



Index Insights | Sustainable Investment – Climate Risks

Anticipating the climate change risks for sovereign bonds

Part 2: Insights on the financial impacts

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Introduction

The huge economic transformation to achieve the Paris Agreement objectives requires a sizeable reallocation of assets. This assigns the financial sector a key role in tackling climate change. Forward-looking analysis in a scenario-based framework is crucial to assess the financial risks of climate change.

This paper, which is the second of a two-part study, explores the effects of climate change risks on sovereign bond returns and proposes an innovative and practical methodology that measures the anticipated costs from climate change. The results from the first study ([Anticipating the climate change risks for sovereign bonds – Part 1: Insights on the macroeconomic impacts](#)) have been used in this research. The findings are as follows:

- The impact from indebtedness varies considerably, which may be highly significant for some economies, particularly in relation to transition risks.
- Because the default probabilities are heterogenous, the large residual fiscal capacity in some economies will reduce their likelihood of default, especially with regard to transition risks.
- At the index level, the financial impact of physical risks could be evident as early as 2030, followed by a few years later for transition risks. The potential decline in returns is comparable in both types of risks by 2050.
- Overall, the results underline the benefits of an orderly transition to the development of sustainable economic and financial activities.

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1. Executive summary

What this study proposes

- Regulators and international institutions require financial risks assessment of climate change, however the practical methodology frameworks available are lacking. This paper provides an innovative and practical methodology which measures the financial impact of climate change risks on sovereign fixed-income assets.
- The proposed framework uses the macroeconomic impact estimates from the first research (Part 1) and aligns with the scenario-based and forward-looking approach recommended by regulators and international institutions.

What are the climate change risks assessed?

- Physical risks are assessed in a “hot house” world scenario by estimating the impact of global warming on the economy ([see Part 1 paper](#)).
- Transition risks are assessed in a “disorderly transition” scenario by evaluating the abatement costs (monetary amount of remaining emissions to be abated after the carbon budget has been depleted).

How do climate change impacts translate into financial risks?

- Our methodology estimates the impact of climate change on sovereign credit risk spread, and therefore on bond yields and returns.
- We have developed proprietary default-probability and financial models to simulate the potential fallout of climate change on sovereign bonds.

What are the main results?

- Physical risks will mainly affect emerging market economies based in areas that are most impacted by climate change, while advanced economies that emit more greenhouse gases and are more carbon-dependent will be mostly affected by transition risks.
- The probability of sovereign defaults is likely to increase over time and could undermine the creditworthiness of economies with weak fiscal capacity.
- Therefore, sovereign bond yields for these economies could diverge sharply, affecting returns for investors.

2. Introduction

2.1 Background

Climate change has become everyone's business in a very short period. Some of its effects are already at work throughout the globe (e.g., harder, longer, and more widespread droughts and floods; more frequent, stronger, and earlier heat waves; rising sea levels; melting permafrost, etc.). As stated by the United Nations Office for Disaster Risk Reduction (UNDRR) in its Human cost of disasters¹ report, climate change is having significant economic and financial impacts in some regions of the world today, forcing societies to reinvent themselves (see Climate change adaptation and disaster risk reduction in Europe², European Environment Agency [EEA]). As described by the Task force on Climate-related Financial Disclosures³ (TCFD) or the Network for Greening the Financial System⁴ (NGFS), climate change-related financial risks are broken down into two main categories of risks: (i) those related to the transition to a low-carbon economy (i.e., transition risks), and (ii) the physical risks.

However, in its latest Global Financial Stability Report (2020)⁵, the IMF highlights that financial markets are underestimating climate change risks. In particular, the IMF examines the impact of physical risk on financial stability and finds that equity investors do not appear to fully price climate risks. This confirms the findings of earlier research on sovereign bonds (Capelle-Blancard *et al.*, 2019⁶) that highlight the strong links between environmental risks and sovereign spreads. London Stock Exchange Group and Beyond Ratings also worked exhaustively on this topic, leading to similar conclusions (Reznick *et al.*, 2019⁷ and 2020⁸). The NGFS (2019) recognizes the "strong risk that climate-related financial risks are not fully reflected in asset valuations", and thus considers a better assessment of the transition and physical risks as a high priority for the financial sector.

2.2 Assessing climate change risks: a scenario-based approach

The methodology developed in Part 1⁹ of the research is forward-looking and scenario-based (see the TCFD, 2017b¹⁰, NGFS, 2019, IMF 2019¹¹, EC 2019¹², BoE 2019¹³ or BIS 2020¹⁴). Building on the NGFS typology, macroeconomic impacts are estimated in the "worst-case" scenarios – a "hot house world" and a "disorderly transition." Physical risks were assessed in a "hot house world" scenario by estimating an economy's productivity loss from a temperature increase. Also assessed were the potential economic shocks of a very abrupt transition, akin to the "disorderly transition" scenario.

¹ United Nations Office for Disaster Risk Reduction (2020), Human cost of disasters, An overview of the last 20 years – 2000-2019.

² European Environment Agency (2017), Climate change adaptation and disaster risk reduction in Europe, Enhancing coherence of the knowledge base, policies and practices.

³ TCFD (2017a), *Final report – Recommendations of the Task Force on Climate related Financial Disclosures*. The Task force on Climate-related Financial Disclosures (TCFD) was created in 2015 after the Financial Stability Board was requested by the G20 to "review how the financial sector can take account of climate-related issues".

⁴ NGFS, (2019), *First comprehensive report – A call for action Climate change as a source of financial risk*.

The Network for Greening the Financial System (NGFS) is a network of central banks and supervisors, launched at the One Planet Summit in 2017 in Paris, aiming at strengthening the global response required to meet the goals of the Paris agreement and to enhance the role of the financial system to manage CC -related risks.

⁵ IMF (2020), *Global financial stability report – Chapter 5: Climate Change: Physical Risk and Equity Prices*.

⁶ Capelle-Blancard, G. *et al.* (2019), *Sovereign bond yield spreads and sustainability: An empirical analysis of OECD countries*. Journal of Banking & Finance, 98, 156-169.

⁷ Reznick, M. *et al.* (2019), *Pricing ESG risk in sovereign credit*, Research paper by Hermes Investment Management and Beyond Ratings.

⁸ Reznick, M. *et al.* (2020), *Pricing ESG risk in sovereign credit – Part II: Developed and emerging-market spreads split the difference*, Research paper by Hermes Investment Management and Beyond Ratings.

⁹ Lancesseur, N. and T. Lorans (2021), [Anticipating the climate change risks for sovereign bonds – Part 1: Insights on the macroeconomic impacts](#), Research paper by FTSE Russell.

¹⁰ See also TCFD (2017b) *Technical Supplement: The Use of Scenario Analysis in Disclosure of Climate-related Risks and Opportunities* and TCFD (2019), *2019 Status Report*.

¹¹ Grippa *et al.* (2019), *Climate Change and Financial Risk*, Finance & Development.

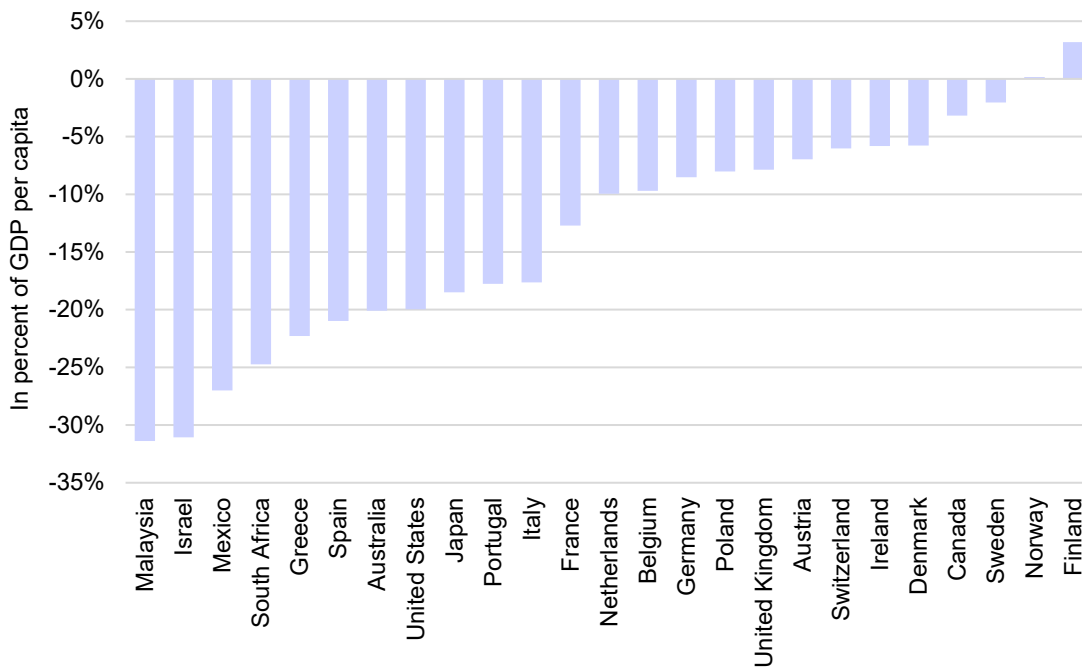
¹² European Commission (2019), *Guidelines on non-financial reporting: Supplement on reporting climate-related information*, 2019/C 209/01

¹³ Bank of England (2019), *Enhancing banks' and insurers' approaches to managing the financial risks from climate change*, Bank of England Prudential Regulation Authority, Supervisory Statement SS3/19

¹⁴ Bank for International Settlements (2020), *Green Swan 2 – Climate change and Covid-19: reflections on efficiency versus resilience*, BIS Speech by Luiz A Pereira da Silva, May 13.

Focusing on the 26 constituent countries¹⁵ of the FTSE World Government Bond Index (WGBI), the main findings from the first study are shown in Charts 1 and 2. According to our study, Malaysia and Israel show a projected loss (in GDP-per-capita) of 31% from physical risks by 2050 (i.e., the highest impacted countries in the WGBI universe). But the charts also show that most of the WGBI countries would suffer from unmitigated global warming, except for Norway and Finland.

Chart 1. Change in GDP per capita by 2050 compared to a world without climate change, RCP 8.5 scenario



Source: Beyond Ratings, based on Burke and Tanutama (2019) calibration and Burke et al. (2015) data for temperature at country level.

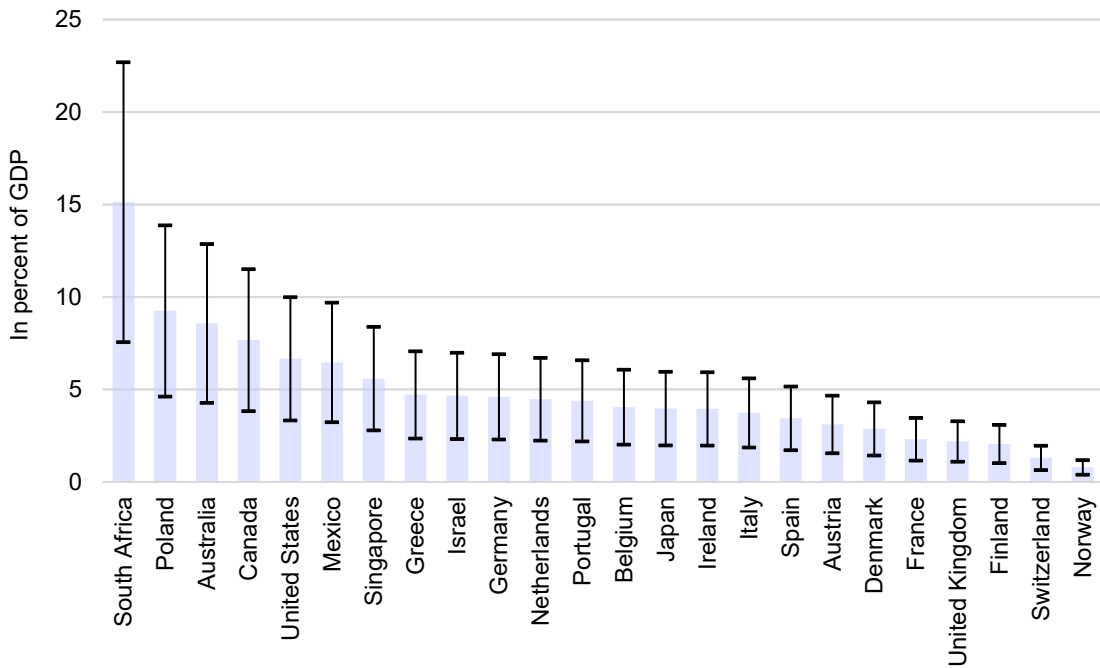
Chart 2 estimates the total abatement costs¹⁶ from transition risks in GDP¹⁷ terms in the WGBI universe. South Africa, Mexico, Poland, the United States, Australia, and Canada have the highest abatement costs-to-GDP ratio, and thus are the most exposed to transition risks. The situation is all the more worrying in large economies, where the depletion year of their carbon budget is very close, especially in the United States, Australia, and Canada.

¹⁵ Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Israel, Italy, Japan, Malaysia, Mexico, Netherlands, Norway, Poland, Portugal, Singapore, South Africa, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

¹⁶ The total abatement costs for an economy translate, in monetary terms, as the amount of remaining emissions to be abated after depletion of that economy's carbon budget.

¹⁷ GDP projections for SSP2 scenario from MaGE model (CEPII) are used here.

Chart 2. Total abatement costs (in percentage of GDP)* incurred from the depletion year



Source: Beyond Ratings.

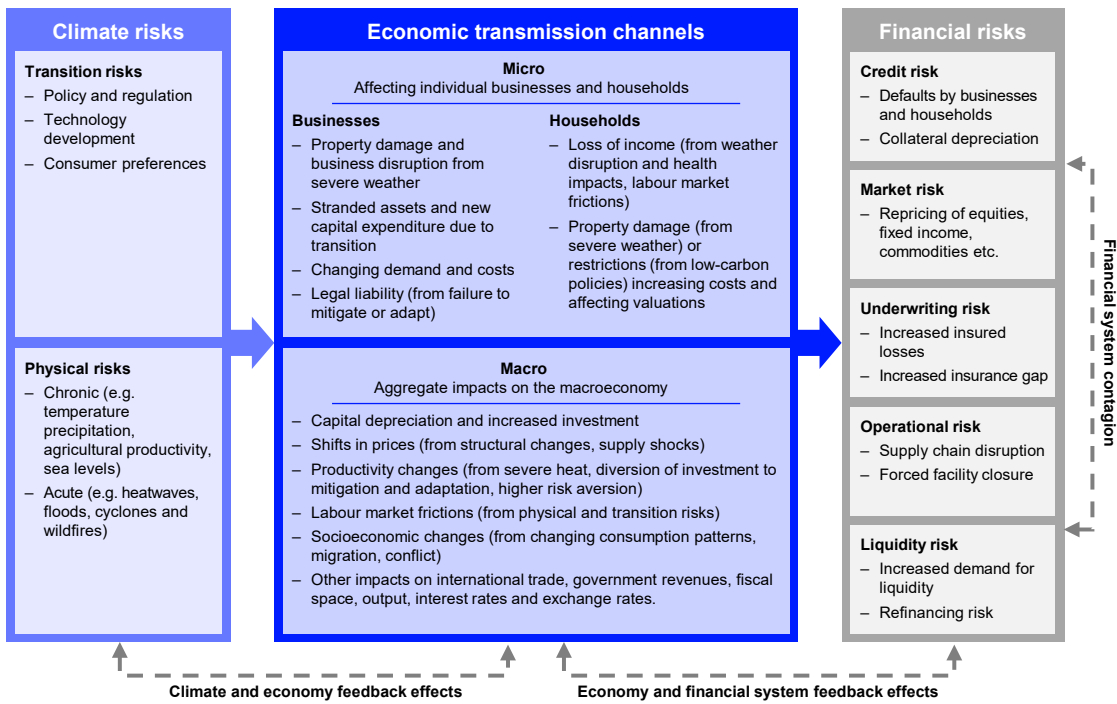
*Note: the level of the impact represented by the histogram bar are calculated with a technology cost of 200\$/tCO₂ (reference), although the lower and the upper ends of the sensitivity bar are calculated respectively with a cost of 100\$/tCO₂ and 300\$/tCO₂ (range estimated by the IPCC for the DACCS technology).

2.3 From climate change-related scenarios to asset repricing

The recent and growing literature in climate economics can help model and quantify how climate change-related shocks feed through the economic and financial system (Battiston *et al.*, 2017¹⁸). Chart 3 illustrates the main transmission channels from climate change to economic impacts and financial risks (e.g., depreciation of tangible assets, repricing of financial assets, defaults).

¹⁸ Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., & Visentin, G. (2017). A climate stress-test of the financial system. *Nature Climate Change*, 7(4), 283-288.

Chart 3. Transmission channels: from climate change to economic impacts and financial risks

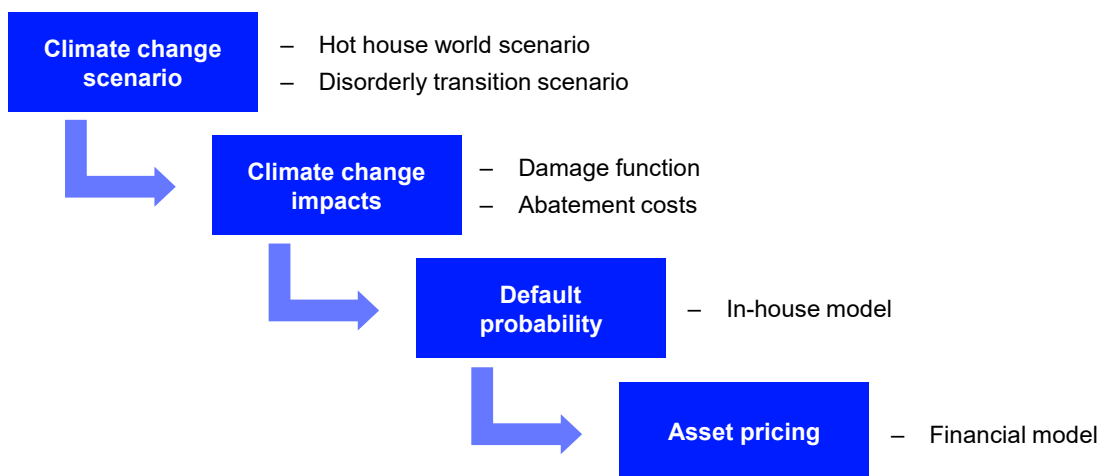


Source: NGFS.

3. From climate change risks to asset returns: the modelling approach

To account for the impacts of climate change on sovereign bond returns (see Chart 4), we use the findings from our Part 1 research: (i) the “hot house world” scenario, *i.e.*, physical risks, and (ii) the “disorderly transition” scenario, *i.e.*, transition risks.

Chart 4. The modelling process



Source: Beyond Ratings.

We use the economic impacts assessed in the first paper to derive the sovereign debt dynamics. In the “hot house world” scenario, we assume that damages arising from physical risks are attributed to sovereign fiscal revenues, and in the “disorderly transition” scenario, abatement costs are imputed to government expenditures.

Using the framework of default threshold developed by Collard *et al.* (2015¹⁹, 2016²⁰) and empirical calibration, we model the effects of climate change *via* the debt dynamic, thus making the link between climate change, default probability, and sovereign bond returns. More details on the steps of the modelling process are provided in the rest of this section.

3.1 Climate change impacts on debt dynamics

In this paper, the impacts of climate change on debt dynamic are as follows:

- In the “**hot house world**” scenario, damages would increase the debt-to-GDP ratio since it lowers fiscal revenues as losses from infrastructures, employment, manufactured products and services should reduce the tax base
- In the “**disorderly transition**” scenario, abatement costs are assumed to be fully funded by the government because investment in backstop technologies²¹ is mainly a matter of public policy. It would, therefore, add to the budget balance and increase the debt-to-GDP ratio.

In the baseline scenario (*i.e.*, no climate change-related risks), the debt-to-GDP ratio is assumed to be constant and equal to the last known value.

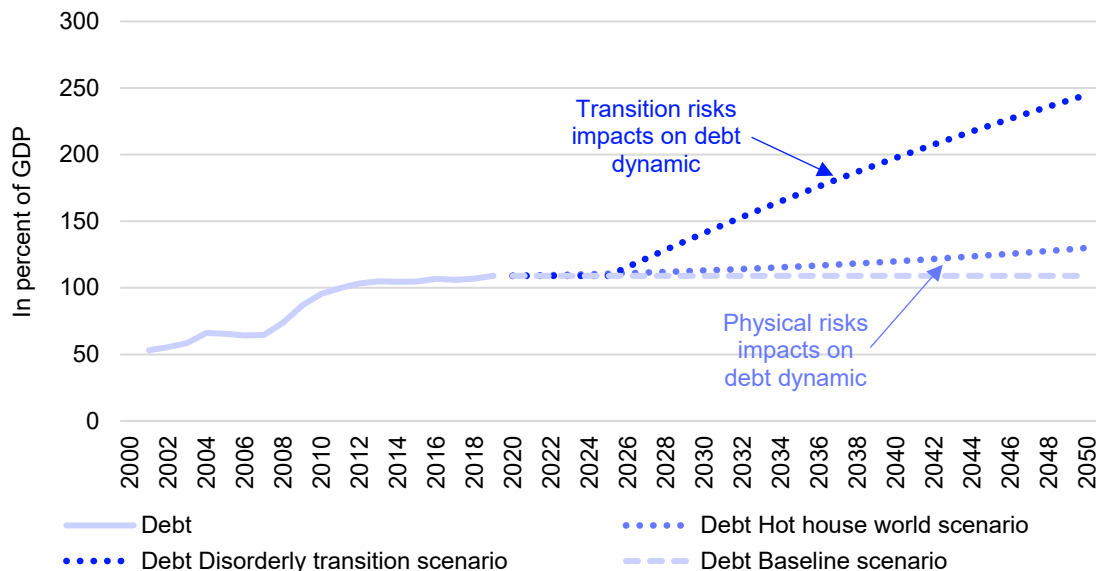
¹⁹ Collard, F. *et al.* (2015). Sovereign debt sustainability in advanced economies. *Journal of the European economic association*, 13(3), 381-420

²⁰ Collard, F. *et al.* (2016). The reluctant defaulter: a tale of high government debt.

²¹ The climate change backstop technologies can be defined as cheap, easily scalable technologies that eliminate the disruptive effects of climate change without significant negative externalities. The investments in such technologies could be significant and supported firstly by public authorities.

Case: United States

Chart 5. Climate change impacts on debt dynamic – United States



Source: Beyond Ratings.

Chart 5 illustrates the potential impacts of transition and physical risks on debt dynamic for the United States. The abatement costs (for the “disorderly transition” scenario, or the damages in the case of the “hot house world” scenario) are added to the current debt-to-GDP ratio, projected as constant in the baseline scenario.

The United States transition risks are the more important source of pressure on the debt dynamic. This is not a general rule (e.g., for some economies, physical risks seem to be the costliest risks with regards to pressure on public finances).

Estimates of debt-to-GDP ratio are calculated for each year and each economy in the WGBI universe and in both climate scenarios. This leads to a model-based default probability.

3.2 Default probability model setting

3.2.1 An ability-to-pay model

The aim of the model is to calculate the probability of sovereign default, using the notion of default threshold. The latter is the maximum debt-to-GDP ratio which can be reimbursed by the government without default (Collard *et al.*, 2015, 2016).

This notion of default threshold²² is used in recent studies aiming to determine a sovereign ability-to-pay model or “excusable default,” where a given sovereign defaults due to a lack of financial resources.

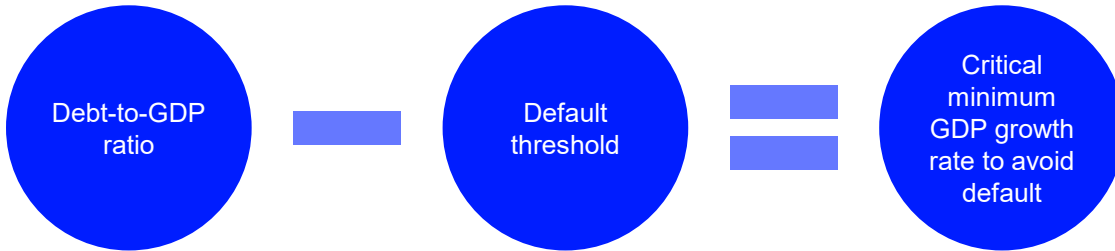
In the framework used here, the difference between the default threshold and the current debt-to-GDP ratio is the remaining amount (in percent of GDP) of “fiscal space”²³ before the default. When the government debt-to-GDP ratio reaches or exceeds this default threshold, the sovereign is expected to default.

²² In the reference paper (Collard *et al.*, 2015, 2016), the default threshold is endogenously determined for some developed economies, as a function of the maximum amount that government can borrow from the market and the maximum primary budget surplus it can obtain.

²³ The “fiscal space” is an established and agreed term in public economics. It is commonly defined as the budgetary capacity that allows a government to provide resources for public purposes without undermining its fiscal sustainability.

This remaining amount or fiscal capacity between the default threshold and the current debt-to-GDP ratio is at the core of the default probability modelling of this framework and is defined as the “critical minimum growth rate” (see Chart 6).

Chart 6. Default threshold, debt-to-GDP ratio and critical minimum GDP growth rate



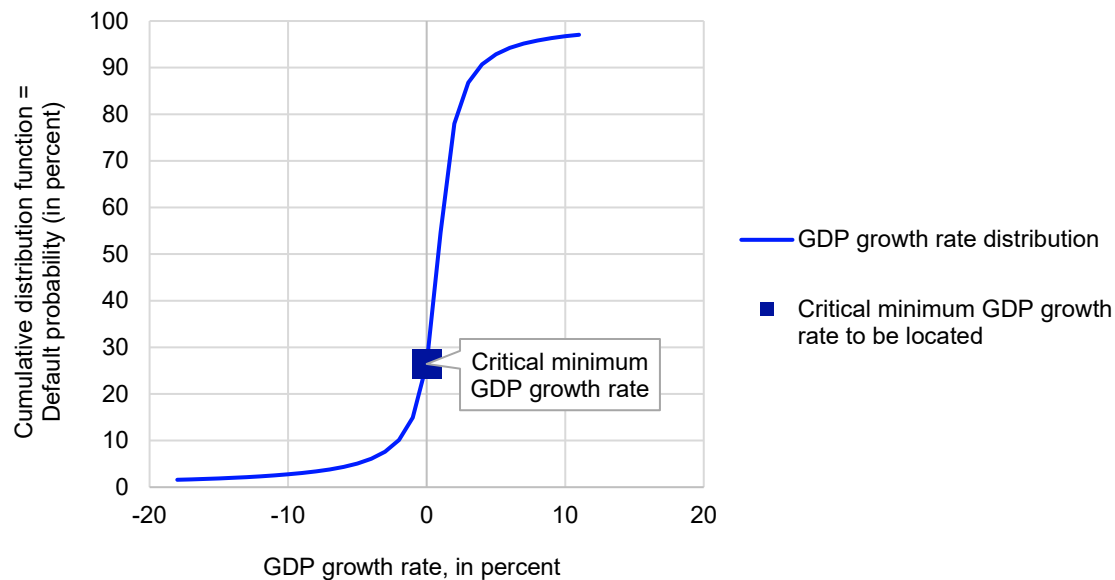
Source: Beyond Ratings.

Indeed, for a given set of fiscal policy and expectations, the evolution of the debt-to-GDP ratio relies on the GDP growth rate only. For a given default threshold, the probability that debt-to-GDP ratio will exceed the default threshold corresponds to the probability that GDP growth has declined to the same level.

This leads to the definition of default probability, which corresponds to the probability that GDP growth rate will be equal or lower than the differential between current debt-to-GDP ratio and the default threshold, *i.e.*, the critical minimum GDP growth rate (see Chart 6 and Appendix B for further details).

Chart 7 highlights the relationship between the critical minimum GDP growth rate and the default probability, relying on the GDP growth rate distribution. In this example, the critical minimum GDP growth rate stands at 0%, which means that the debt-to-GDP ratio is equal to the default threshold. Based on the GDP growth rate distribution, the probability of attaining a GDP growth rate equal or lower than 0% (*i.e.*, to be in recession) is close to 30%, which represents the default probability.

Chart 7. From critical minimum GDP growth rate to default probability (illustrative case)



Source: Beyond Ratings.

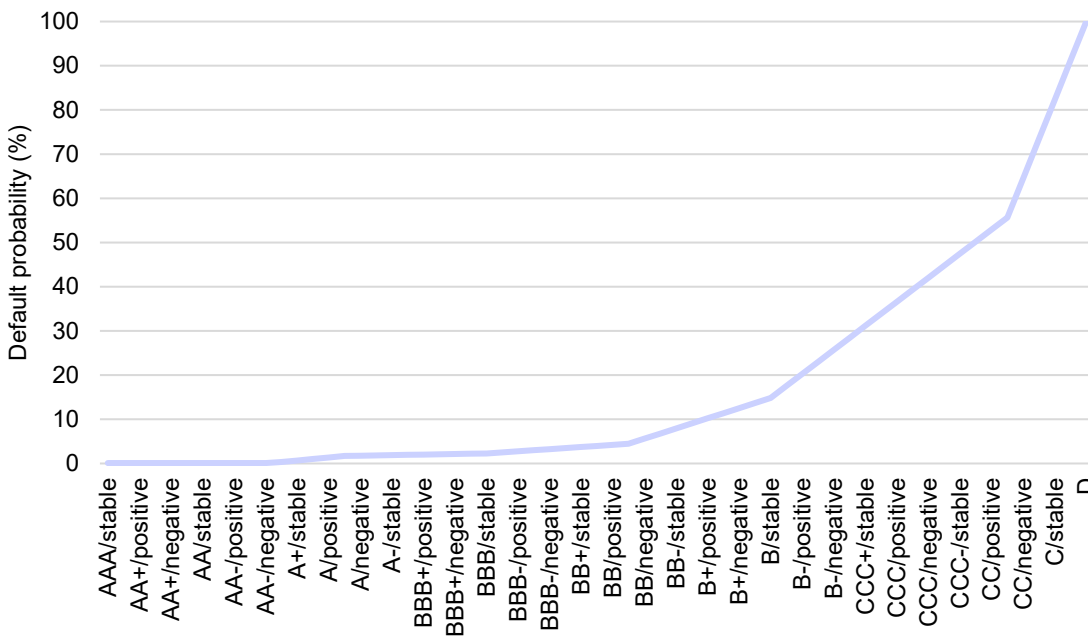
Once the conceptual framework is defined, a calibration process follows to compute default probability estimates.

3.2.2 Calibration for an empirical model

In the reference paper of Collard *et al.* (2015, 2016, *op. cit.*), the default threshold is endogenously determined. Here, we use an empirical calibration to estimate a default threshold. Such calibration relies on sovereign ratings from credit rating agencies (CRAs). Since the purpose of this analysis is not to build solely a default probability model, but to also study the potential impacts of climate change on public indebtedness (and thus on sovereign bond returns), it has the benefit of using publicly available information.

In this calibration process, historical CRAs ratings are converted into historical default probability (see Chart 8), using the methodology from Polito and Wickens (2015²⁴) and described in detail in Appendix C.

Chart 8. Conversion rule used for translating CRAs' ratings into historical default probability



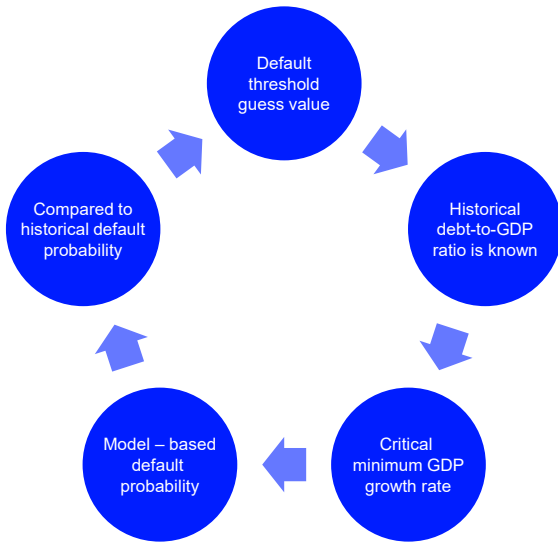
Source: Beyond Ratings.

Chart 9 shows the calibration for the default threshold. The model is run for different values of the default threshold (from 10 to 500% of GDP). As the historical debt-to-GDP ratio is already known, the corresponding critical minimum GDP growth rate can be derived. From this result, we can determine the cumulative distribution function of the GDP growth rate, which corresponds to the model-based default probability. Finally, the model-based default probability is compared to the historical default probability derived from CRAs ratings.

Then, the calibrated value of the default threshold is the lowest difference between the model-based default probability and the converted historical default probability.

²⁴ Polito, V., & Wickens, M. (2015). Sovereign credit ratings in the European Union: a model-based fiscal analysis. *European Economic Review*, 78, 220-247.

Chart 9. Calibration process for default threshold

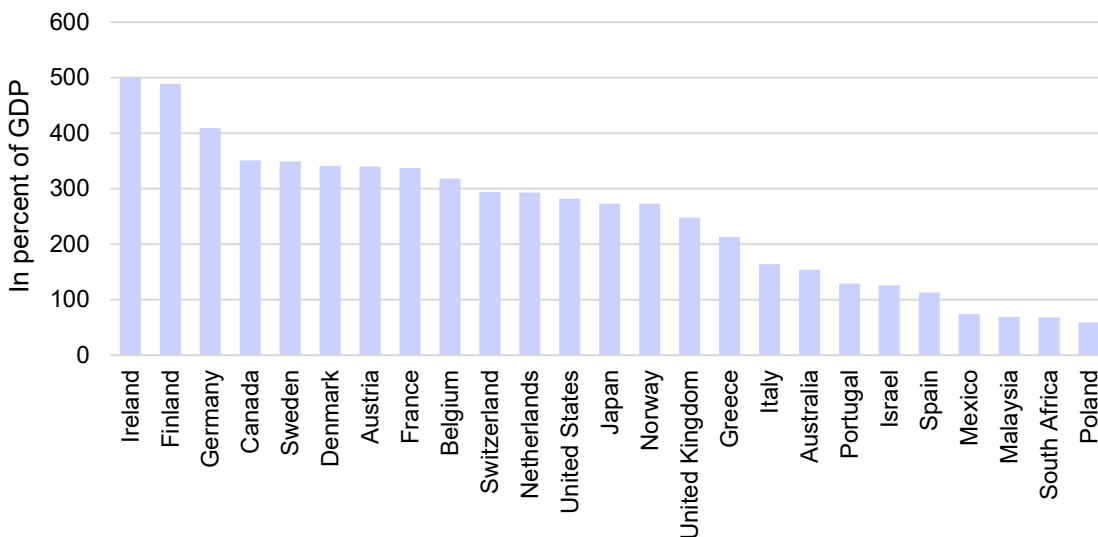


Source: Beyond Ratings.

To calculate the cumulative distribution probability for the critical minimum GDP growth rate, we fit the Cauchy distribution²⁵ to the economy’s empirical GDP growth rate distribution, following Williams *et al.* (2017²⁶).

Chart 10 shows the resulting default threshold for each economy in the WGBI universe. According to this calibration methodology, Ireland seems to have the highest default threshold (*i.e.*, 500% of GDP), followed by Scandinavian and Western European economies. At the other end of this spectrum, emerging market economies such as, South Africa, Malaysia, Mexico, and some Southern or Eastern Europe economies (*i.e.*, Poland, Portugal, Italy, Greece, and Spain) have the lowest default thresholds. Although Australia seems to have a low default threshold, its current debt-to-GDP ratio is relatively low compared to other advanced economies (59% of GDP in 2020), and therefore gives it more fiscal capacity.

Chart 10. Calibrated default threshold with latest available year used for estimates



Source: Beyond Ratings.

²⁵ In the reference paper from Collard *et al.* (2015), a standard normal distribution is used. The Cauchy distribution is close to the Normal distribution but allows for fatter tails and thus fits better for our purposes.

²⁶ Williams, M. A., Baek, G., Li, Y., Park, L. Y., & Zhao, W. (2017). Global evidence on the distribution of GDP growth rates. *Physica A: Statistical Mechanics and its Applications*, 468, 750-758.

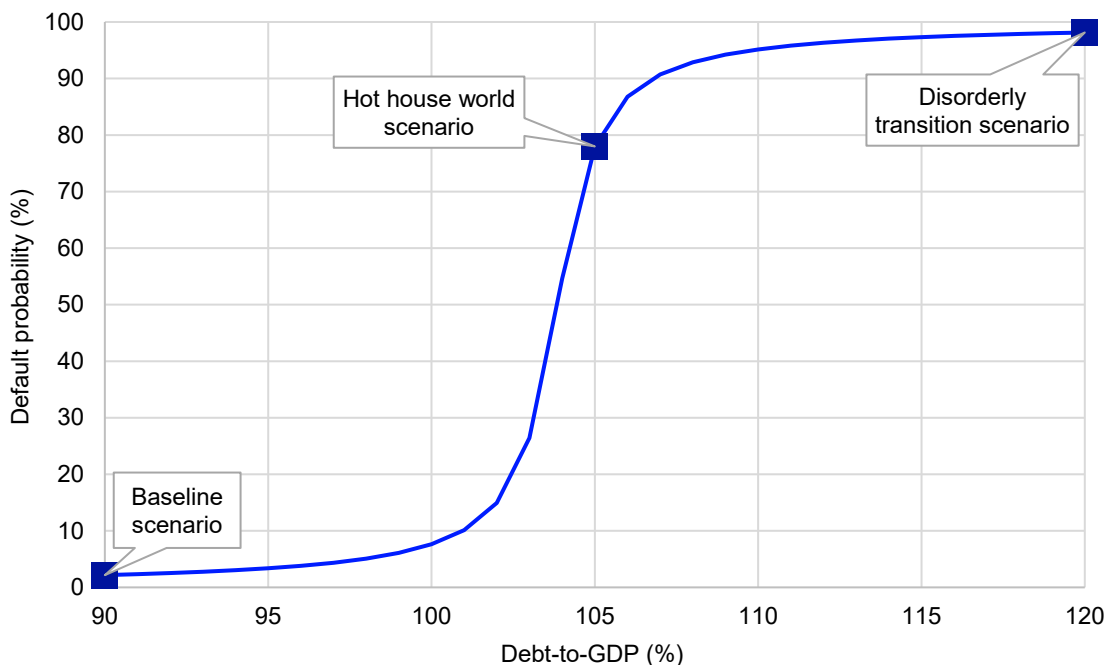
3.2.3 Climate change and default probability function

In this model-based framework, each specific climate change-related scenario will lead to a different pressure on public finances (*i.e.*, increase in debt-to-GDP ratio). For a given default threshold and cumulative distribution of GDP growth rate, an increase in debt-to-GDP ratio will lead to an increase in the model-based default probability as highlighted in Chart 11.

In Chart 11, the debt-to-GDP ratio in the baseline scenario, kept constant in the simulation, is at 90% of GDP. This corresponds to a default probability close to 0. However, in the “hot house world” scenario, the debt-to-GDP has increased to 105% of GDP, which leads to a default probability increase of up to 80%. Finally, in this example, the “disorderly transition” scenario leads to an increase of the debt-to-GDP ratio of up to 120%, which corresponds to a near 100% default probability.

However, the fact that the default probability is higher in the “disorderly transition” scenario than in the “hot house world” scenario does not mean it is a general rule. The magnitude of risks depends on the economy’s transition and physical risks exposures.

Chart 11. Climate change impacts and default probability function (illustrative case)



Source: Beyond Ratings.

For the simulation of default probability, the default threshold is kept constant²⁷ and equal to the last calibrated value. The distribution of GDP growth rate is then used to determine the likely frequency a GDP growth rate will be lower or equal to the minimum critical GDP growth rate.

3.3 Financial model

Once the default probability has been estimated with respect to the effects of climate change, a financial model (see Appendix D for further details) translates the default probability into sovereign bond returns.

First, we determine a default risk premium following the Hull formula²⁸ (see Appendix D for further details). This default risk premium allows us to determine the sovereign interest rate. This figure helps to understand the impact of climate change on sovereign bonds; since the default risk premium is a positive

²⁷ Indeed, one can expect that CC would also bear on expectations about the default threshold and the distribution of GDP growth rate. Thus, this assumption might be relaxed in future studies.

²⁸ Hull, J.C. (2012). Options, Futures and Other Derivatives. 8th Edition, Pearson, Chapter 24.

function of default probability, an increase in default probability due to climate change will lead to an increase in the sovereign interest rate.

Second, bond returns are derived from the interest rate following a simplified modelling framework based on the modified duration and convexity (see Appendix E for further details). In this framework, an increase in yield will therefore reduce the bond return.

As a result, the potential impact of climate change on sovereign bonds returns becomes evident. As climate change damages would affect the debt dynamic, default probability could increase leading to a rise in a sovereign’s bond yield, thus reducing the return.

Charts 12-a, -b, -c and -d illustrate this chain of events for the case of Mexico:

- Chart 12-a shows a progressive debt-to-GDP increase in the hot house world scenario, with the debt-to-GDP ratio exceeding the default threshold in 2038. Transition risks materialize in the disorderly transition scenario from 2045, with the ratio increasing and exceeding the default threshold by 2047
- As the debt-to-GDP ratio increases in both scenarios, the default probability increases also in Chart 12-b
- This rise in the default probability leads to an increase in sovereign yields in Chart 12-c
- Relative to a baseline scenario, cumulative returns are therefore negative in both scenarios, as highlighted in Chart 12-d.

Chart 12-a. Climate change impacts on debt dynamic – Mexico

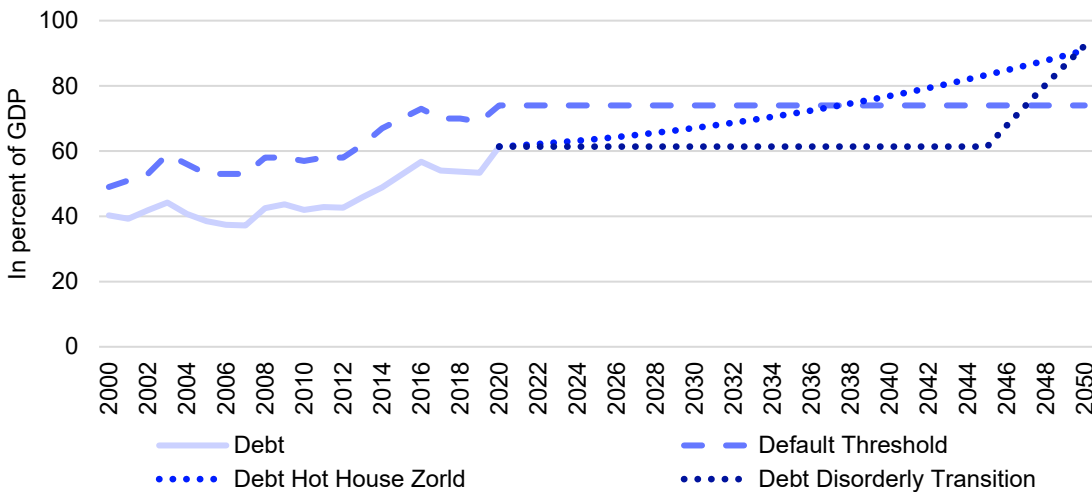


Chart 12-b. Climate change impacts on default probability – Mexico

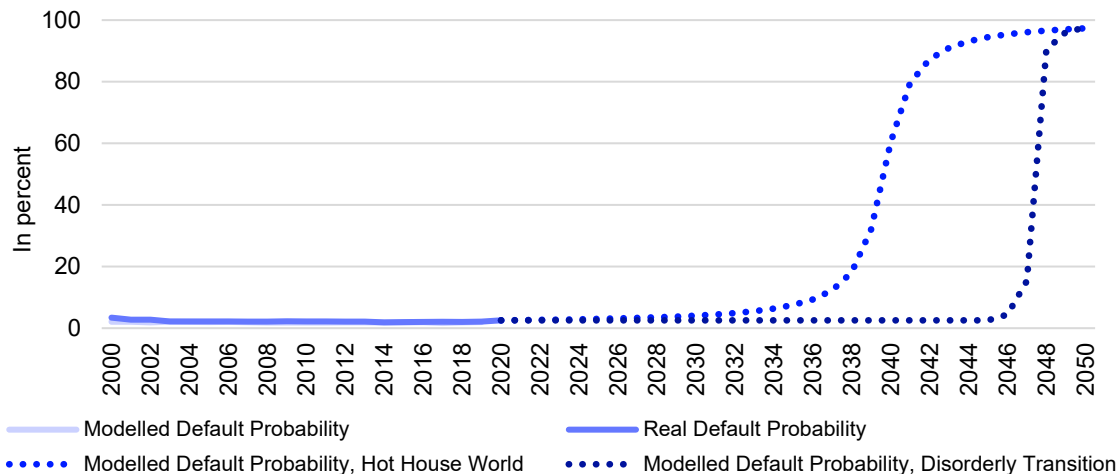


Chart 12-c. Climate change impacts on sovereign yields – Mexico

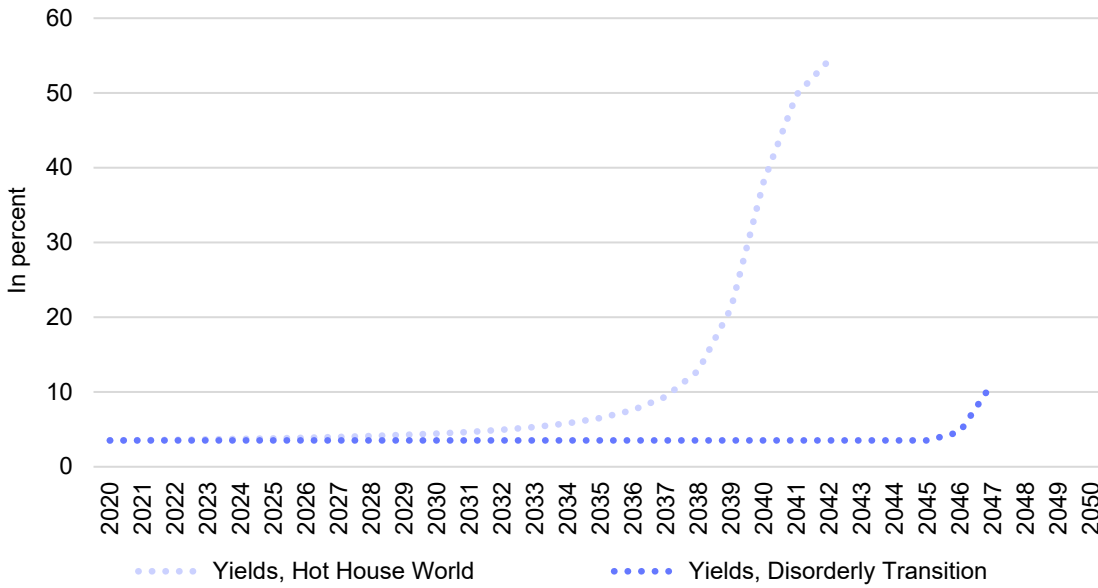
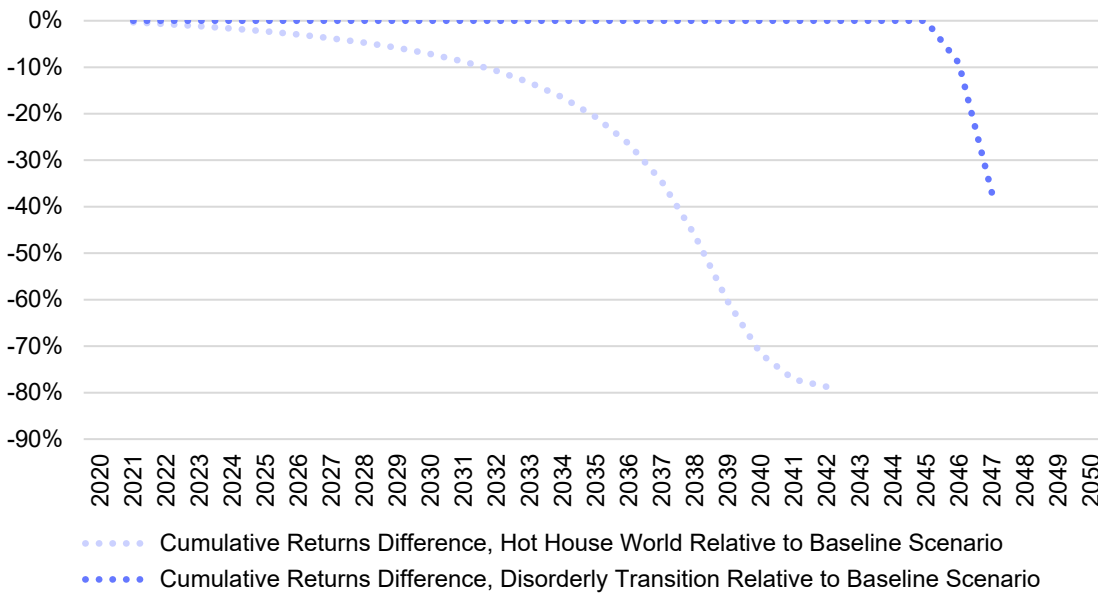


Chart 12-d. Climate change impacts on cumulative returns – Mexico



Source: Beyond Ratings.

This approach is applied to each economy in the WGBI universe, and results are shown in the next sections.

4. Physical risks financial materiality

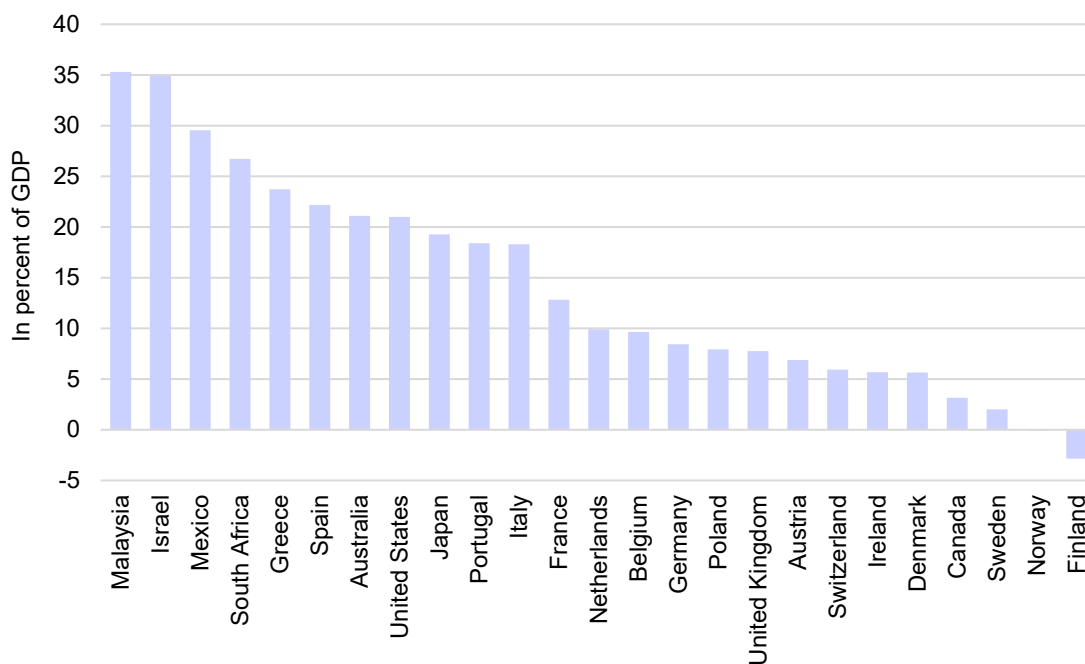
The financial impact of physical risks is analyzed in a “hot house world” scenario. The scenario assumes that greenhouse gas (GHG) emissions increase until 2080 and global warming is over 3°C. The Representative Concentration Pathway²⁹ 8.5 scenario can therefore be approximated assuming that GHG emissions continue to grow by the end of the century and corresponds to an average global warming of 4.3°C (with simulations from +3.2 to +5.4°C). The reader interested in more information about the scenario and the economic impacts should refer to the first paper in this series. In the next section, we estimate physical risks directly impacting debt dynamics.

4.1 Physical risks pressures on public finances in a hot house world scenario

In the “hot house world” scenario, the economic impact from climate change due mainly to physical damages are expected to decrease the government fiscal revenues and increase the debt-to-GDP ratio. Chart 13 highlights the multiple impacts of physical risks on this ratio. Malaysia, for example, would be expected to experience a debt-to-GDP ratio increase of 35 percentage points by 2050.

Emerging market economies and Israel seem to be the most impacted by physical risks (*i.e.*, Malaysia, Mexico, and South Africa), but even European economies (*i.e.*, Greece, Spain, Italy, or France) and Australia or the United States should see a significant increase in their debt-to-GDP ratio due to the physical risk impacts arising in the hot house world scenario according to our modelling.

Chart 13. Debt increase in the hot house world scenario by 2050



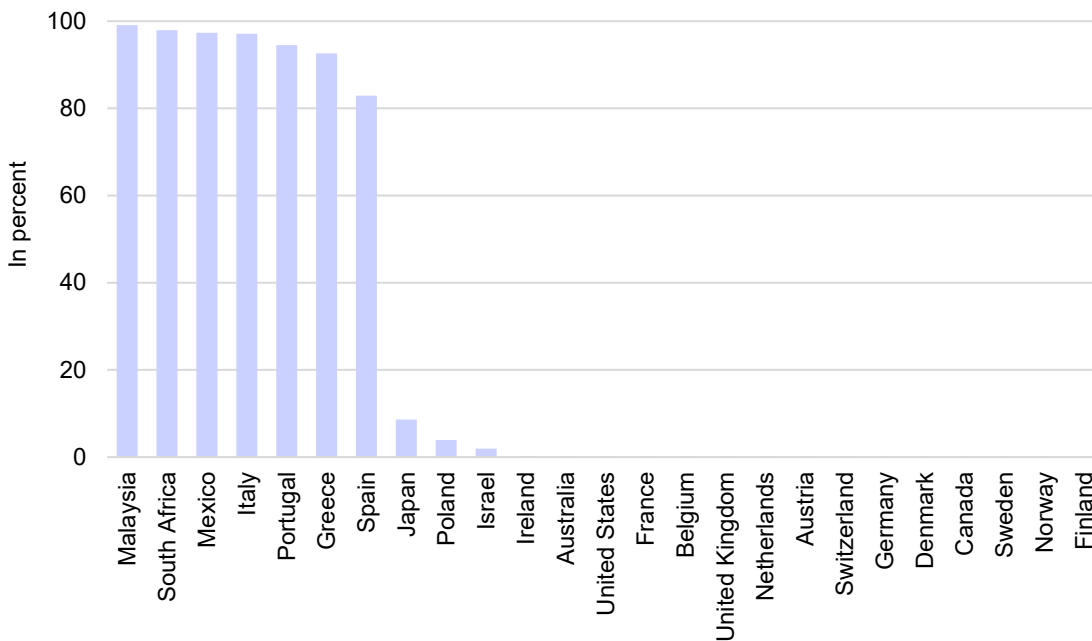
Source: Beyond Ratings.

²⁹ A Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC). Four pathways were used for climate modeling and research, ranging from the most optimistic (*i.e.*, RCP 2.6) to the most pessimistic (*i.e.*, RCP 8.5).

However, this important pressure on public finances does not automatically result in a significant impact on sovereign risk in this framework. Chart 14 shows the resulting default probability by 2050.

Under the “hot house world” scenario, only emerging markets economies (*i.e.*, Malaysia, South Africa, and Mexico) and Southern Europe economies (*i.e.*, Portugal, Italy, Greece, and Spain) would be expected to default. This highlights the diverse financial resilience between countries. While Australia and the United States are expected to incur a large increase in debt-to-GDP ratio (+21 percentage points for both of them), these economies still retain some fiscal capacity due to their large default threshold estimates.

Chart 14. Default probability in the “hot house world” scenario, 2050



Source: Beyond Ratings.

4.2 Climate change impacts from physical risks: Malaysia

Under the “hot house world” scenario, the case of Malaysia stands out. The physical risks seem to weigh heavily on the economy’s fiscal capacity, and for a good reason. Malaysia is a peninsula located in an area that has a higher physical risk exposure than other economies. As stated by Ehsan *et al.* (2019)³⁰, “Malaysia, representing 13% of the total land area within 5 km of a coast, is threatened by the devastating impacts of sea level rise”. Moreover, given that the default threshold is relatively low (see Chart 15-a) compared to other economies, physical risks are expected to rapidly increase the economy’s indebtedness in that scenario and Malaysia could experience an upward trend in its default probability between 2035 and 2040 (see Chart 15-b).

According to our analysis on sovereign bond yields and returns, between 2030 and 2035, the additional indebtedness linked to physical risks would result in an increase in yields (see Chart 15-c) and a decrease in annual returns (see Chart 15-d) over the same period. The Asian peninsula could, therefore, experience episodes of high stress on its sovereign creditworthiness at the end of that period. According to our estimates, the sequence of events is highly dependent on the weakness of the fiscal space in the Malaysian economy.

³⁰ Ehsan S., R. Ara Begum, N. Ghani Md Nor and K. Nizam Abdul Maulud (2019), *Current and potential impacts of sea level rise in the coastal areas of Malaysia*, IOP Conf. Series: Earth and Environmental Science 228 (2019) 012023.

Chart 15-a. Climate change impacts on debt dynamic – Malaysia

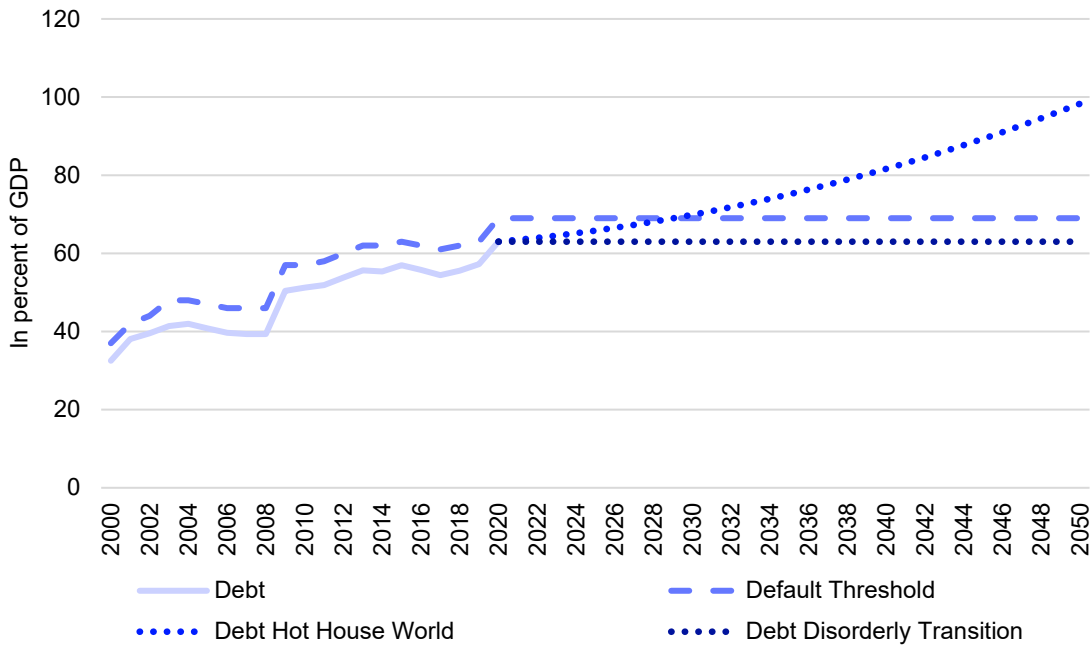


Chart 15-b. Climate change impacts on default probability – Malaysia

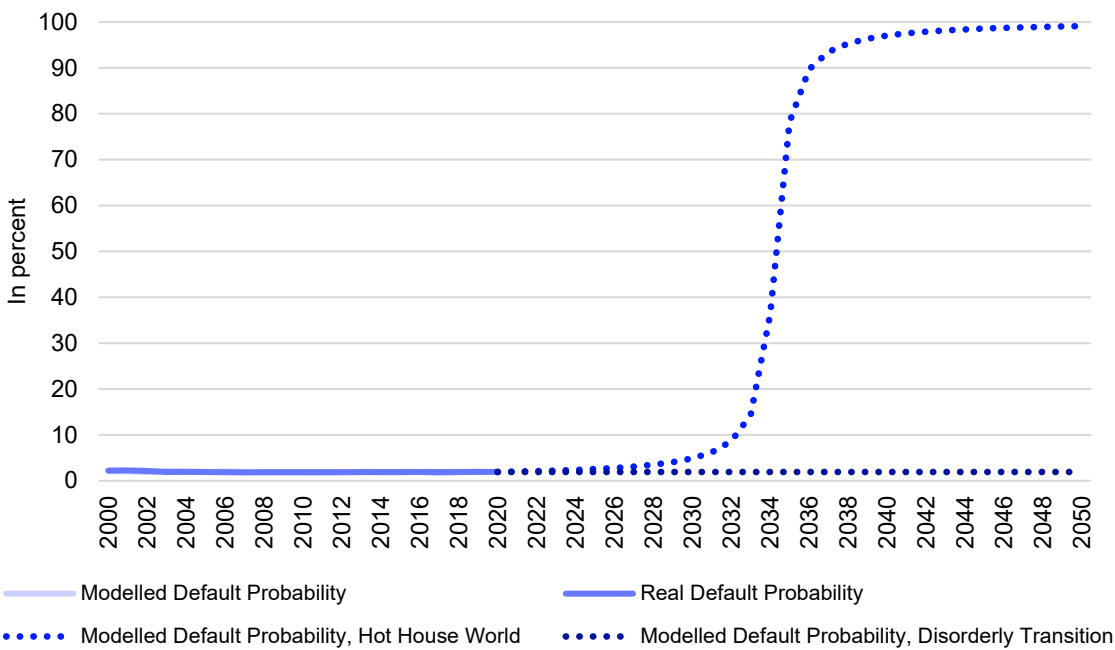


Chart 15-c. Climate change impacts on sovereign yields – Malaysia

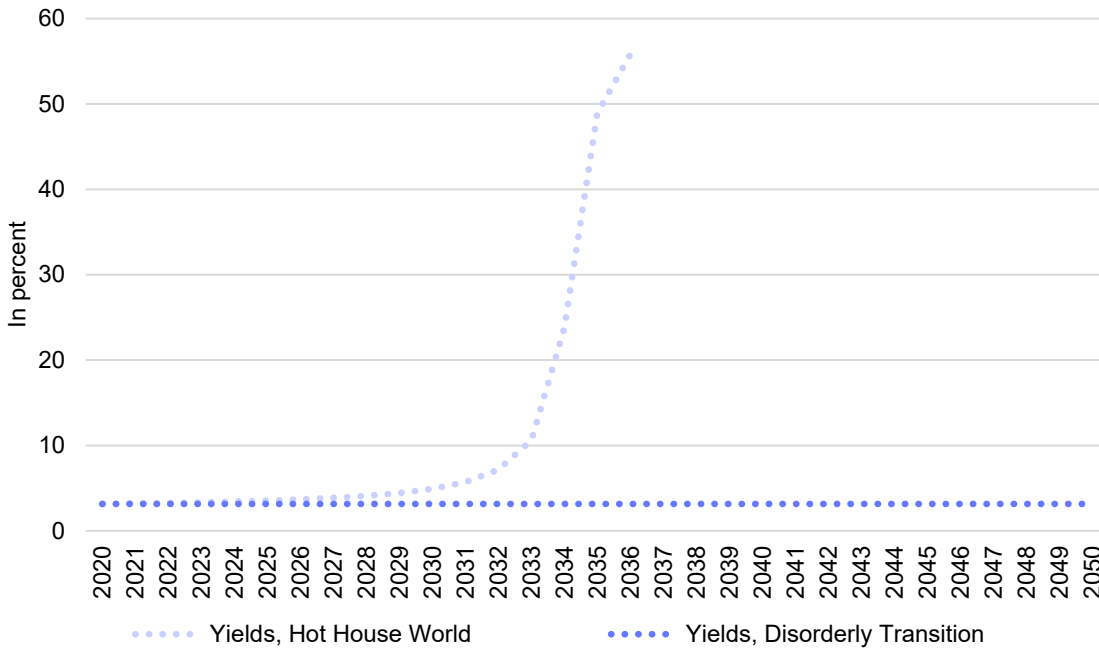
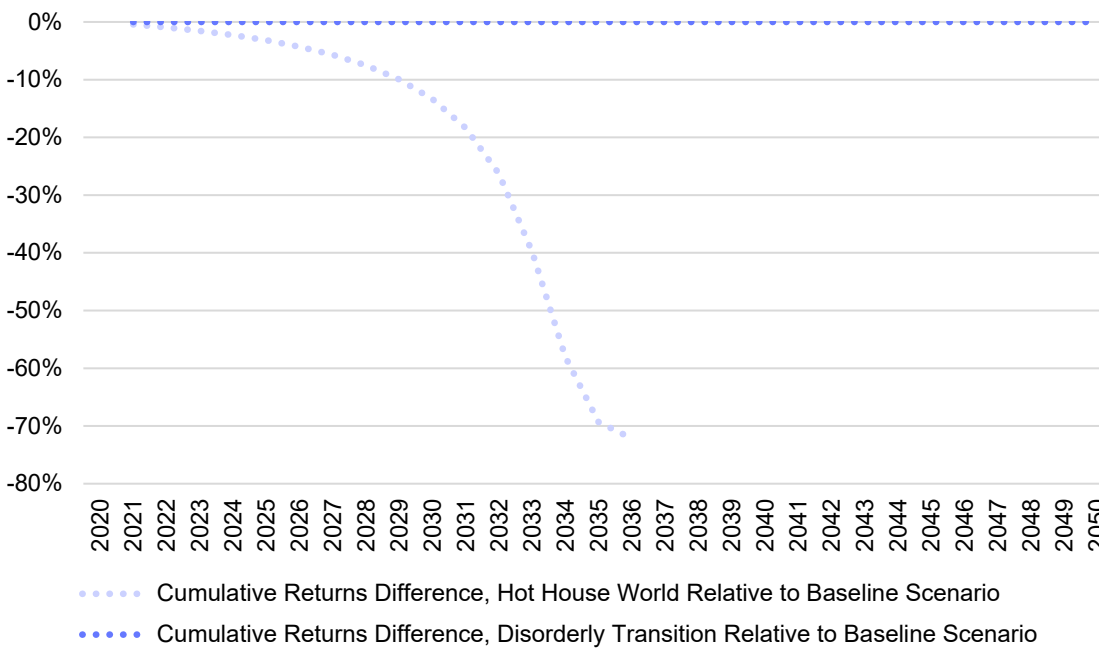


Chart 15-d. Climate change impacts on cumulative returns – Malaysia



Source: Beyond Ratings.

5. Transition risks financial materiality

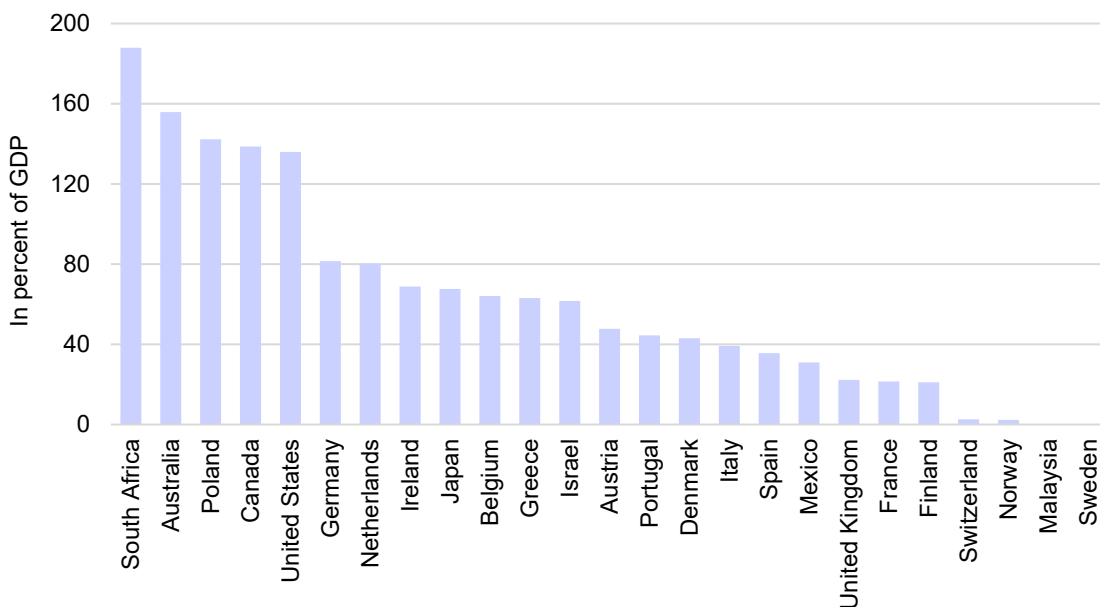
In this section, we analyze the financial impact of transition risks for the disorderly scenario. The latter assumes that climate policies are not introduced until 2030³¹, leading to deeper emissions reductions than in the adverse scenario (*i.e.*, “orderly transition” scenario) Reaching net zero emissions in the second half of the century will require a deep transformation of the global economic system. The economies that are the most dependent on fossil fuels and fossil fuels technologies will be particularly at risk during the transition. National economies would make the mitigation efforts at the very last moment by using technologies of last resort (*i.e.*, backstop technologies), see our first study for more information. In the next section, we estimate the transition risks directly impacting debt dynamics.

5.1 Transition risks pressures on public finances in a disorderly transition scenario

In the “disorderly transition” scenario, climate change economic impacts due notably to mitigation efforts are expected to increase the government fiscal expenditures and then increase the debt-to-GDP ratio. Chart 16 highlights the various impacts of transition risks in this ratio. South Africa is projected to experience a debt-to-GDP ratio rise of almost 188 percentage points by 2050. In contrast to the results for the physical risks scenario, the “disorderly transition” scenario is expected to impact advanced economies more strongly than emerging market economies. In addition, the costs associated with a disorderly transition are expected to be much higher overall than under the “hot house world” scenario, especially since it is the advanced economies that have the most mitigation and adaptation efforts to do to reduce their GHG emissions.

Advanced economies, such as Australia, Canada, and the United States, would seem to pay a heavy price under this scenario, with increases of debt-to-GDP ratio of 156, 139, and 136 percentage points respectively by 2050. Other big players within the WGBI universe, like Germany (+82 percentage points) and Japan (+68 percentage points), could also be severely impacted.

Chart 16. Debt increase in the disorderly transition scenario by 2050



Source: Beyond Ratings.

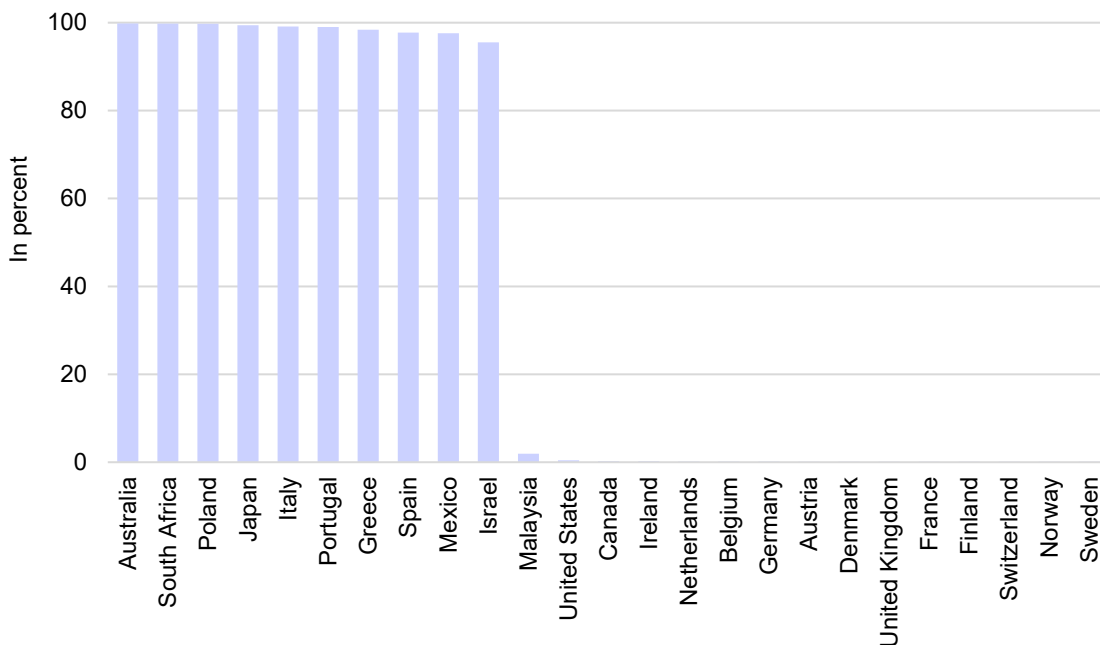
³¹ In the first part, the following hypothesis is questioned for some economies that will have to set up backstops technologies before 2030 because they will have exhausted their fossil resources or depleted their carbon budget.

However, this important pressure on public finances does not automatically translate into a significant impact on sovereign risk. Chart 17 illustrates this point with the scenario’s resulting default probability by 2050.

Since the WGBI universe is predominantly made up of advanced economies, which seem to be the most exposed to the risks of a disorderly transition (the magnitude of costs is higher in this scenario), the number of defaulting economies is higher than under a “hot house world” scenario. Overall, up to 10 economies could be expected to default (*i.e.*, Australia, South Africa, Poland, Japan, Italy, Portugal, Greece, Spain, Mexico, and Israel).

As for the “hot house world” scenario, there are differences in terms of financial resilience. Even if most economies in the WGBI universe are expected to experience a large increase in their debt-to-GDP ratio, some would still have enough fiscal capacity due to large default threshold estimates. For Italy, it appears that despite a smaller increase in its indebtedness linked to the need to finance the transition to a decarbonized economy (+39 percentage points, compared for instance to Germany’s 82), its limited access to fiscal support would be leading the country to experience episodes of high stress on its sovereign creditworthiness within just a few decades.

Chart 17. Default probability in the disorderly transition scenario, 2050



Source: Beyond Ratings.

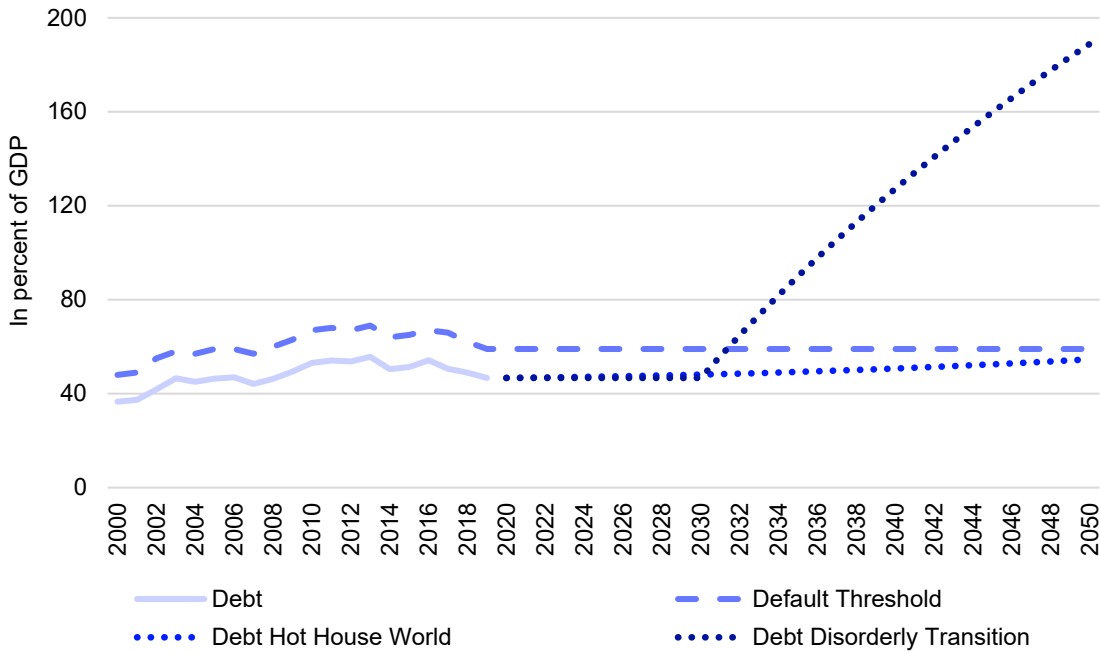
5.2 Climate change impacts from transition risks: Poland

Under the “disorderly transition” scenario, it is interesting to look at Poland, which is one of the first advanced economies projected to default. The transition risks seem to weigh heavily on the economy’s fiscal capacity, and for good reason, since Poland is the second largest coal-mining country in Europe (after Germany), and the ninth largest coal producer in the world. As of 2020, coal powered 74% of Poland’s electricity, but, in September 2020, the government and mining union agreed a plan to phase out coal production by 2049 in order to initiate the necessary transition to a more decarbonized electricity mix.

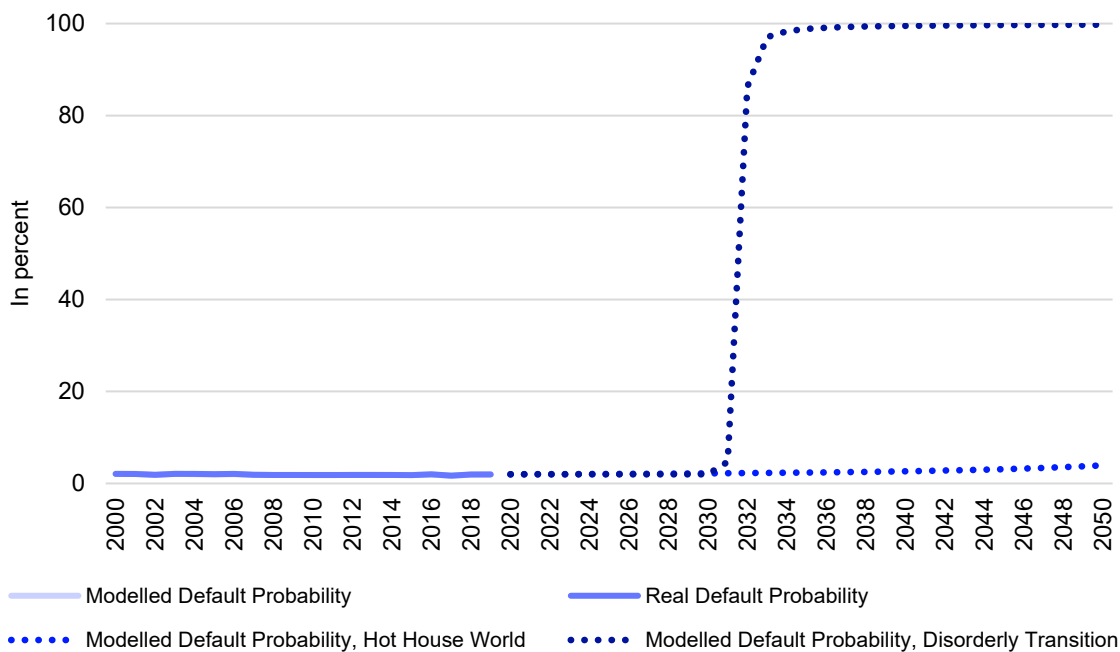
Moreover, given that the default threshold is relatively low (see Chart 18-a) compared to other economies, transition risks are expected to rapidly increase the economy’s indebtedness and, under that scenario, Poland could experience an upward trend in its default probability around 2033 (see Chart 18-b).

Turning to sovereign bond yields and returns, it is important to focus on the period prior to this possible default. Over the two to three years before 2033, the additional indebtedness linked to transition risks would result in a quick increase in bond yields (see Chart 18-c) and a commensurate decrease in annual returns (see Chart 18-d) over the same period. Poland could, therefore, experience episodes of high stress on its sovereign creditworthiness at the end of that period. According to these estimates, and like Malaysia, the sequence of events is highly dependent on how much fiscal space there will be in the economy.

Charts 18-a. Climate change impacts on debt dynamic – Poland



Charts 18-b. Climate change impacts on default probability – Poland



Charts 18-c. Climate change impacts on sovereign yields – Poland

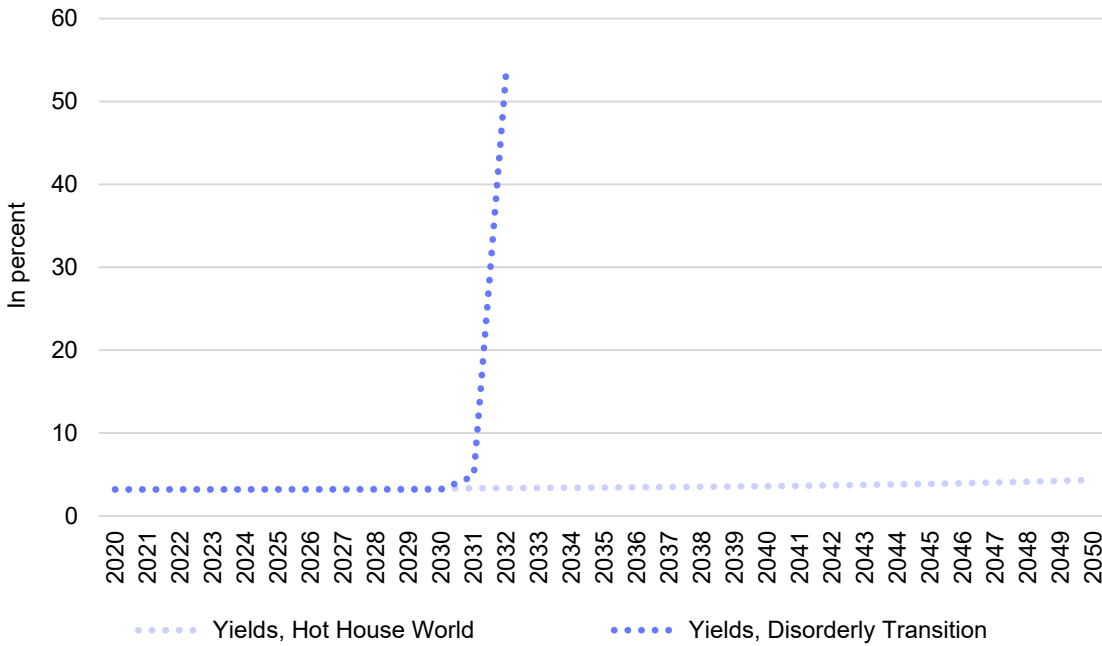
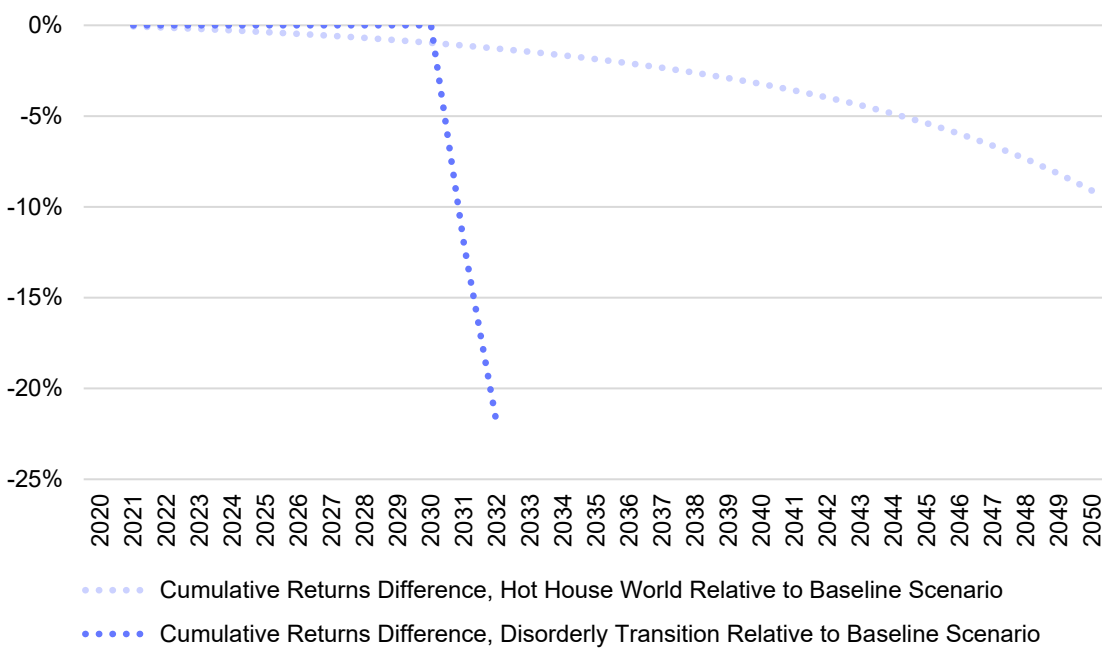


Chart 18-d. climate change impacts on cumulative returns – Poland



Source: Beyond Ratings.

Conclusion

The results highlighted in this paper are based on a forward-looking approach focused on the two distinct “hot house world” and “disorderly transition” scenarios, which are compliant with the NGFS framework. The results from the analysis in the first part of this series have been used in this second study to evaluate the financial costs from global warming.

The modelling approach focuses on the costs of climate change from the point of view of public indebtedness, using a theoretical framework of the debt limit and its effects on the default probability. A financial model then translates these effects into sovereign bond yields and returns for economies that make up the WGBI universe.

Several observations emerge from this paper:

- The absolute costs associated with climate change are expected to be much higher for the transition than the physical risks in countries within the WGBI universe.
- Sovereign debt sustainability could be more challenged for some countries than others. In the run-up to COP 26, it further highlights the complexity of reconciling the various national interests and strategies when addressing global crises and accounting for their costs.
- Regarding the costs associated to the “hot house world” scenario, it appears that a few economies would be impacted. But the fiscal capacity of these economies could be insufficient to absorb the shocks from physical risks.
- On the other hand, if large abatement costs (associated to the “disorderly transition” scenario) could cause default risk for some big players in the index (such as Australia, Japan, or Southern European countries), advanced economies seem to have sufficient fiscal capacity to absorb these costs without stressing their creditworthiness (*e.g.*, the United States, Germany, and France).
- While physical risks could start to impact bond returns as early as 2030, by 2050 the projected decline in returns are globally comparable in both scenarios in the WGBI universe.

Turning to further research on this topic, several areas for improvement should be considered. First, scenarios other than worst case would have to be analyzed, such as the “orderly transition” scenario. Second, the results of our first study could be enriched and extended to other economies. Third, and as mentioned earlier, the modelled results for sovereign bond yields and returns remain dependent on the methodology developed in the financial model. The fiscal space theory and the debt threshold estimates could be challenged, notably by making the default threshold an endogenous variable.

However, further research notwithstanding, the main potential trends highlighted in this paper can already be taken into account by the financial sector to better anticipate the financial impacts of both physical and transition risks.

Appendix

Appendix A – Climate change impacts on debt dynamics

The debt-to-GDP dynamic can be described by the following accounting identity:

$$b_t = b_{t-1} - bb_t$$

Where b_t is the debt-to-GDP ratio and bb the budget balance.

Assuming that bb is such that, in absence of climate damages or transition costs, $\Delta b_t = 0$.

In this report, the following impacts of CC on debt dynamic are considered:

- In the **hot-house world scenario**, damages³² would impact the debt dynamic by lowering fiscal revenues with $-bb_t - D_t$
- In the **disorderly transition scenario**, abatement costs³³ are assumed to be fully funded by the government and then would add to the budget balance: $-bb_t + \Omega_t$

Appendix B – Default probability model

The aim of the model is to compute a probability of default of sovereign, using the notion of default threshold. The default threshold is defined as the maximum debt-to-GDP ratio which can be redeemed by the government without default (Collard et al., 2015³⁴, 2016³⁵).

In this definition of default as a market event, default occurs in period $t + 1$ only if:

$$v^{max} < b_t$$

Where v^{max} is the default threshold as a fraction of GDP.

That is, the government defaults when the debt to be repaid in period $t + 1$ (RHS) is higher than the maximum resources available for the government for that purpose (LHS). Rearranging the first equation, default occurs when the GDP growth rate g_{t+1} is such that:

$$g_{t+1} < b_t - v^{max} \equiv g_{E,t+1}$$

Where $g_{E,t+1}$ denotes the minimum critical GDP growth rate necessary to avoid default.

The probability of default at b_t is then such as:

$$PD(b_t) = \varphi(g_{E,t+1})$$

Where φ is the Cauchy cumulative distribution function. This differs from the standard normal distribution used in Collard *et al.* (op. cit.)

v^{max} (the default threshold) is calibrated such as the computed probability of default matching the magnitude and the order of the historical probability of default. Here the default threshold is then exogenously determined, compared to the endogenous default threshold in Collard *et al.* (op. cit.).

³² Where D_t is the impact of temperature increase on GDP growth.

³³ Where Ω_t are the abatement costs-to-GDP ratio.

³⁴ Collard, F., Habib, M., & Rochet, J. C. (2015). Sovereign debt sustainability in advanced economies. *Journal of the European economic association*, 13(3), 381-420

³⁵ Collard, F., Habib, M. A., & Rochet, J. C. (2016). The reluctant defaulter: a tale of high government debt.

Appendix C – Calibration and data for the default probability model

Three main data are used in the calibration process. Historical GDP growth rates and debt-to-GDP ratio are taken from the World Bank and the International Monetary Fund databases.

Regarding the historical default probability, a more elaborated process is used:

- Historical credit ratings with accompanying outlooks (positive, stable, negative) are retrieved for the three main CRAs
- Credit ratings are transformed in default probability, according to a conversion rule adapter/interpolated from *Standard & Poor's* cumulative default rate for sovereigns at the 5-year horizon
- An average historical default probability is computed with the default probability derived for each CRA.

Regarding the conversion rule from credit rating to default probability, the initial conversion rule is taken from a *Standard & Poor's* report³⁶. In this report, cumulative historical default rates for sovereigns are given for the period 1975-2018, by notation grade. Following a process used by Polito and Wickens (*op. cit.*), default probability for thinner credit ratings are obtained by linear interpolation, and a non-nil default probability is assigned for higher grades, for the sake of the computation.

Appendix D – Sovereign yields

In order to determine a sovereign premium spread pricing, based on our default probability, a simple version of the Hull equation is used, such as:

$$s_t = PD_t(1 - RR)$$

Where s_t is the sovereign spread (credit risk premium only, in basis points), PD_t is the probability of default and RR is the expected recovery rate. The expected recovery rate is fixed at 40%. This simplistic pricing equation helps to understand analytically what the impact of CC on sovereign bonds could be (here a credit spread, without taking into account any maturity factor).

Finally, yields are computed such as:

$$y_t = r + s_t/100$$

Where y_t is a yield, r is a risk-free rate fixed at 2%.

Appendix E – Sovereign bond returns

In order to determine returns (from bond price evolution) from yield movements, the modified duration and the convexity need to be determined.

Modified duration uses the yield-to-maturity and maturity as inputs, such as:

$$d_t = \frac{1}{y_t} \left(1 - \frac{1}{(1 + 0.5y_t)^{2*m}} \right)$$

With d_t the modified duration and m the bond maturity (for convenience, a constant maturity is used here).

Convexity is such as:

$$c_t = \frac{2}{y_t^2} \left(1 - \frac{1}{(1 + 0.5y_t)^{2*m}} \right) - \frac{(2 * m)}{(y_t(1 + 0.5y_t))^{2*m+1}}$$

Then, the investment return over period t is computed as:

$$r_t = y_{t-1} - d_t(y_t - y_{t-1}) + \frac{1}{2}c_t(y_t - y_{t-1})^2$$

³⁶ *Standard & Poor's*, 2018 Annual Sovereign Default And Rating Transition Study, 2019.

Where r_t is the return. This equation shows that if the yield does not change, the two terms on the right equal zero and the return is the yield at the beginning of the period. Then increases in the yield will reduce the return.

This helps to understand what the potential impact of CC on sovereign bonds returns could be: as damages would affect the strength of the economy, probability of default could increase and then force the interest rate up. As mentioned previously, increases in the yield reduce the associated return.

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