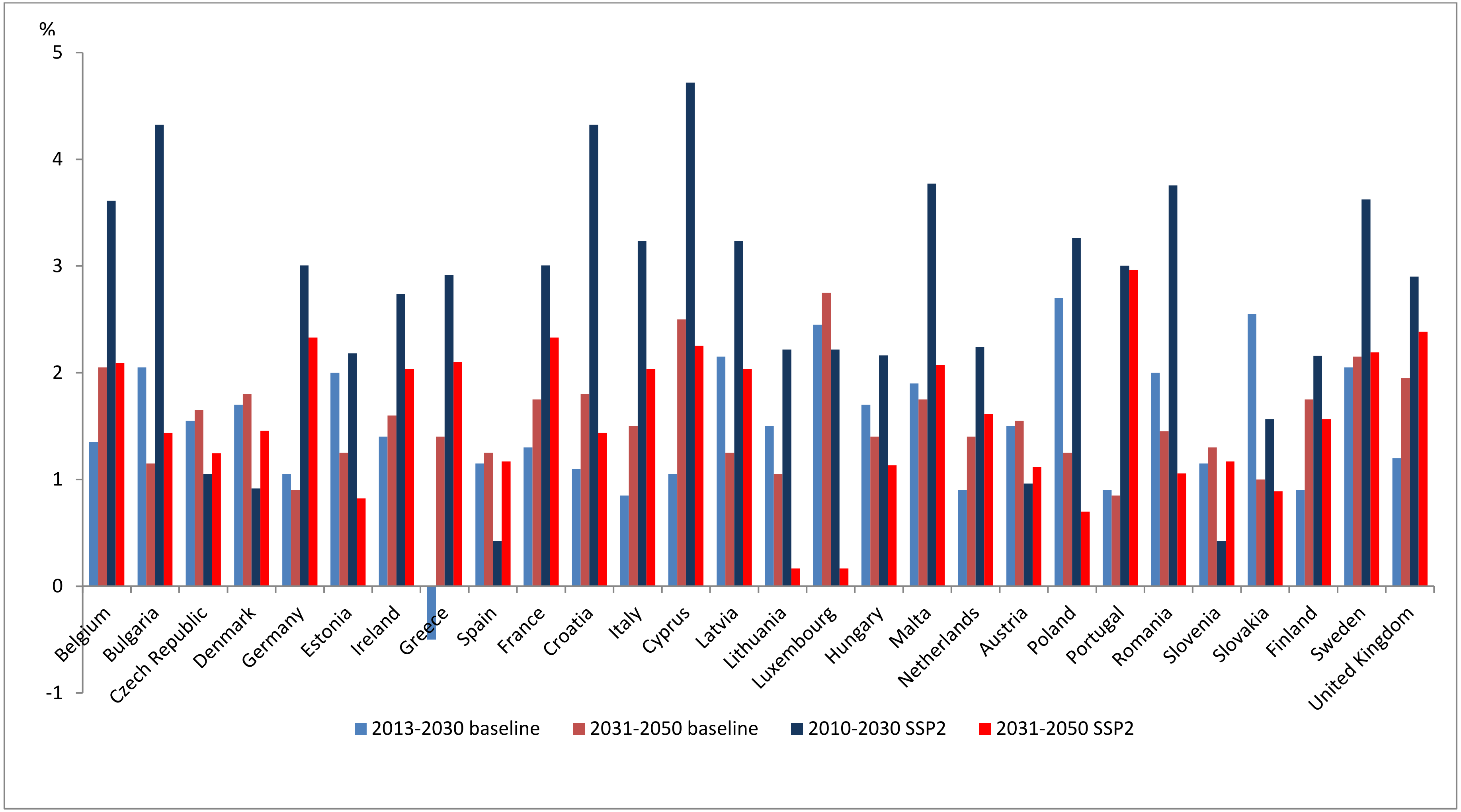


Figure A3: GDP assumptions used in this study (SSP) compared to baseline assumptions used in European Commission (2015).

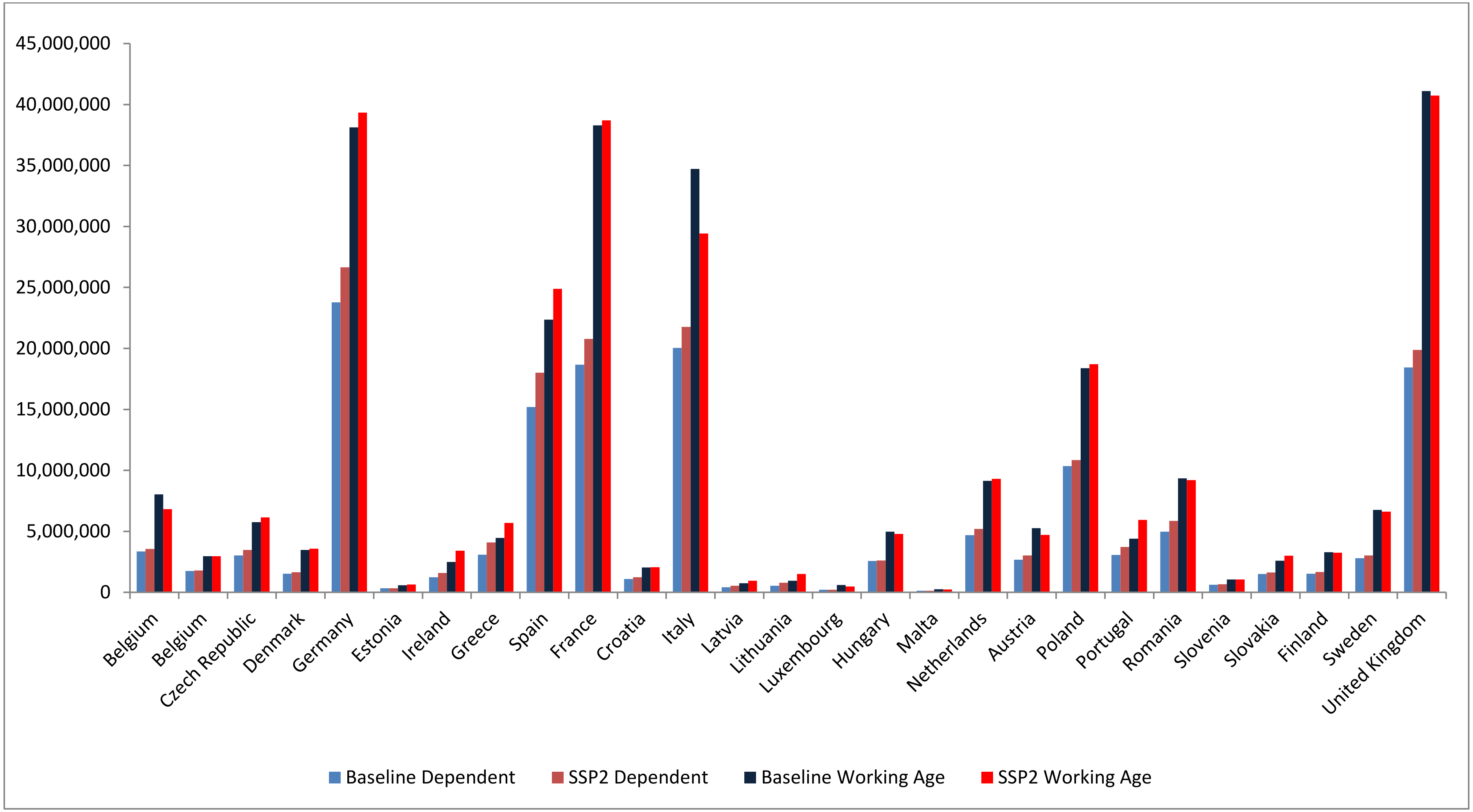


Figure A4: Demographic assumptions used in this study (SSP) compared to baseline assumptions used in European Commission (2015).