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Flood protection gap: evidence for public finances and insurance premiums

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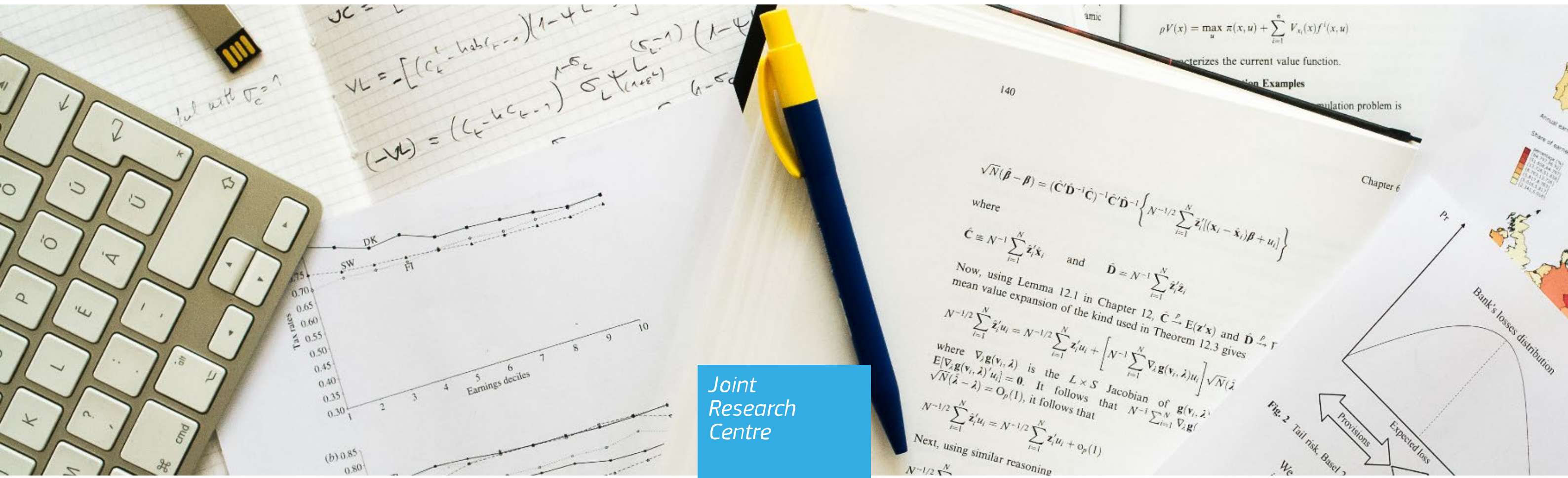

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Executive summary

Natural disasters have always generated considerable losses for financial institutions, the public sector and citizens. Their impact has intensified over the last decade. Climate-related physical risks are a serious concern for both public and private finances, and it is of crucial importance to contain economic losses when physical risk materialize. Due to global warming, weather-related risks such as floods, wildfires, and droughts are projected to increase in frequency, severity and duration. According to recent figures provided by the European Commission (2021a), annual climate-related losses could amount to an estimated EUR 170 billion (1.36% of GDP) under the 3°C global warming scenario in the absence of mitigation and adaptation strategies. River floods are among the climate-related hazards most likely to intensify due to the long-term increase in temperature. Climate-related phenomena could affect GDP levels, and by extension public finances (affecting both public expenditure and revenues), and ultimately the lives of millions of people. It is therefore essential to model the impact of climate-related hazards on the economy and to estimate their overall cost.

While insurance policies can help firms and households mitigate risks and withstand the economic consequences of natural disasters, public measures that enforce mitigation and adaptation policies targeted at areas and businesses affected by natural hazards are also necessary.[1] This paper contributes to the debate by assessing how the landscape would change if the insurance sector covered exposures in each Member State, thereby reducing the need for public measures. It explores whether this would help curb the rise in potential government spending caused by more frequent extreme events.

The methodology presented in this paper enables us to estimate: (i) the increase in insurance premiums necessary to harmonise the minimum level of protection against floods across all European countries; and (ii) the possible reduction in the amount of contingent losses for public finances,[2] even if, under extreme and unlikely circumstances, some insurance contracts may not be honoured because certain insurance companies default in the aftermath of the disaster. While increasing insurance coverage is likely to be beneficial for private and public actors as it could reduce the overall cost for taxpayers, using insurance as a risk transfer mechanism could raise insurability and affordability concerns in a climate-damaged world. Increasing the insurance coverage of natural hazards could imply unrealistically high premiums that would make the product inaccessible to some policyholders. Therefore, as widely discussed in the literature, a portion of extreme risks could become uninsurable as they are not affordable for policyholders. Public and public-private insurance schemes, risk-mitigation activities (i.e. preventive measures), public investment in risk reduction and prevention measures as well as targeted investments in loss prevention, could therefore be necessary.

Policy context

As climate change concerns society as a whole, the European Commission has announced measures to reduce the climate protection gap. The 2021 adaptation strategy aims to improve the understanding of natural disaster insurance penetration in Member States and to promote it. An additional proposal is to roll-out adaptation solutions to reduce the exposure of insurers, and more broadly of society, to climate-related risks, and to increase investment into better climate change adaptation measures. The Commission is also committed to strengthening dialogue between insurers, policymakers, and other stakeholders,[3] identifying and promoting best practices in risk management funding, and exploring innovative solutions to deal with climate-induced risks, such as parametric insurances, mandatory insurance or bundling across risks, and risk transfer solutions (European Commission, 2021b). The Commission is working together with the European Central Bank and members of the European Systemic Risk Board to analyse and manage climate-related risks at EU level, and therefore contributing to the development of analytic frameworks for climate risk assessment.

Main findings and key conclusions

Our findings suggest that the expected losses stemming from floods in one year's time could exceed EUR 33 billion, with only a part of them covered by insurance, and with very large variation as a share of GDP across

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[1] Also public-private insurance schemes (PPPs) that pool risks and allow diversification are another tool. See ECB-EIOPA (2023)

[2] Contingent losses are amounts that, while not directly impacting public finances, might end up being covered by the public sector in an attempt to mitigate the impacts on citizens or the economy of extreme or systemic events. For the case of natural disasters, see e.g. Gamper at al. (2017)

[3] In this regard, see also the Climate Resilience Dialogue, as announced in the Strategy for financing the transition to a sustainable economy

Member States. The analysis shows that an increase of EUR 10.8 billion in written premium (+58%) is needed to level up the insurance climate penetration in the EU to at least 50%. The paper also estimates that uninsured floods, when considered together with potential insurance defaults, have the potential to generate EUR 27 billion in public finance contingent losses every year, and that reducing the climate protection gap by increasing insurance penetration could lower this impact by up to 50%.

Related and future JRC work

This work is related to several ongoing projects aimed at estimating the future economic consequences of climate change and climate-related physical risk, together with potential adaptation measures that would require the support of public and private funds. The outcome of selected works has been included in the annual joint ESRB/ECB reports on climate change and climate risk since 2019. JRC keeps contributing to the ESRB/ECB Climate Project Team, providing scientific analysis to support climate risk monitoring and future policies.

Flood protection gap: evidence for public finances and insurance premiums

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Abstract

Climate-related physical risks pose serious concerns for both public and private finances, and it is of utmost importance to contain economic losses when natural catastrophes occur. In this context, the paper models the potential economic impact of currently uninsured floods in the EU. It also assesses the potential reduction in economic losses by increasing the minimum level of flood insurance penetration, and the resulting increment in total premiums required to achieve this objective. First, the paper estimates the share of premiums associated with insured floods events over total premiums. Then, it investigates the extra premiums needed to close the flood protection gap by requiring all EU countries to reach a minimum level of insurance protection. Third, the paper proposes a stylised approach to quantify economic losses associated with uninsured flood events at different levels of insurance penetration, allowing to take into account that insurance protection could be partly ineffective due to defaults in the insurance sector. The model can be used to assess the size of the potential contingent loss for public finances if no preventive measures are taken to increase society's resilience against climate and weather-related risks, and compare it with a safeguard mechanism under an "average" or "worst-case" scenario. Results show that insurance premiums should be at least doubled to reach a harmonised level of penetration equal to 75%. Results show that average yearly uninsured losses could amount to EUR 27 billion today. Under an alternative scenario accounting for an increase in insurance penetration, losses would decrease by up to 50%.

JEL Code: C15, G22, E6, Q54

Keywords: Physical risk, flood events, insurance, protection gap, insurance premiums

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1. Introduction and literature review

Natural disasters have always generated considerable losses for financial institutions, the public sector and citizens. Their impact has intensified over the last decade. According to the European Environmental Agency (2022), weather and climate-related events caused EUR 450-520 billion in economic damage between 1980 and 2020 in the 32 European Economic Area countries. In addition, the number of reported natural disasters has almost doubled since 2010, as have the economic costs (Canova, F. and Pappa E., 2021). At global level, CRED and UNISDR (2018) calculate that climate-related disasters amounted to USD 2.45 billion between 1998 and 2017, rising by 251% during this 20-year period.

Due to global warming, weather-related risks such as floods, wildfires, and droughts are projected to increase in frequency, severity and duration. According to recent figures provided by the European Commission (European Commission, 2021a), annual climate-related losses could amount to an estimated EUR 170 billion (1.36% of GDP) 'under the 3°C global warming scenario, in the absence of adaptation strategies. River floods are among the climate-related hazards most likely to intensify due to the long-term increase in temperature. For example, the recent catastrophic flooding of July 2021 in Belgium and Germany, which caused devastating damage to households and businesses, generated losses of up to EUR 32 billion (Mohr, 2022). The last three decades were among the most flood-rich periods in Europe of the last 500 years (Blöschl et al. 2020), and according to Feyen et al. (2020) river flood-related losses will reach EUR 50 billion per year (6 times more than now) under a 3°C increase in temperature in 2100 scenario. This will expose half a million people (three times more than today) to river flooding each year, and 2.2 million people to coastal inundation, and will generate losses of up to EUR 250 billion. Data analysists worldwide are gathering information on the level of losses associated with natural disasters. The JRC Risk Data Hub (JRC RDH), a platform developed by the European Commission, plays a central role in collecting information on the economic damages and human losses across Europe from hazard events.

With the potentially disastrous effects of climate change in Europe, it is essential to consider the impact on the economy and potential impacts on public finances. Climate-related phenomena could affect GDP levels, and by extension public finances (affecting both public expenditure and revenues), and ultimately the lives of millions of people. It is therefore essential to model the impact of climate-related hazards on the economy and to estimate their overall cost. In 2007, Hallegatte et al. (2007) suggested that changes in the distribution of extremes could result in significant GDP losses in the absence of specific adaptation plans. Therefore, more accurate estimates of economic damages from climate-related events should consider the distribution of extremes, instead of their average cost, and make explicit assumptions on the organisation of future economies. On the same line of research, Prettenthaler et al. (2017) and P. Jindrová et al. (2019) use advanced extreme value theory and fit heavy-tailed distributions to quantify the size of flood-related losses in Europe.

The World Bank and the European Commission have proposed a risk management model for fluvial and surface water floods coupled with a macro-fiscal analysis (see Solon-Swan economic growth model) to evaluate the impact of damages to assets - caused by disasters – on GDP and government spending. Recently, Gagliardi (2022) presented a stylised stress test to evaluate the fiscal impact of extreme weather and climate events. The authors quantify the deviation from the Commission's 10-year baseline debt-to-GDP projections should a past extreme event reoccur in the medium term. The paper notes that such an event may pose risks to fiscal (debt) sustainability in some countries, namely Spain and Czechia, but remain manageable under standard global warming scenarios. Results point to a debt increasing effect of up to 5 percentage points of GDP.

A complementary strand of research focuses on the financial risks associated with weather-related events. Mandel et al. (2021) quantify the risks of floods by modelling the propagation of climate-related shocks through financial networks. They show that both a country's exposure to climate-related natural hazards and its financial leverage have an impact on the magnitude of global risks. Morana and Sbrana (2019) show that the increase in climate-related risks has a direct impact on the catastrophe bonds market, resulting in a decrease in the returns. Lending institutions may also be severely affected by climate-related catastrophic events, as they could create adverse economic conditions leading to an increase in insolvency rates in specific economic sectors. This could increase the number of corporate defaults, and consequently the risk to lenders. The European Central Bank (2022) published a preliminary climate stress test to assess the exposure of the banking sector to the impact of losses due to drought, heatwaves, and flood risks, by making use of data on the geographic location of their lending activities. Results show that the combined credit and market risks losses for a sample of 41 European institutions would amount to EUR 70 billion, under a three-year disorderly transition scenario[4].

The increasing frequency and/or severity of extreme events may also affect the affordability and availability of insurance in the future. According to the European Insurance and Occupational Pensions Authority (EIOPA 2022a), property insurance is the business line that was the most affected by these climate-related risks. This latest publication discusses the potential impact of both extreme weather events and gradual global warming by assessing the potential negative consequences on the insurance sector. Tesselaar et al. (2020) study EU river flood insurance systems' vulnerability to climate change. They apply a dynamic integrated flood insurance model and conclude that the rise in premiums causes problems of affordability, leading to a decline in the demand for flood insurance products. This, in turn, increases the financial vulnerability of households to flooding. The authors claim that government reinsurance for flood risk can be a suitable solution.

Finally, the Commission is working together with the European Central Bank and members of the European Systemic Risk Board to analyse and manage climate-related risks at EU level, and therefore contributing to the development of analytic frameworks for climate risk assessment[5].

2. Scope of the paper

Climate-related events affect multiple stakeholders, from firms and households to the insurance and financial sectors, and could eventually impact public finances in case the state decides to intervene to cover losses following extreme events. The insurance sector can play a central role in managing the overall costs of climate-related disasters by reducing costs that could potentially impact public finances, and by incentivising the development of good practices to reduce vulnerability through adaptation and mitigation measures. In other words, the insurance sector has a role to play in closing the protection gap by providing new insurance solutions, enhancing risk awareness[6], developing new risk transfer solutions and creating the right incentives. Along this line of research, Holzheu and Turner (2018) address the discussion on the protection gap for extreme events and set out a framework to quantify the protection, by geography and risk type, in historical and expected terms. Following an empirical analysis of the key drivers of the protection gap, the authors propose several measures to narrow it.

EIOPA has developed a pilot European dashboard that illustrates the insurance climate protection gap at Member State-level (EIOPA 2022b, NGFS 2019) for natural catastrophes and selected climate risks. The data show that protection gaps vary significantly between Member States, as well as between different perils. While the lowest protection gap is observed for windstorms, flood is the peril with the highest number of countries showing a high protection gap, specifically the Netherlands, Germany and Croatia. There are notable differences between insurance products in terms of accessibility, coverage, risk pricing and options across the EU, as well as differences in the share of disposable income to afford insurance premiums (Tesselaar, 2020). If insurance uptake does not increase to a minimum level of potential damage in every Member States, there may be withdrawals from the EU's main solidarity instrument, the Solidarity Fund, which was designed to respond to 'exceptional' and 'uninsurable' disasters. Commission staff working document (2021c) outlines the current state of knowledge in that respect.

The European Commission has therefore announced measures to reduce the climate protection gap. The 2021 adaptation strategy (European Commission, 2021a)[7] aims to improve the understanding of natural disaster insurance penetration in Member States and promote it. An additional proposal is to roll-out adaptation solutions to reduce the exposure of insurers, and more broadly of society, to climate-related risks, and to increase investment into better climate change adaptation measures. The Commission is also committed to strengthening dialogue between insurers, policymakers and other stakeholders, identifying and promoting best

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[4] A disorderly transition scenario assumes delays in the implementation of climate policies to limit warming.

[5] The latest contribution, 'The macroprudential challenge of climate change' includes several analysis and data provided by the JRC.

[6] See for instance the report of SwissRe (2021), where 'no action is not an option' available here.

[7] https://ec.europa.eu/clima/eu-action/adaptation-climate-change/eu-adaptation-strategy_fr

practices in risk management funding, and exploring innovative solutions to deal with climate-induced risks, such as parametric insurances, mandatory insurance or bundling across risks, and risk transfer solutions (European Commission, 2021b).

This working paper contributes to the debate by assessing how the landscape would change if the insurance sector covered exposures in all EU Member States, thereby reducing the need for public measures. This course of action could minimise the rise in public costs and provide the financial capacity to rebuild infrastructures in the aftermath of extreme natural, thereby keeping the economy stable. The paper focuses on coastal and river floods specifically.

The methodology presented in this paper enables us to quantify: (i) the increase in insurance premiums necessary to harmonise the level of protection against flood events across all European countries; and (ii) the possible reduction in the amount of public finance losses even under a 'worst-case' scenario where the insurance mechanism is only partially effective due to defaults in the insurance sector. On the former, we need to estimate the share of premiums for fire and other damages to property insurance pertaining to floods. The flood-related expected losses are assumed to be the insured share of climate-related losses associated with floods (coastal and river), which are calculated using the Risk Data Hub's figures on the number of people exposed. Starting from this assumption, we assess by how much written premiums would increase if the insurance sector were called to reduce the climate protection gap in silos (i.e. without considering adaptation or mitigation measures or the involvement of other actors in reducing economic losses).

The second part of the analysis uses a stylised model to assess the maximum loss for public finances under a worst-case scenario where some insurance companies default in the aftermath of flood events, rendering the insurance protection only partly effective. The framework does not address the issue of changes in risk unit prices, and assumes that neither preventive measures to increase the resilience of society against climate and weather-related risks, nor increases in the frequency or severity of extreme events due to climate change are considered.[8]

Preliminary findings suggest that the expected losses stemming from floods in one year could exceed EUR 33 billion. Only a quarter of climate-related losses are covered by insurance, and there is significant variation across Member States[9]. Premiums for floods account for 12.5% of premiums for fire and other damages to properties and businesses, and an increase of EUR 10.8 billion (+58%) is needed to level up the insurance climate penetration in the EU to at least 50%.

Finally, the paper shows that floods, together with possible insurance company defaults, have the potential to generate EUR 27 billion in public finance losses every year. Reducing the climate protection gap could lower the impact by 50%, even when considering the possibility of insurance defaults. While increasing insurance coverage is likely to be beneficial for private and public actors as it could reduce the overall cost for taxpayers, using insurance as a risk transfer mechanism could raise insurability and affordability concerns in a climate-changed world. Increasing the insurance coverage of natural hazards could lead to an increase in premiums for certain risks, which could make the product inaccessible to some policyholders. On this, the literature consensus is that a portion of extreme risks is not insurable as it may not be financially sustainable for policyholders. The results seem to support the need to develop and roll-out adaptation measures to increase climate resilience, as envisaged by the climate adaptation strategy. Risk-mitigation activities (i.e., preventive measures), public investment in risk reduction and prevention measures, as well as targeted investments in loss prevention are necessary. Once future disaster-related spending decreases, the insurance market will be able to provide additional coverage against these disasters.

The paper is structured as follows. Section 3 describes the database and the methodology used to estimate the impact of insurance premiums. Section 4 presents methodology and results to quantify the impact on public finances. Finally, Section 5 presents the conclusions.

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[8] Based on the latest projections from climate change modelling it would also be possible to include future impacts.

[9] https://www.eiopa.europa.eu/what-do-about-europes-climate-insurance-gap-2023-04-24_en

3. Impact on insurance premiums

The proposed framework aims to quantify the size of premiums written associated with an increase in insurance penetration in the EU.

3.1. Methodology and data

Insurance coverage for natural disasters is typically part of fire or property insurance (EIOPA 2022b), and the proposed type of coverage varies from country to country. Due to the lack of detailed data on insured natural catastrophic events, statistics for these lines of business are not available. Therefore, we rely on information for climate-related events and general statistics on the insurance sector to disentangle the share of premiums and provisions set aside for natural hazards. We then estimate the increases in premiums when increasing the minimum insurance penetration level.

3.1.1. Expected economic losses from flood events

Data on coastal and river floods have been taken from the last figures available on the Risk Data Hub[10]. This is an EU-wide web-based geographical information platform developed by the European Commission's Joint Research Centre. The Hub's database collects data on disaster losses from historical natural hazards at local, regional, and national levels. The platform also provides georeferenced exposure data for various assets, such as buildings, population, critical services, and the environment, together with a vulnerability indicator. The former aims to assess exposure to natural hazards, while vulnerability refers to the predisposition of the exposed elements to withstand natural hazards and is assessed as a multidimensional social, economic, political, environmental, and physical indicator. Each hazard is covered with a specific grid resolution (100m for river and coastal floods), and an aggregation at the level of local administrative units is also available. Figure 1 presents a risk-evaluation map for the EU, based on a relative score measuring the population at risk in the event of natural catastrophes. To calculate the expected annual human loss (*EAHL*) over 1 year,[11] the corresponding exposures of people (*EP*) under different return periods are weighted using the probability of occurrence ($POc, period$),[12] where the 'return periods' are estimates of the interval of time between events[13]:

$$EAHL_i = \sum_{period} EP_{i,period} \times PO_{C,period} \tag{1}$$

To evaluate the monetary loss of each country *i* due to flood events, we start with the 2020 GDP at current market prices and apply the share of population affected ($EAHL_i$) over the total population of a country[14]. As exposure alone is not sufficient to determine the final risk, as it is possible to be exposed but not vulnerable to a particular hazard, the expected economic loss (EEL_i) is calculated by rescaling the monetary loss using the vulnerability index (V_i) of each country.

$$EEL_i = GDP_i \times \frac{EAHL_i}{Total\ population_i} \times V_i. \tag{2}$$

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[10] https://drmkc.jrc.ec.europa.eu/partnership/Scientific-Partnerships/Risk-Data-Hub

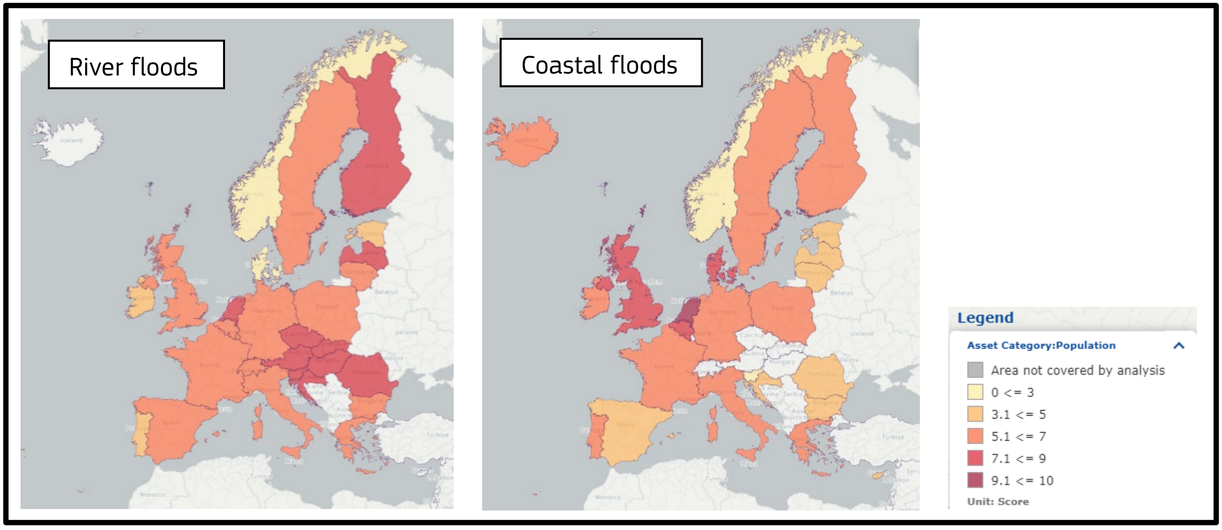
[11] A one-year time horizon has been chosen because contracts for non-life insurances are usually short-term, while life insurance contracts are usually long-term.

[12] We focus on human exposure which represents the total number of fatalities, namely people whose households have been affected by the flood and people that got injured.

[13] For example, a return time of 100 years indicates that the event will occur once in 100 years on average, therefore the probability a similar event could occur in the same interval of time is 1% (1/100). A more technical explanation of these topics is provided in the DRMKC - Risk Data Hub website.

[14] Statistics on both GDP and total population are sourced from Eurostat.

Figure 1: Risk-evaluation map for river and coastal floods



Source: JRC Risk Data Hub website

Figure 2 shows the size of expected economic losses per country due to floods. The Netherlands is the country most affected[15], followed by Germany, France and Italy. Interestingly, although the Netherlands has the highest size of coastal flood-related losses, Germany is the most affected by river floods. At EU level, the total amount of average expected economic losses (in 1 year) due to flood events amounts to around EUR 33 billion. When excluding the Netherlands, the amount of average expected economic losses decreases to EUR 22.5 billion. We note that expected economic loss (EEL_i) does not weight the effect of existing flood protection, which is particularly relevant for the Netherlands[16]. For example, when incorporating these mitigation measures, Feyen et. al (2020) estimate that river flooding causes damages of EUR 7.8 billion per year, roughly 0.06% of 2020 GDP and the amount could increase to up to EUR 50 billion per year, under a 3°C global warming scenario. Adaptation strategies could reduce the amount of projected annual economic losses to around EUR 8-9 billion. The authors also find that for coastal floods, current economic losses stand at around EUR 1.4 billion per year and could reach EUR 239 billion per year in 2100 in a no-adaptation, high emission scenario.

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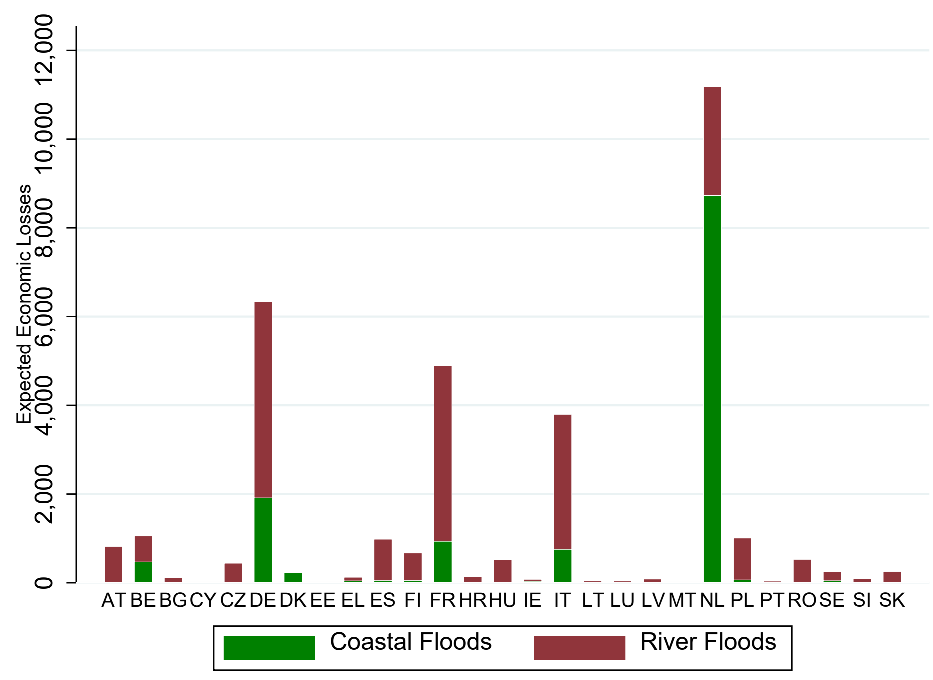
[15] This very high expected value is mainly due to the presence of an extremely large loss in the extreme case of dyke failures, See also the discussion of the Dutch case on the following page.

[16] See Scussolini et. al. (2016) and Kuik et. al (2016) for a detailed discussion about flood protection standards.

Figure 2: Expected economic loss (EEL_i), EUR million



Source: JRC Risk Data Hub, Eurostat, JRC elaboration

3.1.2. Insurance penetration

Our model relies on estimates of insurance penetration as published on the EIOPA dashboard to obtain the share of natural-related losses that are insured (IP_{flood}). Specifically, the dashboard offers four possible buckets per country and per peril, including 0-25%, 25-50%, 50-75%, and 75-100%. The final assessment is based on the size of insured losses according to RiskMap and LitPop data sources[17], expert judgments of supervisory authorities, as well as qualitative estimations. We refer to EIOPA (2022b) for the methodology.

For our purposes, values in each bucket are interpolated based on the average size of insurance coverage according to the other sets of information mentioned above. Figure 3 shows our final estimates for flood insurance penetration (IP_{flood}). Of the countries analysed, Denmark, Spain, France, Hungary, Ireland, Luxembourg, Belgium, Slovenia, Finland, Czechia and Sweden have the highest insurance penetration values, with ratios higher than 75%. Some of these countries have public-private partnerships in place, that provide reinsurance for natural disasters risks, or mandatory insurance schemes that are required by law or by banks (see ECB-EIOPA, 2023). The existence of such schemes in part explain the higher penetration rate in these countries. Greece and the Netherlands have the lowest insurance penetration values. The case of the Netherlands is quite peculiar. Due to most of the country being below sea level, the risk of flooding is substantial. According to DNB (2017), around 60% of the Netherlands is susceptible to flooding and potential losses could be significant, particularly in the event of a dyke breach. The government may step in and compensate for damages, but only if the event is officially classified as a 'natural disaster' and private insurance is not available. Flood losses are not usually covered by insurance companies in the Netherlands due to the high underlying risk. Despite the low probability of such an event, the insurance sector cannot provide coverage without imposing unattractively high risk-based premiums for customers. DNB (2017) discusses the trade-off between establishing a private market for flood risk insurance and implementing a public safety net. The study suggests that insuring flood risk through premiums may not always be more cost-effective than a reimbursement scheme using public money in the case of declared natural disasters.

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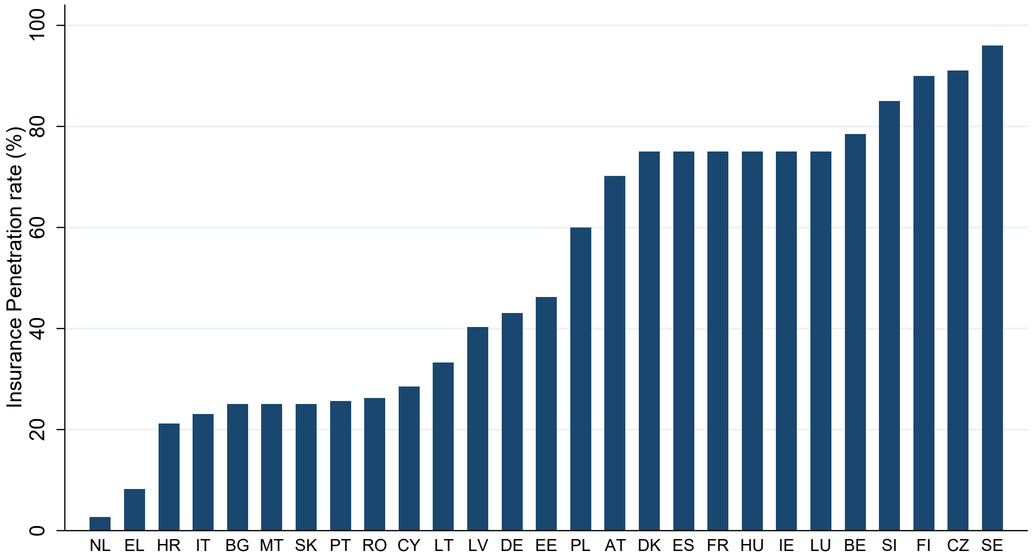
[17] RiskMap and LitPop are two data providers that collect and maintain data on insurance penetration and potential replacement costs in the case of a natural disasters. More information on these two data providers, together with the assumptions made, are available in the technical description annex of the EIOPA Dashboard on the insurance protection gap for natural catastrophes.

Figure 3: Insurance penetration rate for floods (IP_{flood}), EU countries



Source: EIOPA dashboard, JRC elaboration

3.2. Premiums for flood-related events

In order to estimate the potential amount of premiums that need to be underwritten to increase the penetration rate up to a certain level, we propose a two-step methodology. Firstly, we calculate the actual premiums by assuming that the expected economic loss (EEL_i) represents, at MS level, the total amount of potential losses due to flood related events. Secondly, we project the increase in premiums in response to a shock, which is an increase in insurance protection, by leveraging the relationship between technical provisions and gross written premiums.

Initially, we assume that the expected economic losses are directly translated into pure premiums; thus, an additional euro of expected economic loss equates to a one euro increase in pure premiums. Gross written premiums are then derived by multiplying the pure premium by a margin that encompasses the insurer's expenses, commission fees, and the cost of risk. We assume that the margin coefficient remains constant and and independent of the expected economic loss. In reality, however, the margin coefficient may be somewhat influenced by expected economic losses due to variations in risk cost or economies of scale. Our consideration does not extend to the potential additional capital which might further increase premiums. The margin is calculated, using aggregated annual EIOPA data, dividing the gross premium earned by the gross claims incurred for each quarter, excluding reinsurance. Employing earned premiums and incurred claims assures temporal alignment between the payment of premiums and the settlement of claims within the same period. We use the margin as of the end of 2022 at EEA level, which is equal to 47.5%. This margin has shown stability over several years.[18] Based on these assumptions, the current pure premiums (EPP_i), and gross premiums (EGP_i) related to flood events are calculated as follows:

$$EPP_i = EEL_i \times IP_{flood\ (i)_i} \tag{3}$$

$$EGP_i = EEL_i \times IP_{flood\ (i)} \times (1 + margin_i). \tag{4}$$

When quantifying the additional premiums required to increase the insurance penetration rate, this approach presents several limitations. Firstly, it assumes a linear relationship between the increase in insurance penetration and the amount of premiums needed to achieve this increase. As a matter of fact, the marginal cost of risk typically remains unchanged if correlations among risks remain the same. However, increasing coverage of losses concentrated in areas at risk of flood events leads to a larger portfolio with higher correlated

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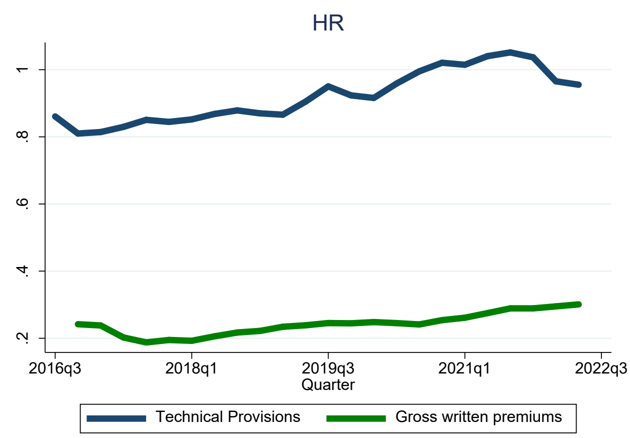
[18] Data for the margins come from the EIOPA website, template "Premiums, claims and expenses" at solo level. The margin ranges from 47% to 52% in the time period 2017-2022.

risks and fewer diversification effects. Consequently, the margin might adjust to reflect this heightened risk, resulting in a non-linear impact on premiums. Secondly, shareholders demand greater returns for increased risks, which policyholders must ultimately finance.. Finally, a riskier pool also generates higher capital requirements, to provide an additional safety layer. Such effects are however very difficult to estimate.

Therefore, to partially address the potential additional costs arising from increasing insurance penetration, we incorporate an additional term to capture the potential nonlinearity between expected losses and premiums. This non-linearity is estimated by looking at the relationship between premiums and technical provisions. We rely on the assumption on the notion that expected insured economic losses represents a consistent part of insurers' technical provisions at the start of a contract,[19] and that there is a close association between the level of written premiums and technical provisions, with both variables expected to move together. Technical provisions represent the risk-weighted costs, while the premium represents the main revenues of the insurance business. As a result, an increase in insurance coverage will lead to adjustments in both gross written premiums and technical provisions.[20] We estimate the cointegration relationship between technical provisions and gross written premiums, and the response in the system in the event of an increase in the provisions, as it would occur with an increase in the level of insurance penetration. A preliminary visual inspection of gross written premium versus technical provision shows that the two variables may co-move and display non-stationarity (see Figure 4 as an example for Croatia). This creates the prerequisites for testing for cointegration.

Figure 4: Technical provisions and gross written premium for Croatia (EUR million)



Note: gross written premiums are transformed into quarterly premiums .and smoothed with a moving average of three periods.

Source: EIOPA insurance statistics, JRC elaboration.

Testing cointegration

The two series are cointegrated if each of them is an integrated process of order 1, or I(1), but a linear combination of the two is stationary, or I(0), and their relationship can be estimated using an Error Correction Model (ECM). To model the joint dynamics of technical provisions and premiums, taking into account their

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[19] According to the Solvency II Directive (Articles 76 and 77), a technical provision represents the amount that an insurance company will have to pay if they transfer their insurance obligation. In other words, the technical provision represents an amount to be held if an institution has to settle all insurance obligations, including the current ones and those that materialise in the future. In simple terms, this represents the pure costs, actual and future, of an insurance contract. It includes a best estimate of all probability-weighted average of future cash flows, plus a risk margin. The best estimate liabilities, which are the larger portion of the technical provisions, under Solvency II represents the expected future outflow resulting from in-force business considering the time value of money. As an example, collecting an amount of premiums equal to the best estimate and investing it in a financial instrument yielding the weighted average risk free rate used to discount future outflows would results in a net present value equal to zero. In other words, and actuarially fair bet that does not consider transaction costs or any other costs. At the start of a contract, the best estimate should thus be composed exclusively of expected future losses. Therefore, if the best estimate represents a large part of technical provisions, in the long run these should be in a fixed relationship with expected economic losses covered by contracts underwritten.

[20] Also this assumption has some limitations. Firstly, technical provisions also encompass past claims and are influenced by various factors, including interest rates, inflation, and changes in calculation methodologies. Secondly, technical provisions represent a stock, whereas premiums constitute a flow. Although there can be considerable divergences between expected economic losses, premiums, and technical provisions in the short term, over the long run, these magnitudes should, on average, move together.

common past history, we estimate a set of Vector Error Correction Models (VECM). The model includes an underlying long-run relationship among the series (cointegration relationship) and a short-run dynamics.

More formally, let a $K \times 1$ vector of variables y_t ($t = 1, \dots, T$) that are integrated of order 1, or $I(1)$.[21] The variables are said to be cointegrated with a cointegration vector β, if there exists a vector β such that βy_t is a vector of $I(0)$ variables. The formal representation of a VECM(p) is the following:

$$\Delta y_t = v + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-1} + \varepsilon_t \tag{5}$$

where $\Pi = \sum_{i=1}^{p-1} A_j - I_k$ and $\Gamma_i = -\sum_{j=i+1}^{j=p} A_j$. To assess the order of cointegration of the VECM, we use the Johansen tests for cointegration (see Johansen, 1995), which applies a two likelihood-ratio test for inference on the rank r, obtaining the so-called trace statistic. The null hypothesis of the trace statistic is that there are no more than r cointegration relations. The method obtains an estimation of $\hat{r}$. In addition, we also include the Schwarz Bayesian information criterion (SBIC) or the Hannan and Quinn information criterion (HQIC), which indicates the number of cointegrated equations that minimise each information criterion. Appendix 4 reports the estimated trace statistics, together with the number of cointegrated equations according to SBIC or HQIC. The results show that for all Member States but Portugal the number of cointegrated equation is equal to 1 for at least two of the three tests considered. Variables are included in logs. In order to keep the long-term dynamic fixed (variables move together) we impose that the cointegrating vector, i.e. the long-run coefficients for the (log-difference) of the gross written premiums is equal to 1 and the (log-difference) of technical provisions is equal to -1. Short-run deviations are allowed, since no constraints are imposed for this dynamics.

Response to shocks

As previously mentioned, the purpose of the cointegration analysis is to account for a structural relationship between technical provisions and premiums, using this relationship to gauge the potential response to a shock — in our scenario, an increase in expected economic losses borne by insurers. This is done by calculating the orthogonalised impulse response function (OIRF) of the system. Ib the case of a VECM, the orthogonalised shock (here, a shock on technical provisions) has a permanent effect on the premiums. Therefore, the OIRF increases after a few steps and then stabilises at the new equilibrium level. Essentialy, we assume that a country-level shock, due to an increase in the protection level, affects the technical provision, which will be translated into a permanent shock on the gross written premiums. We calculate the OIRF for each VECM over eight steps, and we choose the last value of the OIRF as a reference for the shock. Thus a one-unit shock on the technical provision would increase additionally the gross written premium by the value of the 1 plus the OIRF at the last step.

To determine the pure and the gross premiums that need to be underwritten for Member State i in order to increase the minimum level of insurance penetration up to 50% (EGP_i^{50}) or 75% (EGP_i^{75}) for each Member State, we multiply the actual values by the orthogonalised impulse response function for Member State i, $OIRF_i$:

$$\mathrm{EPP_i^{50}} = \max\left(0.5, \mathrm{IP_{flood\ (i)}}\right) \times \mathrm{EEL_i} \times (1 + \mathrm{OIRF_i}) \tag{6}$$

$$\mathrm{EPP_i^{75}} = \max\left(0.75, \mathrm{IP_{flood\ (i)}}\right) \times \mathrm{EEL_i} \times (1 + \mathrm{OIRF_i}) \tag{7}$$

$$\mathrm{EGP_i^{50}} = \max\left(0.5, \mathrm{IP_{flood\ (i)}}\right) \times \mathrm{EEL_i} \times (1 + \mathrm{OIRF_i}) \times (1 + \mathrm{margin_i}) \tag{8}$$

$$\mathrm{EGP_i^{75}} = \max\left(0.75, \mathrm{IP_{flood\ (i)}}\right) \times \mathrm{EEL_i} \times (1 + \mathrm{OIRF_i}) \times (1 + \mathrm{margin_i}) \tag{9}$$

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[21] Integrated or order 1, or I(1) means that the first difference $\Delta x_t = x_t - x_{t-1}$ is stationary, or I(0).

3.3. Results

According to EIOPA (2022a), non-life and all property-related premiums are likely to increase in the absence of mitigation and adaptation measures, given the risk-based calculation of the insurance premiums. Nevertheless, the European Commission's strong commitment to strengthening the EU's resilience to climate change, through initiatives such as the European Green Deal, the strategy on adaptation to climate change and the Climate Resilience Dialogue should mitigate the potential damages of climate risks and extreme weather events.

In our empirical analysis, we therefore assume that the actual premiums reflect the short-term riskiness typical of non-life insurance, as opposed to long-term life insurance. To quantify the increase in insurance premiums required to achieve a minimum level of penetration in all Member States against flood events, we apply the previously presented methodology. For each Member State, Table 1 presents the estimations of the pure premiums (EPP_i) and gross written premium (EGP_i). Table 1 also reports the actual insurance penetration for floods $\mathrm{IP}_{\mathrm{flood(i)}}$ for each MS and the value of the $\mathrm{OIRF}_{\mathrm{i}}$.[22]

The total amounts of pure premiums needed to increase the penetration rate for floods are roughly EUR 20 billion and EUR 26 billion for a minimum penetration of 50% and 75%, respectively. Our estimation of the pure premium at around EUR 12.6 billion (see Table 1) is relatively close to the actual amount of premiums for flood events according to EIOPA (2022a), which is around EUR 10 billion[23]. However, when including insurance margins, the two amounts diverges substantially; the total EGP yields EUR 18.6 billion of premiums using our proxies. The final estimated gross written premiums needed to reach a minimum harmonised penetration of 50% (75%) are around EUR 30 (38) billion. It is worth noting that the additional amounts that comes from the shock via the OIRF, based on the observed relationship in the data, are rather small (the average is about 2-3%). One potential explanation is that we impose fixed long-run coefficients, constraining the variables to co-move in the long-run and diverging only in the short-run. Another explanation is that the modelling framework is quite suitable for small, marginal increases in the insurance coverage (which are the ones that we observe in the data) but it might not be adequate for large increases in the insurance penetration.

According to our model, total premiums written for flood events should therefore be increased by more than 58% to reach a minimum 50% penetration across the EU. The additional premiums amount to EUR 10.8 billion to reach a minimum of 50% penetration, and EUR 19.7 billion to achieve a minimum 75% penetration rate. These estimates are clearly a lower bound, given that our framework does not consider several factors that could substantially increase premiums.

However, the increases vary widely between Member States, depending on their exposure to flood events and, more importantly, their starting insurance penetration rates. The Netherlands alone accounts for more than half of the additional premiums written required for a 75% penetration rate, due to a high risk of flooding, low insurance penetration, and lack of coverage for potential losses from floods (see the earlier discussion regarding the Netherlands). Other Member States requiring a substantial increase in premiums written include Germany and Italy. Under these conditions, insurance companies are likely to be willing to cover risks not currently insured only at higher premiums. Therefore, this estimate is clearly on the conservative side. Other economic factors not related to the willingness to buy additional coverage could explain why insurance coverage is lower in certain countries and regions. From the insurers' perspective, increasing the riskiness of the portfolio demands capital, which is costly. Furthermore, as risk increases, so do the prices of reinsurance, potentially deterring both investors and potential new policyholders.

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[22] The estimated plots of the OIRF for each Member State are reported in Appendix 4.

[23] According to EIOPA(2022a) the overall gross written premium for extreme climate events amount to EUR 19.3 billion in the EIOPA sample. The same source reports that the exposure to flood risk represents around 27% of the total exposures to climate. Using these values and considering that the EIOPA sample covers around 51.76% of the total non-life gross written premium, a rough estimation points to an actual total amount of premiums for flood events of around EUR 10.06 billion. This estimation is only a proxy since generally for the non-life insurances, multiple risks are bundled together, and the coverage for natural catastrophes is part of the fire or property insurance.

Table 1: Estimation of the additional expected premiums.

		Panel A			~~Panel B~~			
Member State	$IP_{flood\,(i)}$	$(1+OIRF_i)$	EPP_i (EUR Mn)	EGP_i (EUR Mn))	EPP_i^{50} (EUR Mn)	EPP_i^{75} (EUR Mn)	EGP_i^{50} (EUR Mn)	EGP_i^{75} (EUR Mn)
AT	70%	1.006	575.08	849.81	*578.64*	618.14	849.81	913.43
BE	78%	1.014	827.15	1 222.29	*839.04*	839.04	1 222.29	1 222.29
BG	25%	1.036	27.43	40.53	56.83	85.24	83.98	125.97
CY	28%	1.003	0.31	0.46	0.55	0.83	0.82	1.22
CZ	91%	1.033	401.12	592.74	414.45	414.45	592.74	592.74
DE	43%	1.003	2 724.51	4 026.07	3 177.37	4 766.06	4 695.27	7 042.91
DK	75%	1.000	171.62	253.60	171.64	171.64	253.60	253.60
EE	46%	1.026	6.13	9.06	6.81	10.21	10.06	15.09
EL	8%	1.002	10.16	15.01	62.19	93.28	91.89	137.84
ES	75%	1.011	736.34	1 088.10	744.15	744.15	1 088.10	1 088.10
FI	90%	1.047	603.93	892.44	632.37	632.37	892.44	892.44
FR	75%	1.008	3 666.91	5 418.68	3 694.64	3 694.64	5 418.68	5 418.68
HR	21%	1.021	29.18	43.12	70.39	105.58	104.01	156.02
HU	75%	1.021	387.19	572.16	395.50	395.50	572.16	572.16
IE	75%	1.007	57.56	85.06	57.94	57.94	85.06	85.06
IT	23%	1.002	874.12	1 291.71	1 899.78	2 849.66	2 807.34	4 211.01
LT	33%	1.027	13.28	19.63	20.52	30.78	30.33	45.49
LU	75%	1.079	29.28	43.27	31.60	31.60	43.27	43.27
LV	40%	1.025	33.54	49.57	42.70	64.05	63.10	94.65
MT	25%	1.023	0.00	0.00	0.00	0.01	0.01	0.01
NL	3%	1.039	295.88	437.23	5 810.21	8 715.32	8 585.88	12 878.82
PL	60%	1.008	604.68	893.55	609.30	761.63	893.55	1 125.47
PT	26%	1.011	11.91	17.60	23.51	35.26	34.74	52.11
RO	26%	1.030	137.40	203.04	269.84	404.77	398.75	598.13
SE	96%	1.001	235.14	347.46	235.46	235.46	347.46	347.46
SI	85%	1.019	75.45	111.50	76.91	76.91	111.50	111.50
SK	25%	1.029	63.81	94.30	131.30	196.95	194.03	291.04

Total Premiums	12 599.12	18 618.00	19 943.45	25 929.45	29 470.87	38 316.52
Total Premiums (excluding NL)	12 303.24	18 180.77	14 133.23	17 214.13	20 884.99	25 437.70
Additional Premiums			7 344.33	13 330.33	10 852.88	19 698.52

Note: premiums in grey-italics refers to MS that already reach the penetration level of 50% or 75%. EPP stands for Expected Pure Premiums (without margins), while EGP stands for Expected Gross Premiums (with margins).
Source: JRC elaboration using data from EIOPA insurance statistics.

Figure 5 illustrates the distribution of the potential increase in gross premium needed to harmonise the insurance penetration up to 50% or 75% at EU level. Considering a harmonised level of 50% for insurance penetration for floods, on average, Member States that do not reach this threshold (see also Figure 3) should increase their penetration by 76.15% (with a standard deviation of 41%)[24]. Instead, considering a harmonised level of 75%, the average increase is 143% (with a standard deviation of 78%).

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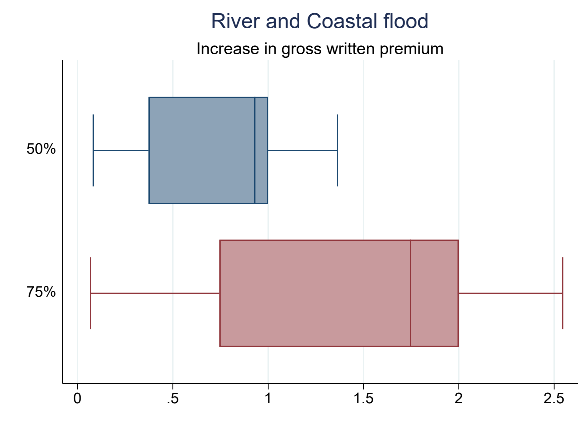
[24] Relative change of the penetration rate.

Figure 5: Percentage increase in gross written premium



Note: the boxplot represents the distribution, across Member States, of the percentage increase of gross written premium in order to harmonise the insurance penetration for river and coastal floods up to 50% (blue boxplot) and 75% (red boxplot). The Netherlands and Greece (outliers) and Member states that already reach the 50% (75%) penetration are excluded from the plot.
Source: EIOPA insurance statistics, JRC elaboration.

4. Economic losses to public finances

The aim of the framework outlined in this section is to estimate the changes in impact on public finances when flood-related damages occur under different insurance penetration rates, while considering that insurance might be partly ineffective due to insurance sector defaults. To address this point, we use a stylised stress test model to assess the maximum loss to which public finances are exposed. If an insurance company defaults due to unexpected events that exceed its repayment capacity, it cannot provide appropriate coverage to its policyholders, and not all claims can necessarily be covered. In such cases, public finances may be subject to financial losses. Our stylised framework quantifies the maximum loss to public finance in a worst-case scenario where flood-related losses, eventually under an increased penetration rate, are accompanied by insurance defaults. [25]

4.1. Methodology and data

We assume that the insurance sector can be regarded as a portfolio of counterparty risks. Within the portfolio, each insurer has a small, but non-zero probability of causing a liability to policyholders upon default. Upon default of an insurance undertaking, the exposure at default (EAD_c) is the maximum amount of the company's liabilities to claimants, beneficiaries and insured. The loss given default (LGD) is the percentage loss that will effectively be incurred on the exposure once the defaulted company's recovery rate is considered. With the one-year probability of default of the company given by PD_c, the expected liability (EL_c) for a single company '*c*' over the period of 1 year, is given by:

$$EL_C = LGD \times EAD_C \times PD_C. \tag{10}$$

Since we are not interested in a single insurance undertaking, but in all insurance companies at individual country level (or even at the aggregate EU-27 level), we can make some simplifying assumptions to estimate the loss distribution of the insurance sector in each country, without the need to estimate the loss distributions of individual insurance undertakings (see European Commission, 2010 and European Commission, 2021c for a fuller discussion). As different insurers may have different loss rates, information on the distribution of losses from insurance defaults is necessary to assess the effective risk the public is exposed to. The loss-rate distribution can be seen as the loss rate on a portfolio of exposures to several insurance undertakings. Specifically, we use the Vasicek model (Vasicek 2002) to define the event of default as occurring when the

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[25] In this analysis we are not considering explicitly the role of reinsures, though the use of reinsurance will affect reserves and provisions. Also, when considering the potential impact of insurance default we are considering the whole portfolio, and not just flood risks, and we do not take into account the mitigating impact of Insurance Guarantee Schemes. The impact of Solvency II regulation in minimizing the default rate of insurers is implicitly taken into account in the choice of maximum probability of default.

insurer's asset value falls below a predetermined threshold. The value of L_i for country i represents the maximum loss that should not be expected to exceed in 1 year with a probability level α is given by:[26]

$$L_i = EAD_i \times LGD \times N\left[\frac{\sqrt{\rho+\delta(1-\rho)}\, N^{-1}(1-\alpha)+N^{-1}(PD)}{\sqrt{1-\rho-\delta(1-\rho)}}\right]. \tag{11}$$

Some notes on the parameters used in our analysis:

- The *LGD* is set equal to 15% as in European Commission (2021c).
- *PD* is fixed at 0.5% for simplicity, this value being the maximum probability of default, which should be attained in the Solvency II framework and therefore marks an upper bound for the probability distribution of defaults.
- ρ is the correlation among defaults and has been set at 20%, consistent with European Commission (2021c).
- δ is the concentration exposure term, tackling the fact that a portfolio of insurers consists of a discrete number of relatively large exposures. This correction term is calculated on the basis of the companies' market share, as a proxy for the relative size of individual exposures in the portfolio[27], by summing up the squares of the relative sizes of the markets shares. We estimate δ separately for each country based on information from EIOPA on the market share of the top 1, top 3, top 5, top 10, and top 15 insurance undertakings. We refer to European Commission (2021c) for more details and we report the estimated values of δ per country for the total insurance sector in Figure 10 of Appendix 3.
- $\mathrm{EAD_i}$ is the total exposure of the portfolio. In our case it is estimated as the sum of $\mathrm{TP_i}$, our best estimate of liabilities and risk margin, and $\mathrm{SRC_i}$ the total amount of funds that an insurer is required to hold to ensure that the company will be able to meet its obligations with a probability of at least 99.5%(Table 2).[28] We assume that $\mathrm{EAD_i}$ increases together with the increase in insurance penetration. We calculate the additional exposures at default to be equivalent to the extra losses that would be covered by the insurance sector.

Table 2: Exposure at default, EUR million (as of 2021)

Member State	Exposure at default
AT	82 219
BE	268 167
BG	3 680
HR	4 226
CY	2 524
CZ	12 519
DK	257 384
EE	1 668
FI	69 404
FR	1 300 185
DE	767 461
EL	15 599
HU	5 867
IE	124 731
IT	599 635
LV	1 136
LT	1 114
LU	56 426
MT	4 911

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[26] It is one of the most widely applied tools for quantitative financial risk management and it is mostly used to assess default portfolio risk across a variety of business sectors, including the insurance sector. The framework of Vasicek (2002) hinges on the asymptotic behaviour of an extended Merton model (Merton, 1974) when the number of exposures in the portfolio of insurers goes to infinity. This model was also initially proposed for counterparty default risk module in QIS3 and QIS4.

[27] The calculation methodology is the same as that of the calculation of the Herfindahl–Hirschman Concentration Index (HHI), used widely in competition literature.

[28] Liabilities at the time of default for individual insurers can be much larger and could deviate substantially from the sum of TP and SCR. In addition, there might be additional capital buffers on top of the current minimum capital requirements. Thus, the estimation of the EAD provides a conservative lower bound for the exposures and the subsequent calculation of losses.

Member State	Exposure at default
NL	83 161
PL	16 383
PT	19 988
RO	2 724
SK	4 041
SI	6 261
ES	208 083
SE	211 736

Source: EIOPA insurance statistics and JRC elaboration

We apply this modelling framework under two scenarios. In the baseline scenario, we consider the expected economic loss (EEL_i) estimated using Risk Data Hub values and the one-year expected liability from insurer's defaults at country level EL_i. Specifically, we compare the situation with the actual insurance penetration rate to a situation with a harmonised 75% insurance penetration rate for flood events across all Member States. The baseline expected losses (BL_i) are therefore calculated as follows:

$$BL_i = EL_i + \left(1 - \mathrm{IP}_{\mathrm{flood,i}}\right) \times EEL_i \tag{12}$$

where $\mathrm{IP}_{\mathrm{flood,i}}$ represent the actual penetration rate, which will be increased up to 75% for Member States that do not reach this threshold. This amount represent the potential expected losses to public finances in 1 year for flood-related events.

In a second, more severe, worst-case scenario, we look at what would happen in the case of a compound event. We do so by considering uninsured flood-related losses together with losses stemming from defaults in the insurance sector in a tail scenario. Under this scenario, we consider a set of very rare events that occur once every 200 years (i.e. with a probability of 0.5%) and therefore, we evaluate the losses L_i with a confidence level $\alpha = 0.5$. Similarly, we consider only losses from flood events with a return period of 200 years ($EEL_{i,200}$). Specifically, we begin by calculating the share of the population affected by floods events with a return period of 200 years ($EA_{population,200}$) as a proportion of the total population. We than apply the 2020 GDP at current market prices and the vulnerability index for each country to the formula, as follows:

$$EEL_{i,200} = GDP_i \times \frac{EA_{population,200}}{Total\ population_i} \times V_i. \tag{13}$$

Finally, worst-case scenario losses on public finances WCL_i are calculated as the sum of uninsured flood losses and leftover losses from insurance sector defaults:

$$WCL_i = L_i + \left(1 - \mathrm{IP}_{\mathrm{flood,i}}\right) \times EEL_{i(200y)} \tag{14}$$

where L_i represents the maximum loss that should not be expected to be exceeded in 1 year with a probability level of 0.5%, and $EEL_{i(200y)}$represents the expected economic losses from a flood event with a return period of 200 years. In line with the baseline, we compare the situation with the actual insurance penetration rate to a situation where there is a harmonised 75% insurance penetration rate for flood events across all Member States[29].

4.2. Results

The results of the baseline scenario are of a similar order of magnitude as the previous analysis. Notably, when considering the baseline expected losses (BL_i) with the current protection rate, expected losses are estimated to be around EUR 27 billion. This amount represents the average losses that could occur in 1 year that would need to be covered by the private or the public sector, owing to the potential defaults of insurance companies and uninsured flood-related losses. When considering a harmonised minimum level of protection of 75% across Member States, this amount drops substantially. Since losses due to the default of insurance companies represent only a small fraction of the total, the final overall reduction is directly due to an increase in insurance protection. At EU level, the reduction in expected losses, increasing the penetration rate to 75%, comes to around EUR 14 billion, an amount smaller with respect to the increase in gross written premium of EUR 19.6 billion presented before. When excluding the Netherlands, the baseline figure stands at EUR 15.7 billion. This drops to

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[29] Note that we do not take into consideration the correlation between the different events, assuming instead that a very large flood will correspond to an extreme fragility situation in the insurance sector. The actual probability of the compound event could therefore be lower than 0.5%

EUR 10.6 billion when penetration increases to 75%. Figure 6 Panel A (left boxplot) shows that the reduction in public losses when increasing the penetration level to 75% is substantial, amounting to 40-60% for most Member States.

However, some caveats need to be considered when reading the results. Firstly, flood impact estimates are affected by a higher degree of uncertainty, since they cannot be comprehensive and they cannot cover all potential consequences of global warming. Secondly, in this scenario we do not consider adaptation and mitigation measures or the effect of actual and future flood defences. Furthermore, it is challenging to model adaptation, as this course of action also requires strong commitment by public and private stakeholders, which is difficult to include in the analysis. Finally, we are not considering the role of re-insurance. Nevertheless, the estimations in our analysis provide an additional assessment that could help inform the policy debate on reducing the insurance protection gap or increasing adaptation measures.

Our model also reflects a worst-case scenario where a very extreme weather-related event take place (a catastrophic event that occurs once every 200 years) everywhere in the EU, and insurers' defaults make them unable to fulfil their contractual commitments. In this very extreme (and unlikely) event, aggregated public finance losses can be relevant and impactful. The results show that total losses for the EU would amount to EUR 1 576 billion in 1 year. The confidence level for this projection is 99.5%. When excluding the Netherlands, the projected losses amount to EUR 1 194 billion. Increasing the insurance penetration to 75% would reduce losses by around 50-70% for most Member States (Figure 6 Panel A, right boxplot). This scenario results in a 10% decrease in GDP on average, with considerable differences between countries depending on exposure to river and coastal floods and the actual level of insurance protection (Figure 6 Panel B)[30].

Based on our model, harmonising insurance coverage to 75% across all EU countries could potentially cut public finance losses in half. The confidence level for this is 99.5%. Moreover, numbers suggest that harmonising the insurance penetration rate might reduce losses by up to 80% in countries with a low penetration rate. Figure 7 shows that the reduction will be 40-60% for six Member States and 60-80% for another six Member States.

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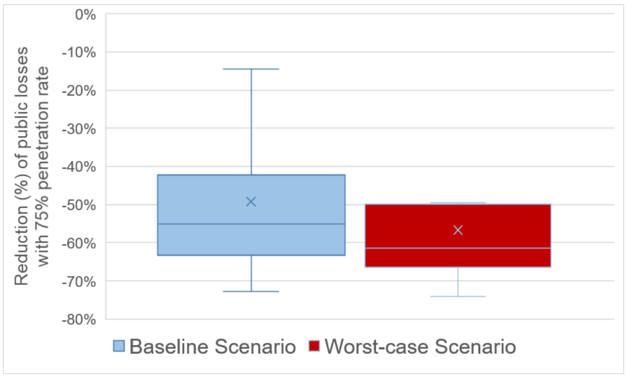
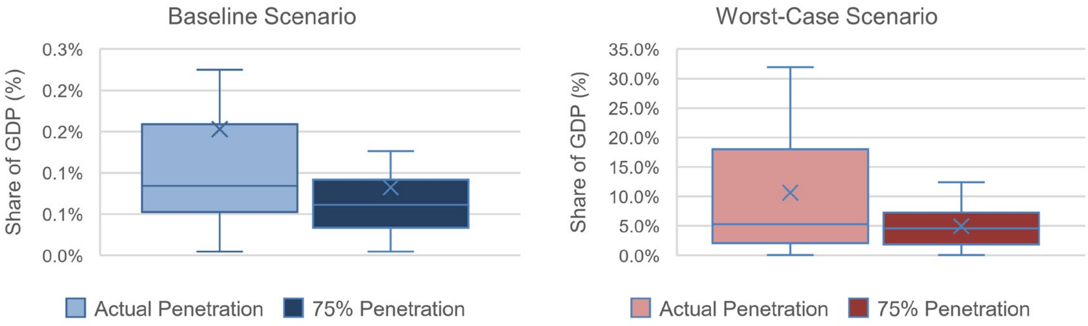
[30] This extreme scenario must be considered as very unlikely, as extreme floods usually affect only a limited area. For example, the flood event in July 2021 had approximately a 1-in-200 year probability of occurrence, but affected only part of Belgium, Germany, and the Netherlands. Results are available under different confidence levels, upon request.

Figure 6: Reduction in public finance losses in the baseline and worst-case scenario, where the insurance penetration rate is harmonised at 75% (Panel A – percentage reduction, note 'inverted' scale). Distribution of public finance losses in EU in the baseline and worst-case scenario, under the actual insurance penetration rate and under a harmonised level of insurance penetration of 75% (% GDP, Panel B, α = 0.5%. Outliers are excluded from the plot).

Panel A

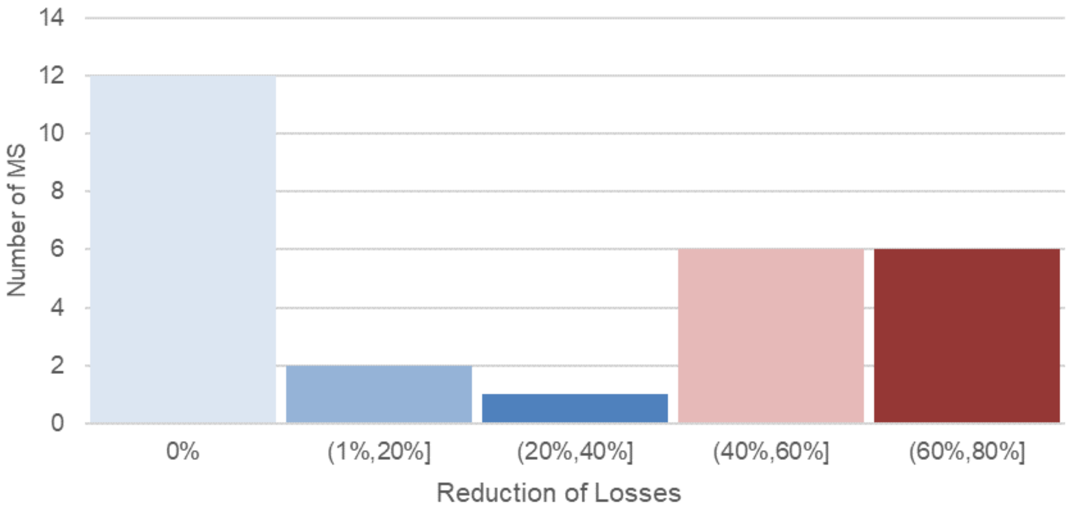


Panel B



Source: EIOPA insurance statistics, EIOPA dashboard, Risk Data Hub, and JRC elaboration

Figure 7: Frequency of the reduction of public finance losses under an insurance penetration level of 75% (Worst-case scenario, α = 0.5%).



Source: EIOPA insurance statistics, EIOPA dashboard, Risk Data Hub, and JRC elaboration

5. Conclusion

Due to climate change, weather-related risks are projected to increase in frequency, severity and duration, and to affect financial stability. Natural disasters can be devastating, generating significant losses for financial institutions, the public sector and citizens alike. Against this background, the paper offers a stylised modelling approach to quantify the increase in insurance premiums necessary to harmonise the level of protection against floods across all European countries. It explores the scale of public finance losses in a worst-case scenario where floods and increases in the insurance premiums are accompanied by defaults in the insurance sector.

Findings suggest that the expected losses stemming from floods could exceed EUR 33 billion (EUR 22.5 billion when excluding the Netherlands) in 1 year. Only a fraction of potential losses are covered by insurance, with significant variation between Member States. Our estimations show that an increase of EUR 10.8 billion (+58%) would be needed to harmonise the penetration rate in Europe to a minimum of 50%.

Finally, the paper shows that floods, together with possible insurances defaults, have the potential to generate EUR 27 billion in annual public finance losses, and increasing insurance penetration for floods to up to 75% could lower the impact by up to 50%. In a worst-case scenario (a rare event that could occur once every 200 years), losses can be substantial. We show that for some Member States losses can be reduced by 80% when insurance penetration is harmonised at 75%. Given the high uncertainty of flood impact estimates, the results of our models are highly sensitive to the initial loss data and the underlying assumptions, including no mitigation effects, and do not consider the effect of actual and future flood defences. In addition, we are not explicitly modelling the effect of re-insurance.

Although increasing insurance coverage would seemingly be beneficial for both private and public actors, even in a worst-case scenario, reducing overall costs for taxpayers, using insurance as a risk transfer mechanism could raise insurability and affordability concerns in a climate-damaged world. Moreover, increasing the insurance coverage of natural hazards could result in unrealistically high premiums that would be unaffordable for policyholders.

The paper therefore supports the consensus that a portion of extreme risks is not insurable as it may not be financially bearable for policyholders. Risk-mitigation activities (i.e. preventive measures), public investment in risk reduction and prevention measures as well as targeted investments in loss prevention, are necessary. Once future disaster-related expenditures are reduced, the insurance market will be able to provide additional coverage against these disasters. Future research could therefore explore the issues of increased risk and unit risk prices as the penetration rate increases. The scientific evidence resulting from this research would presumably demonstrate the need to develop and roll out adaptation measures to increase climate resilience, as envisaged in the climate adaptation strategy.

References

Antofie, T., Luoni, S., Eklund, L. G., & Montserrat, M. F. (2020). *Update of Risk Data Hub software and data architecture*. Ispra, Italy: JRC technical report.

Balbás, A., Garrido, J., & Mayoral, S. (2009*). Properties of distortion risk measures*. *Methodology and Computing in Applied Probability,* 11(3), 385-399.

Blöschl, G., Kiss, A., Viglione, A., Barriendos, M., Böhm, O., Brázdil, R., Coeur, D., Demarée, G., Llasat, M. C., Macdonald, N., Retsö, D., Roald, L., Schmocker-Fackel, P., Amorim, I., Bˇelínová, M., Benito, G., Bertolin, C., Camuffo, D., Cornel, D., Doktor, R., Elleder, L., Enzi, S., Garcia, J. C., Glaser, R., Hall, J., Haslinger, K., Hofstätter, M., Komma, J., Limanówka, D., Lun, D., Panin, A., Parajka, J., Petri ´c, H., Rodrigo, F. S., Rohr, C., Schönbein, J., Schulte, L., Silva, L. P., Toonen, W. H. J., Valent, P., Waser, J., and Wetter, O. (2020). *Current European flood-rich period exceptional compared with past 500 years*. Nature, 583(7817):560–566.

Canova, F. and Pappa E., (2021). *Costly Disasters & the role of fiscal policy: evidence from US states*. European Economy Fellowship Initiative discussion paper.

DNB - De Nederlandsche Bank (2017) *Waterproof? An exploration of climate-related risks for the Dutch financial sector.*

Engle, R. F., and C. W. J. Granger. 1987. *Co-integration and error correction: Representation, estimation, and testing*. Econometrica 55: 251–276.

EIOPA (2022a). *European insurers' exposure to physical climate changes risk. Potential implications for non-life business*. EIOPA-22/278, 20 May 2022.

EIOPA (2022b). *The dashboard on insurance protection gap for natural catastrophes in a nutshell*. EIOPA-22/507, 05 December 2022.

European Central Bank (2022). *Climate risk stress test – Methodology, scenarios and quality assurance.*

ECB – EIOPA (2023). *Policy options to reduce the climate insurance protection gap* Discussion Paper

European Commission (2010). *Insurance Guarantee Schemes: derivation of loss distributions and funding needs.* Ispra (Italy): Methodological report for internal use by the European Commission.

European Commission (2021a), *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change.*

European Commission (2021b). *Closing the climate protection gap - Scoping policy and data gaps*. Commission staff working document.

European Commission (2021c). *Insurance Guarantee Schemes: quantitative impact of different policy options*. Joint Research Centre. JRC technical report

European Environmental Agency (2022). *Economic losses and fatalities from weather- and climate-related events in Europe*. Briefing no. 21/2021.

Feyen, L., Ciscar Martinez, J. C., Gosling, S., Ibarreta Ruiz, D., Soria Ramirez, A., Dosio, A., Naumann, G., Russo, S., Formetta, G., Forzieri, G., Girardello, M., Spinoni, J., Mentaschi, L., Bisselink, B., Bernhard, J., Gelati, E., Adamovic, M., Guenther, S., De Roo, A., Cammalleri, C., Dottori, F., Bianchi, A., Alfieri, L., Vousdoukas, M., Mongelli, I., Hinkel, J., Ward, P. J., Gomes Da Costa, H., De Rigo, D., Liberta', G., Durrant, T., San-Miguel-Ayanz, J., Barredo Cano, J. I., Mauri, A., Caudullo, G., Ceccherini, G., Beck, P., Cescatti, A., Hristov, J., Toreti, A., Perez Dominguez, I., Dentener, F., Fellmann, T., Elleby, C., Ceglar, A., Fumagalli, D., Niemeyer, S., Cerrani, I., Panarello, L., Bratu, M., Després, J., Szewczyk, W., Matei, N., Mulholland, E., and Olariaga- Guardiola, M. (2020). *Climate change impacts and adaptation in Europe:* JRC PESETA IV final report. Technical report, Publications Office, Luxembourg.

Gamper, C., Signer B., Alton L. and Petrie M. (2017), *Managing disaster-related contingent liabilities in public finance frameworks,* OECD Working Papers on Public Governance, No. 27, OECD Publishing, Paris, https://doi.org/10.1787/a6e0265a-en.

Gagliardi, N., Arévalo, P., and Pamies S. (2022). *The Fiscal Impact of Extreme Weather and Climate Events: Evidence for EU Countries*. European economy discussion papers, 168, July 2022.

Hallegatte, S., Hourcade, J. C., Dumas P. (2007). *Why economic dynamics matter in assessing climate change damages: illustration on extreme events.* Ecological Economics, Elsevier, 62 (2), pp.330-340.

Jindrová, P., & Pacáková, V. (2019). *Natural catastrophe models for insurance risk management*. Wseas Transactions on Business and Economics, 16, 9-17.

Johansen, S. (1995). *Likelihood-based inference in cointegrated vector autoregressive models*. OUP Oxford.

Kuik, O., Scussolini, P., Mechler, R., Mochizuki, J., Hunt, A., & Wellman, J. (2016). *Assessing the economic case for adaptation to extreme events at different scales*. ECONADAPT Deliverable, 5.

Mandel A., Tiggeloven T., Lincke, D.,· Koks E., Ward P., Hinkel J. (2022). *Risks on global financial stability induced by climate change: the case of flood risks*. Climatic Change. 166: 4.

Merton, R. (1974). *On the Pricing of Corporate Debt: the Risk Structure of Interest Rates*. Journal of Finance, 29(2), 449-470.

Mohr, S., Ehret, U., Kunz, M., Ludwig, P., Caldas-Alvarez, A., Daniell, J. E., Ehmele, F., Feldmann, H., Franca, M. J., Gattke, C., Hundhausen, M., Knippertz, P., Küpfer, K., Mühr, B., Pinto, J. G., Quinting, J., Schäfer, A. M., Scheibel, M., Seidel, F., and Wisotzky, C. 2022: *A multi-disciplinary analysis of the exceptional flood event of July 2021 in central Europe. Part 1: Event description and analysis*. Nat. Hazards Earth Syst. Sci. Discuss.

Morana, C., and Sbrana, G. (2019). *Climate change implications for the catastrophe bonds market: An empirical analysis*. Economic modelling, 81, 274-294.

NGFS (2019). *A call for action Climate change as a source of financial risk.*

Prettenthaler, F., Albrecher, H., Asadi P., and Köberl, J. 2017. *On flood risk pooling in Europe, Natural Hazards,* Journal of the International Society for the Prevention and Mitigation of Natural Hazards, ISSN 0921-030X Vol 88 (1).

Scussolini, P., Aerts, J. C., Jongman, B., Bouwer, L. M., Winsemius, H. C., de Moel, H., & Ward, P. J. (2016). *FLOPROS: an evolving global database of flood protection standards*. Natural Hazards and Earth System Sciences, 16(5), 1049-1061.

Tesselaar M., Botzen W.J.W., Haer T., Hudson P., Tiggeloven T., Aerts J. C. J. H. (2020) *Regional Inequalities in Flood Insurance Affordability and Uptake under Climate Change*. Sustainability 2020, 12, 8734; doi:10.3390/su12208734.

Tesselaar, M.; Botzen, W.J.W.; Aerts, J.C.J.H (2020). *Impacts of Climate Change and Remote Natural Catastrophes on EU Flood Insurance Markets: An Analysis of Soft and Hard Reinsurance Markets for Flood Coverage*. Atmosphere 2020, 11, 146. https://doi.org/10.3390/atmos11020146

Vasicek, O. (2002). *The Distribution of Loan Portfolio Value*. Risk (December).

Appendices

Appendix 1. Insurance statistics

EIOPA insurance statistics provide aggregated information on the insurance sector in each European country. As natural disasters are often bundled together with fire or property insurance lines of business, it can be assumed that the technical provisions and gross premiums for the non-life business line as of 2021-Q4 (see Table 3) already include the insured economic losses stemming from floods.

Table 3: Technical provisions and gross premiums written, EUR million (as of 2021-Q4)

Member State	**Total technical provisions**	**Technical provisions non-life**	**Gross premiums written non-life**
AT	77 263.13	9 678.80	11 833.46
BE	285 209.56	34 357.55	24 006.02
BG	2 720.34	1 824.04	2 379.72
CY	2 052.00	657.00	579.19
CZ	11 048.47	3 935.17	5 486.99
DE	618 292.50	234 143.25	152 575.25
DK	261 115.65	7 943.88	10 369.07
EE	1 391.94	368.65	556.20
EL	15 143.80	3 126.04	2 127.70
ES	210 435.73	27 934.09	39 969.68
FI	70 851.83	3 277.83	3 957.15
FR	1227 615.37	176 294.05	127 516.25
HR	3 863.80	1 077.90	1 176.39
HU	5 564.88	814.73	1 998.13
IE	92 509.83	71 219.98	42 354.51
IT	610 109.47	53 913.35	36 848.89
LT	936.03	386.67	604.90
LU	41 134.37	39 897.93	20 442.72
LV	1 095.96	302.25	406.49
MT	3 741.13	3 265.84	4 345.59
NL	45 282.76	27 802.90	63 695.57
PL	11 307.88	9 434.79	10 438.91
PT	17 392.53	3 277.65	5 721.86
RO	1 808.57	1 450.69	2 028.85
SE	212 677.09	20 703.17	13 152.58
SI	5 412.24	1 439.42	2 358.66
SK	3 961.63	763.61	1 053.05

Source: EIOPA insurance statistics

Appendix 2. Insurance losses

We consider a portfolio of n insurers with an asset value modelled by the random variables $A_i,\ i = 1, \dots, n$. According to Merton (1974), the dynamics of the asset value $A_i(t)$ of an insurance company i can be described by a diffusion-type stochastic process, using the stochastic differential equation:

$$dA_i(t) = \mu_i A_i(t)dt + \sigma_i A_i(t)dW_i(t),$$

where μ is the expected rate of return per unit of time (the drift parameter), σ^2 is the instantaneous variance of return per unit of time (σ is the volatility parameter) and $W = \{W(t), t \geq 0\}$ is standard Brownian motion. Applying Itô's lemma, Equation above is solved by:

$$\ln A_i(T) = \ln A_i(0) + \left(\mu_i - \frac{\sigma^2}{2}\right)\mathrm{T} + \sigma_i W_i(T),$$

$$= \ln A_i(0) + \left(\mu_i - \frac{\sigma^2}{2}\right)\mathrm{T} + \sigma_i \sqrt{T} X_i(T),$$

with $W_i(T) = \sqrt{T} X_i(T)$.

Suppose that the default of insurer i occurs at time T when the asset value $A_i(T)$ falls below a threshold K_i. Since the probability of default is equal to PD and X_i is standard normally distributed with cumulative distribution function N, we know that:

$$PD = P[A_i(T) < K_i]$$

$$= P\left[X_i(T) < \frac{\ln K_i - \ln A(0) - \left(\mu_i - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}\right]$$

$$= N\left[\frac{\ln K_i - \ln A(0) - \left(\mu_i - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}\right].$$

Vasicek (2002) introduces a dependence structure on a common factor Y (such as an economic index) in the driving process X_i of the asset value A_i. These driving processes have equal pairwise correlations ρ and are represented as:

$$X_i = \sqrt{\rho}\, Y + \sqrt{1-\rho}\, Z_i,$$

where Y and $Z_1, \dots, Z_n$ are mutually independent standard normal random variables. The term $\sqrt{\rho}\, Y$ is the firm's exposure to the common factor and the term $\sqrt{1-\rho}\, Z_i$ is the company specific risk, with Z_i an idiosyncratic risk factor.

We define L_i as the random variable equal to 1 if insurer i defaults at time T and 0 otherwise. The loss rate L on the portfolio of insurers is then obtained via:

$$L = \sum_{i=1}^{n} \frac{L_i}{n}.$$

The probability of a portfolio loss is evaluated by assuming different scenarios for the economy, reflected by the value of the common factor Y. For a fixed value of Y, the default random variable L_i is linked to the driving process X_i of the asset value A_i via:

$$p(Y) = P[L_i = 1|Y] = P[X_i(T) < N^{-1}(PD)|Y]$$

$$= P\left[Z_i < \frac{N^{-1}(PD) - \sqrt{\rho}Y}{\sqrt{1-\rho}}\right]$$

$$= N\left[\frac{N^{-1}(PD) - \sqrt{\rho}Y}{\sqrt{1-\rho}}\right],$$

where $p(Y)$ is called the stressed default probability on the portfolio, under scenario Y. Conditional on Y, the variables L_i are independent and identically distributed, with a finite variance. The portfolio loss L then converges to its expectation $p(Y)$ for large n, using the law of large numbers, such that $P[L \leq x] \approx P[p(Y) \leq x]$.

Under the assumptions of the Vasicek portfolio model, the following formula for the asymptotic $(n \to \infty)$ cumulative distribution function, cdf, of the loss rate L can be derived:

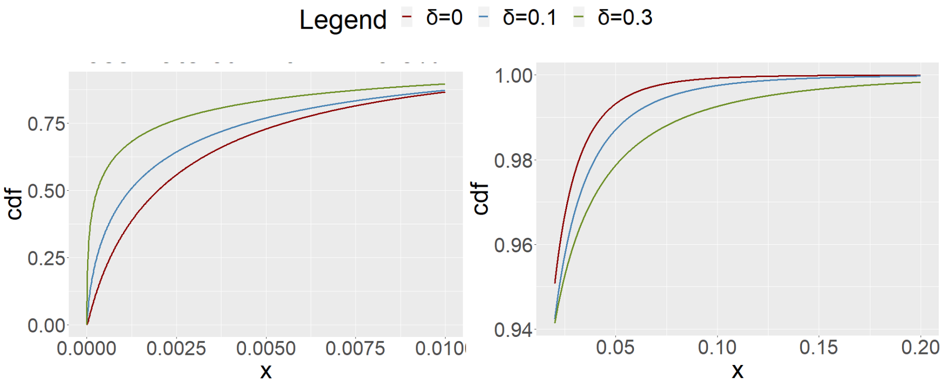
$$F_L(x) = P[L \leq x] = N\left[\frac{\sqrt{1-\rho} \cdot N^{-1}(x) - N^{-1}(PD)}{\sqrt{\rho}}\right].$$

The standard form of the Vasicek model relies on an asymptotic approximation to obtain its analytical solution. The main consequence of ignoring granularity in the portfolio is that part of the residual idiosyncratic risk which is not diversified in a small portfolio is ignored. Moreover, in the case of portfolios dominated by a few large exposures, the variance of the losses could be underestimated. In Vasicek (2002) the author tackles this problem by introducing a correction term based on the squared sum of the shares of exposures in the portfolio. ρ is then replaced by $\rho + \delta(1-\rho)$, where δ is the quadratic sum of weights and the weights are defined as the ratio of the size of each insurance company to the total market size. This results in the following loss rate distribution:

$$F_L(x) = P[L \leq x] = N\left[\frac{\sqrt{1-\rho-\delta(1-\rho)} \cdot N^{-1}(x) - N^{-1}(PD)}{\sqrt{\rho+\delta(1-\rho)}}\right],$$

with N the cdf of a standard normal distribution, ρ the correlation coefficient, δ the granularity parameter and PD the probability of default. The cumulative distribution function of L is displayed in Figure 8. Parameter ρ is fixed at 0.2, PD at 0.5% and $\delta \in \{0, 0.1, 0.3\}$. Note that the loss rate cdf is shown for two different x-ranges, to fully capture the behaviour of the distributions and their relative position for different parameter values.

Figure 8: Cumulative distribution function of the loss rate ($\boldsymbol{L}$), with fixed $\boldsymbol{\rho} = \mathbf{0.2}$ and $\boldsymbol{PD} = \mathbf{0.5\%}$



Instead of looking at the distribution of losses, one could think about the maximum loss that is not going to be exceeded with a certain probability. This could then serve as an estimate of the economic losses that cannot be covered by the insurance sector because they exceed the financial resources available for such events and become the liabilities stemming from defaults in the insurance sector. If the EAD is given for all insurers as a whole, and if the LGD is fixed, then $LGD \times EAD \times L$, with L the loss rate on the portfolio of insurers, is a good estimate for the loss within the insurance sector. Since L is not known at the beginning of the year, we make use of the distribution of L as derived above, to get an idea of the maximum loss that can occur within the sector.

We therefore exploit the value at risk as a widely used risk measure. For continuous distributions, we can simply write $VaR_\alpha(X)$ as the value satisfying:

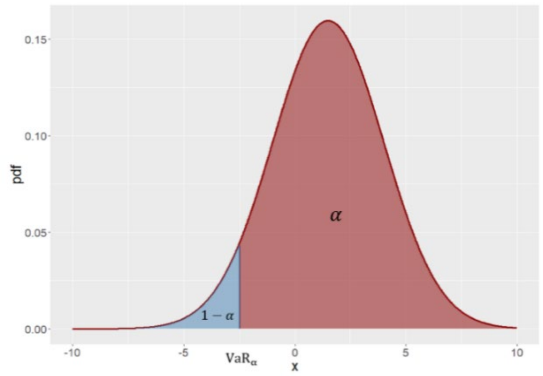
$$P[X > VaR_\alpha(X)] = \alpha,$$

Or equivalently:

$$P[X \leq VaR_\alpha(X)] = 1 - \alpha.$$

A graphical representation can be found in Figure 9.

Figure 9: Graphical definition of the value at risk



By using equation above, we can easily calculate the value at risk at level α, $VaR_\alpha(L)$, of the loss rate L. Now, $L \in [0,1]$ and the closer the loss rate to 1, the worse; so, the situation of highest risk is located in the right tail of the distribution of L. We are therefore interested in the loss rate that is not going to be exceeded with a high probability $1-\alpha$; i.e. we will focus on values for α close to 0:

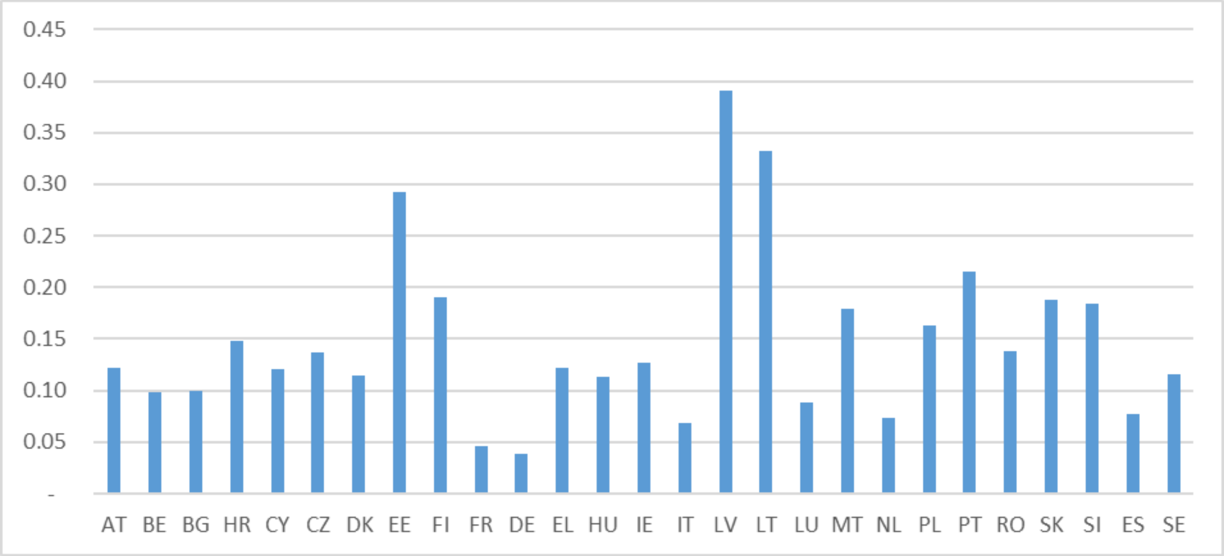
$$VaR_\alpha(L) = N\left[\frac{\sqrt{\rho+\delta(1-\rho)}\cdot N^{-1}(1-\alpha)+N^{-1}(PD)}{\sqrt{1-\rho-\delta(1-\rho)}}\right].$$

The insurance loss for any given probability level $1-\alpha$ is calculated as follows:

$$Insurance\ loss = EAD \times LGD \times N\left[\frac{\sqrt{\rho+\delta(1-\rho)}\,N^{-1}(1-\alpha)+N^{-1}(PD)}{\sqrt{1-\rho-\delta(1-\rho)}}\right].$$

Appendix 3. Concentration exposure analysis

Figure 10: Concentration exposure (δ) per country



Appendix 4. Estimating the cointegrating rank of a VECM

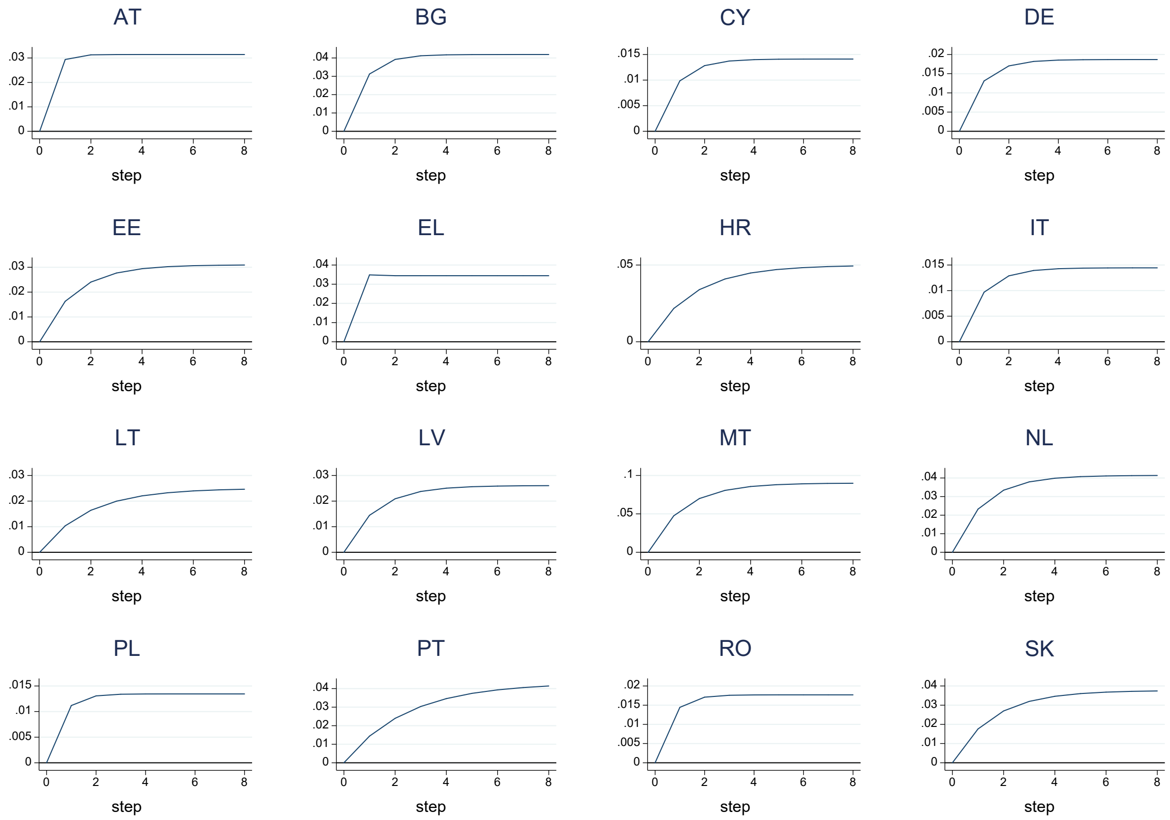
The following table reports the trace statistic for the Johansen test for cointegration for rank equal to zero (no cointegration) and 1 (1 cointegrated relation). Critical values are reported below the table. We also report the number of cointegrated equations that minimise the Schwarz Bayesian information criterion (SBIC) or the Hannan and Quinn information criterion (HQIC).

Table 4: Cointegration tests

Member State	Trace statistic for rank = 0	Trace statistic for rank = 1	N. cointegrated equations Trace	N. cointegrated equations SBIC	N. cointegrated equations HQIC
AT	45.7813	2.45906	1	1	1
BG	13.24317	0.077474	0	1	1
CY	35.791	0.017004	1	1	1
DE	61.58071	0.014585	1	1	1
EE	31.10602	4.38167	1	1	1
EL	67.15307	1.011892	1	1	1
HR	18.40463	0.462921	0	1	1
IT	53.64698	7.421367	0	1	1
LT	17.48768	0.010107	0	1	1
LV	40.80424	5.461651	1	1	1
MT	18.73374	3.481797	0	1	1
NL	40.8729	0.974584	1	1	1
PL	29.00478	6.122742	1	1	1
PT	5.289727	0.860002	0	0	0
RO	32.80166	0.011164	1	1	1
SK	18.0907	3.835788	0	1	1

Note: critical values for the trace statistic at rank=0: 5% = 15.41; 1% = 20.04 . Critical values for the trace statistic at rank=1: 5% = 3.76; 1% = 6.65 .

Figure 11: Orthogonalised Impulse Response Functions (OIRF)



OIRF after VECM. Impulse variable: Technical Provisions. Response variable: Gross Premium Written.

Note: estimates of the orthogonalised impulse response function after the VECM.

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