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Stress Testing the Global Economy to Climate Change-Related Shocks in Large and Interconnected Economies

Yeu Jin Jung, Camilo E. Tovar, Yiqun Wu, and Tianxiao Zheng

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WORKING PAPER

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Strategy, Policy, and Review Department

Stress Testing the Global Economy to Climate Change-Related Shocks in Large and Interconnected Economies*

Prepared by Yeu Jin Jung, Camilo E. Tovar, Yiqun Wu, and Tianxiao Zheng

Authorized for distribution by Delia Velculescu

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ABSTRACT: We stress test the global economy to extreme climate change-related shocks on large and interconnected economies. Our analysis (i) identifies large and interconnected economies vulnerable to climate change-related shocks; (ii) estimates these economies' external financing needs-at-risk due to these shocks, and (iii) quantifies the spillovers to the global economy using a global network model. We show that large and interconnected economies vulnerable to climate change could trigger a drain of \$1.8 trillion in international reserves (2 percent of 2019's global GDP). Domestic and multilateral macroeconomic policies can help reduce these global losses to about \$0.8 trillion. The scenario highlights the importance of considering global spillovers when assessing the impact of climate change-related shocks.

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I. Introduction

Climate change has become an existential issue. Global temperatures have increased at unprecedented levels over the past 40 years and are expected to increase by 1.5°C by 2030 and by 2.2 to 3.5°C by 2100 (IPCC, 2022). While there is uncertainty about the specific development and speed of climate change, these trends will lead to a significant increase in the frequency and severity of extreme weather events, such as heat waves, droughts, and floods (IMF, 2020a). Aside from inflicting devastating natural disasters, climate change is changing the pattern of diseases and mortality of the global population.

Not surprisingly, the number of countries suffering from the adverse impacts triggered by climate change is increasing. While many small economies have been the most affected by climate change, no country will be spared from these trends. Extreme weather events over past couple of years, including record-breaking rainfalls and floods in China and Western Europe (e.g., Germany), or the scorching heatwaves in Asia (e.g., India), South and North America (e.g., Brazil, Canada, the United States, and the United Kingdom), confirm the exposure of large economies to climate change-related shocks.

Extreme weather events and climate-related disasters—once considered tail-risk events—are becoming more frequent and need to be carefully analyzed. Evidence increasingly shows that climate change-driven events could adversely impact natural capital, result in the destruction of infrastructure, disrupt livelihoods, and cause mass migration, with devastating humanitarian consequences (IMF, 2019a). Climate change also has profound implications for the health and safety of the global population. Recent analyses have shown that the risk of infectious diseases increases around five-fold in the year following a heatwave event such as El Niño (WHO, 2020).¹ Furthermore, extreme weather-related events have proven to trigger severe and persistent output losses across the globe. For example, the damage associated with natural disasters in the small states of the Caribbean and the Pacific is estimated at an average of 2-3 percent of GDP on an annual basis (IMF, 2019d). In the longer run, the per capita GDP of a representative low-income country could be 9 percent lower in 2100 than what it would have been in the absence of temperature increases (IMF, 2017).²

Climate pose large risks to the global economy. Currently, they are ranked among the top risks in likelihood and impact over the next ten years by the World Economic Forum (WEF, Global Risks Report 2022). Recent studies have shown that sovereign risk and climate change risks are interwoven, and extreme weather has often played a prominent role in sovereign default episodes (Mallucci, 2020). Extreme climate-related event reduces governments' ability to issue debt and restricts their access to financial markets. Evidence shows that financial markets have already started to price-in the risk of climate change on sovereign debt (Zheng and Tovar, 2022).

Despite the increasing evidence about the adverse economic and financial effects of climate change, the magnitude and channels through which climate change operates are not clearly understood. As a result, it is

¹ Going forward it may also increase the likelihood of new costly and deadly diseases and pandemics (Stanford Woods Institute for the Environment, 2019).

² Other studies estimate that a 1°C rise in temperature in a given year can reduce that year's annual economic growth by about 1.3 percentage points, with both level and growth effects that persist in the medium term (Dell et al., 2012), or that a persistent increase in average global temperature by 0.04°C per year would reduce, in the absence of mitigation policies, world real per capita GDP by more than 7 percent by 2100 (Kahn et al., 2019).

difficult to draw conclusions about the role and effectiveness of policy responses. A key challenge is that the effects of climate change occur with varying intensity across the globe and tend to materialize slowly, albeit in a cumulative manner. This implies that gradual climate change developments—e.g., global warming and shift of weather patterns (such as precipitations)—impose non-negligible economic impacts in a longer horizon and can be easily overlooked in short-term analyses.

In this paper, we stress test the global economy to severe country-specific climate change shocks. That is, climate change events (e.g., floods, heat waves, draughts) that manifest themselves as economic shocks, that outstrip the capacity of an economy to cope with them. Indeed, the macroeconomic vulnerability of a country to climate change shocks hinges on the country's preparedness and capacity to cope with the shock, say, through adaptation actions (IMF, 2018). Since there is no single instrument measuring climate change, we use a range of indices to identify countries' that are vulnerable to climate change-related shocks. In contrast to most of the literature which has focused on the impact of climate change on small economies, our analysis concentrates on economies that are large, interconnected, and vulnerable to climate change shocks. To identify these economies, we use a dataset covering 63 economies, representing around 80 percent of global GDP. To the best of our knowledge, this paper constitutes the first attempt to quantify, and stress test the global economy to a country-specific climate change-related shock using risk management tools and a global multilayered network model. This framework allows to quantify the economic and financial spillovers and contagion while considering the role of domestic and multilateral macroeconomic policy responses.

The global stress test scenario analysis is designed as follows. First, we identify economies vulnerable to climate change that are large and interconnected to global trade and finance. Climate change vulnerability is captured by their sensitivity, susceptibility, capacity to cope, and to adapt to climate change. Next, we narrow down the list of large, interconnected and climate-change vulnerable economies that have an external financing position that is exposed to climate change-related shocks. To this end, we use a novel forecasting methodology—building on the risk management concept of value-at-risk—that quantifies the conditional effects of climate change-related shocks on the full distribution of external financing needs of these economies. Finally, we quantify these spillover effects on the global economy and its systemic impact as captured by the global losses in international reserves. Our global stress scenario is a tail risk, in which countries, due to their weakened capacity to access international financial markets following climate change-related shocks, see their capacity to service their external debt impaired. This triggers default, contagion, and spillovers across the global economy.

We employ a novel multilayered network model that considers trade and financial linkages across the global economy and other amplification mechanisms operating through sovereign risk premiums to assess the global spillover following the country-specific climate-change related shocks (Porter et al., 2022 a, b and Ramadiah et al., 2022). The model embeds domestic policy responses in the form of monetary and fiscal policies and multilateral financing support through the global financial safety net (i.e., financing through bilateral swap lines, regional financing arrangements, or the International Monetary Fund).

The results of our scenario show that some large and interconnected economies, are very vulnerable to climate-change related shocks due to their broad exposure of their economy (e.g., infrastructure, food systems, human habitats) and their inadequate preparedness (e.g., economic, governance, social).³ This exposure and vulnerabilities, together with their high degree of interconnectedness could result in sizable losses to the world

³ The name of these economies are not disclosed due to potential market sensitivities.

economy following extreme climate-related events. Particularly, the shock can result in wider external financing needs, which undermine market access to external financing, and impair these economies' capacity to service debt. This in turn could trigger default, contagion, spillovers, and other cascading effects that undermine the stability of the global economy.

Our scenario results show that following a climate change-related shock (e.g., record breaking floods or droughts), there is a 50 percent probability that external financing needs in two large economies emerging economies could exceed \$19 billion (5 percent of GDP) and \$342 billion (12 percent of 2019 GDP). Due to the size and degree of interconnectedness of these economies, these larger external financing needs can impair these economies' capacity to access financial markets and trigger a default. Global losses—as captured by the aggregate global losses of international reserves—could reach up to \$1.8 trillion in the absence of any macroeconomic policy action. Exchange rate and fiscal consolidation in line with historical patterns seen in IMF programs could help reduce these losses to about \$1.2 trillion, and multilateral financing support through the global financial safety net, including IMF financing, could further reduce these losses to about \$0.8 trillion. The analysis has important implications for academics and policy makers alike. First, current economic and financial estimates appear to be underestimating the overall effects of climate change-related shocks. We show that localized effects of climate change in a tail risk scenario can have large systemic effects on the world economy. These economic and financial effects operate indirectly by magnifying countries' external vulnerabilities and triggering spillovers and contagion across the world economy. Second, we show that domestic macroeconomic policies are critical in helping contain these systemic effects. Third, multilateral cooperation and policies through the global financial safety net, such as the IMF, can play a key role in containing spillovers and contagion. Fourth, and quite importantly, the global benefits arising from individual countries' efforts for mitigation and adaptation to climate change are likely to be much larger than envisioned in the literature. These policies can help reduce external vulnerabilities and increase the resilience to climate change-related shocks and, therefore, minimize the potential for global economic and financial contagion and spillovers.

The remainder of the paper is structured as follows. Section 2 provides a literature review. Section 3 discusses various measures of climate change vulnerability and identifies large and interconnected countries vulnerable to climate change, whose potential external vulnerability is quantified in Section 4. Section 5 builds on the analysis thus far to stress test the global economy to climate change-related shocks using a multilayered network model. The final section concludes with policy implications.

II. Literature Review

A. Macroeconomic Impact of Climate Change

Studies estimating the macroeconomic impact of climate change generally focus on two channels (Batten, 2020). First, the literature looks at supply-side shocks that affect the productive capacity of the economy.

Examples include the price volatility arising from physical climate risks caused by shortages of commodities, such as food and energy, or the damage to the capital stock and infrastructure caused by the physical impact of climate change-related events (Batten et al., 2016, 2020). Second, climate change may also cause demand-side shocks, for example, by reducing household wealth, i.e., through destruction of household assets from natural disasters, and later private consumption. Investment can also be affected. On the one hand, investment

may increase due to reconstruction activities that follow climate induced natural disasters. On the other hand, investment may be adversely affected due to the uncertainty and financial losses induced by climate-change related disasters, especially if insurance coverage is imperfect (Batten et al., 2020).

The literature suggests that climate change tends to have a negative impact on potential growth. This is evident when examining the impact of climate change on the various sources of growth. Some studies have shown that productivity can decline by about 1.7 percent for each 1°C increase in daily average temperature above 15°C (Deryugina and Hsiang, 2014). Climate change can also have an adverse impact on the rate of productive capital accumulation, as it can induce permanent or long-term damage to capital and land (Stern, 2013), or by increasing its depreciation rate (Fankhauser and Tol, 2005; Keen and Pakko, 2011). Moreover, labor markets are affected by the deviation of weather behavior from the seasonal norms, which can affect both payrolls and the labor supply (Boldwin and Wright, 2015).

Central banks are already incorporating the impact of unusual weather conditions in their GDP forecast models (Batten et al. 2016). Examples include the Bank of England's assessment of unusual snow conditions on the retail, construction, and hospitality sectors (Bank of England, 2018), or the Fed's quarterly assessment of winter weather economic impacts (Gourio, 2015; Bloesch and Gourio, 2015). Central banks have also augmented with climate-related natural disasters their short-term, dynamic stochastic general equilibrium (DSGE) models used for forecasting output and inflation within the time horizon of monetary policy—2–3 years (Batten et al., 2016).

B. Policy Responses and Trade-offs

Policy makers and academics have actively recommended policies to contain the adverse effects of climate change. For instance, the IMF has called upon policy makers to limit the increase in temperature to at most 1.5°C, which is the level still considered safe for our planet. To this end, the IMF's Fiscal Monitor has suggested reducing fossil fuel CO₂ emissions through carbon taxes—levied on the supply of fossil fuels (for example, from oil refineries, coal mines, processing plants) in proportion to their carbon content (IMF, 2019). Specifically, a carbon price of 75 dollars per ton of CO₂ by 2030 would help deliver this goal.

However, climate policies encompass trade-offs and constitute another type of risk to economies across the world. In addition to the physical risks associated with the direct impact of climate change events, transition risks can emerge by-product of policy responses to counteract climate change—e.g., carbon pricing, environmental regulation policies, and trade policies.⁴ For example, CO₂ emission allowances pass-through to power prices, resulting in higher electricity prices for consumers (Fabra and Reguant, 2014; Hintermann, 2016; Lise et al., 2010). It has also been estimated that a carbon tax increase to \$75 a ton of CO₂ would boost average electricity prices by 45 percent cumulatively and gasoline prices by 15 percent for ten years (IMF, 2019c), with adverse effects for consumption and investment.⁵ Coal prices would also rise by more than 200 percent above baseline levels in 2030 (IMF, 2019c). In this context, it will be important to ensure that those groups that are most affected by climate can be compensated.

⁴ Physical risks: Extreme weather events driven (acute) or longer-term shifts (chronic) in climate patterns that give rise to damages to property, infrastructure, and land.

⁵ Higher energy prices from carbon tax would reduce investment and discourage consumption from carbon-intensive goods. Yet, the economic and distributional effects of a carbon tax critically depend on how the generated tax revenue is used.

Some countries are particularly vulnerable to transition risks. The shift from fossil fuels will transform economic production processes. Firms and their employees in energy-dependent sectors (e.g., aluminum, glass, chemicals, plastics, petroleum refining, pulp and paper, and steel), as well as people living in areas poorly served by public transportation, are vulnerable to higher energy prices. Some coal-mining communities and regions are especially at risk. Industries, workers, and communities whose livelihoods depend on fossil fuels may thus oppose reforms to mitigate climate change (IMF, 2019a).

Domestic transition risks can spillover to other countries. Environmental regulation and policies sometimes function as trade barriers. Broner et al. (2015) have examined the role of environmental regulations in determining the success of exporting to the United States in 85 industries from 101 countries for the year 2005. Their study finds that environmental regulations have a significant effect on trade flows and is comparable in magnitude to the effect of physical and human capital on trade flows. Also, climate change policies can lead oil firms to dynamically accelerate extraction, causing a downward shift of the oil spot price and value of oil firms (Barnett, 2019). This could cause major disruptions in trade for oil exporting countries.

While the primary responsibility for managing the transition to low carbon economy rests with governments, central banks and financial regulators are also starting to factor in transition risks from climate change due to its effects on financial stability. In doing so, they are developing policies to encourage climate-based credit risk exposures, so-called “climate stress tests” to assess the solvency of financial institutions across a range of future climate change alternatives (Campiglio et al., 2018).

C. Interconnectedness, Spillovers, and Contagion

Climate change-related events tend to have localized effects, but their impact can reach all economies across the world. Some studies have focused on the cross-border spillover effects of climate change on inflation. For example, extreme weather can impact global food production, and the impact could spill over to the rest of the world if the exporting countries impose export restrictions. Volatility in agricultural production and trade could spark a sharp increase in international food prices and translate into high inflation (Olovsson, 2018). Other studies find that exogenous international food commodity price shocks have a strong impact on consumer prices in the euro area, and these shocks can explain on average 25 to 30 percent of inflation volatility (Peersman, 2018).

The financial sector is an important shock amplifier. There is evidence that losses from natural disasters in insurance markets are increasing (IMF, 2019b). For instance, 26 percent of all losses arising from the world’s largest natural disasters between 1980 and 2015 were covered by insurance policies. Losses from one or more sufficiently large and concentrated events could cause financial stress and/or bankruptcy of insurance companies. Weakened value of real estate collaterals due to climate change risk could negatively affect the banking system’s balance sheet (Olovsson, 2018). Such indirect effects of climate change can spill over to a wider range of economies, as more countries are exposed to increased default risk or loan portfolios with lower values of assets. In capital markets, climate change-related risk rose further on the investor agenda in 2016, and a 60 percent majority of asset owners are now taking action to respond to climate change risks (Asset Owner Disclosure Project, 2017).

Investors in financial markets have started to price in long-term climate risks as for a low-carbon future. For instance, empirical analysis has shown that the long-run temperature elasticity of equity valuations is significantly negative and long-run temperature fluctuations carry a positive risk premium in equity markets

(Bansal et al., 2019). There is also evidence that markets are already pricing in climate-related considerations on sovereign risk (Zheng and Tovar, 2022).

Using network models to assess the effects of climate change can help to adequately consider feedback effects between different actors (e.g., portfolios, institutions, sectors, or countries), including those arising from policies that affect interconnected actors. However, few studies use such models to assess the effects of climate change. One study is Battiston et al. (2017), which uses a network-based climate stress-test methodology and applies it to large Euro Area countries to show that large portion of investors' equity portfolios—particularly for investment and pension funds—are directly and indirectly exposed to climate-policy-relevant sectors. The study also shows that the portion of banks' loan portfolios exposed to these sectors is comparable to banks' capital. At the macroeconomic level, Stolbova et al. (2018) develop a methodology based on financial networks to analyze the transmission of shocks induced by climate policies on the financial sector and the real economy. Nonetheless, we are not aware of any attempt to use this approach to stress test the effects of climate change at the aggregate global macro level, as done in this paper.

III. Vulnerability to Climate Change

In this section we use various indices to identify large and interconnected economies that are vulnerable to climate change-related shocks. We then establish the impact of climate change on the external vulnerability of these economies by assessing how the full distribution of global financing needs shifts with climate change-related shocks.

A. Definitions

An economy's vulnerability to climate change is a multidimensional and complex concept. The Intergovernmental Panel on Climate Change (IPCC, 2014b) defines climate change vulnerability as an economy's "*propensity or predisposition to be adversely affected*" by climate change. Moreover, the IPCC establishes that "*vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt*". The definition thus highlights that climate change vulnerabilities should be assessed comprehensively to reflect not only losses but also the capacity to react.

The macroeconomic vulnerability to climate-change induced natural disasters hinges on economies' conditions (IMF, 2018). In particular, the adverse effects of climate change events on economic activity and production capacity tend to be larger in economies where key economic sectors are dependent on weather conditions and where private insurance markets are underdeveloped. Typically, these conditions are more prevalent in geographically or economically small economies, which are relatively less interconnected with the rest of the world. As a result, these economies tend to be less prepared to deal with climate change-related shocks.

By contrast, the economic impact of climate change has so far mostly been treated as a modest and localized event in larger economies, where some combination of private insurance markets and central budgetary resources tends to support disaster-hit regions. Indeed, large economies have successfully contained negative impacts within their territories. For example, Japan, the Philippines, and Germany were at the top of the list of the most affected countries in 2018, but the damages were well managed within these countries and did not cause significant spillovers. Nonetheless, events in recent years have shown that large economies can be highly vulnerable to the economic effects of climate change.

Thus, the adverse economic and financial effects of climate change-related shocks so far have remained relatively contained. Global losses from about 12,000 extreme weather events between 1999 and 2018 led to about 495,000 deaths and an economic loss of around \$3.54 trillion in purchasing power parity, about 2.5 percent of 2019's global GDP (Germanwatch, 2020). This relatively modest economic loss may be the reason why contagion and spillover effects of climate change have received little attention in the literature, and why until recently most of the attention in the media and across policy circles has focused mostly on small economies.

However, such complacency might not be warranted in the future, as an increasing number of advanced and emerging market economies are being exposed to climate vulnerabilities. A reinsurance company has estimated global economic losses of natural disasters at \$280 billion in 2021 (of which \$120 billion was insured). This exceeds the \$210 billion mark reached a year earlier, or the \$166 billion in 2019. In the United States these losses amounted to \$145 billion (of which \$85 billion were insured) and floods in Germany reached \$54 billion (of which \$13 billion were insured). This was the costliest natural disaster in Germany's history (Munich RE, 2022).

B. Measures of Climate Change Vulnerability⁶

Table 1 describes two alternative composite indices that measure an economy's vulnerability to climate change events. These are the University of Notre Dame's Global Adaptation Index (ND-GAIN) and the Global Climate Risk Index (CRI) by Germanwatch.⁷ These composite indexes consider a wide range of climate change related events, including temperature changes, precipitation, and heat waves. Since they differ substantially on how they capture an economy's vulnerability, they may lead to diverse views on its vulnerability to climate change.⁸

⁶ For more data on climate change, please visit Climate Change Indicators Dashboard (<https://climatedata.imf.org>), developed by IMF in collaboration with other international organizations. The dashboard covers a range of distinctive indicators on climate change and government policy.

⁷ Other studies use natural disasters as proxies to climate change. For example, the IMF (2019) identified 64 economies vulnerable to climate change-induced natural disasters based on the cumulative damages and countries' size. Economies are considered vulnerable if: (1) they experienced reported cumulative damage of at least 20 percent of GDP between 1998-2017 from natural disasters that each caused damage of at least 5 percent of GDP (EMDAT, IMF (2016a)); or (2) they were classified as being small states at extreme or high risk of experiencing natural disasters in IMF (2016a); or (3) they are in the top quartile of countries ranked by disaster vulnerability in the World Risk Index 2018 (World Risk Report, 2018). Three economies (Guinea, Liberia, and Sri Lanka) were added based on staff's judgment.

⁸ For the list of vulnerable economies, see Annex Table A.1.

Table 1. Assessing Country Vulnerabilities to Climate Change Risks

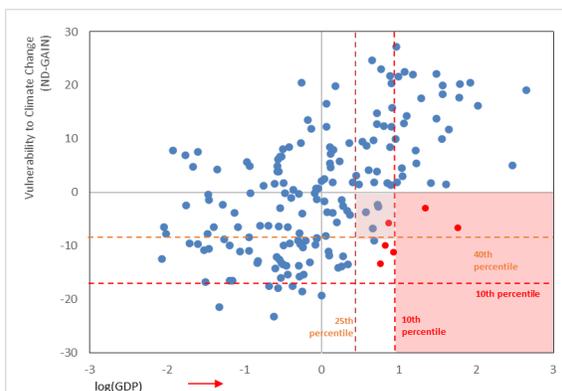
ND GAIN Index	Global Climate Risk Index
<ul style="list-style-type: none"> • The composite index captures both vulnerability and readiness of individual economies. <ul style="list-style-type: none"> - Vulnerability assesses propensity or predisposition of human societies to be negatively impacted by climate hazards. Vulnerability is assessed with six life-supporting sectors—food, water, health, ecosystem services, human habitat, and infrastructure. - Readiness measures an economy’s ability to make effective use of investments for adaptation actions thanks to a safe and efficient environment. Readiness encompasses investment climate (economic readiness), institutional arrangements (governance readiness), and social conditions (social readiness). • GDP related measures and data on recent climate change-related disasters are explicitly excluded. • Index scores are computed as: $ND\ GAIN\ score = (Readiness - Vulnerability + 1) * 50$ 	<ul style="list-style-type: none"> • Global Climate Risk Index (CRI) of Germanwatch analyses quantified impacts of extreme weather events, based on fatalities as well as economic losses both in absolute and relative terms—fatalities, fatalities per 100,000 inhabitants, loss in millions of \$ (PPP), and losses per unit of GDP in percent. • The CRI then creates an average ranking of economies in four indicating categories, with a greater weight on the relative indicators. • Example: Albania ranks 137th in fatalities, 130th in Fatalities per 100 000 inhabitants, 114th in losses and 87th in losses per unit GDP. The final score is computed as: $CRI\ Score = 137 \times 1/6 + 130 \times 1/3 + 114 \times 1/6 + 87 \times 1/3 = 114.17$
Source: Notre Dame Global Adaptation Initiative and Germanwatch .	

The ND-GAIN index appears to be best suited for estimating the global impact of a climate shock, as it takes a multidimensional perspective including the economy’s readiness to make effective use of investments for adaptation actions.⁹ As described in Table 1, the composite index captures both vulnerability and readiness of individual economies, which allows for a more comprehensive assessment of climate shocks. Economies with a higher readiness would be able to take adaptation actions by leveraging public and private sector investment. As such, the likelihood of cross-border economic and financial effects would decline. Hence, for the purposes of this paper, we mainly use the ND-GAIN index to identify large and interconnected economies that are vulnerable to climate change with potential systemic effects on the global economy.

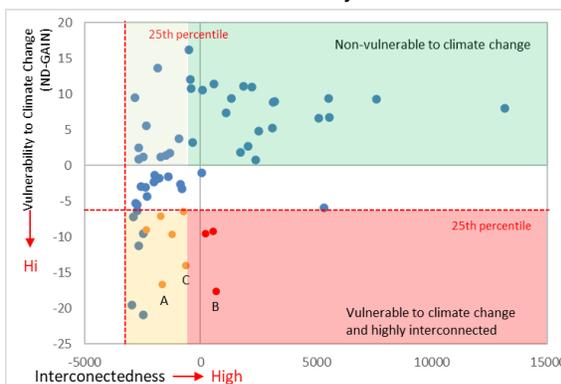
⁹ The readiness indicators include relatively long-term indicators such as political governance, doing business, social inequality, and education.

Figure 1. Economic Size, Interconnectedness, and Climate Change Vulnerability

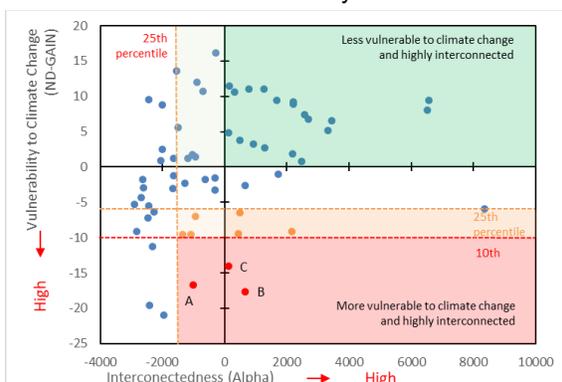
A. Economic Size and Climate Change Vulnerability



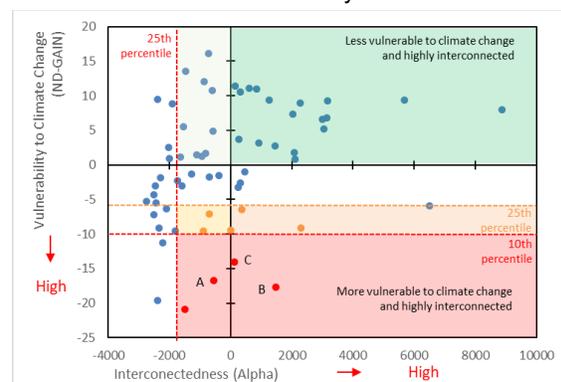
B. Financial Interconnectedness and Climate Change Vulnerability



C. Export Interconnectedness and Climate Change Vulnerability



D. Import Interconnectedness and Climate Change Vulnerability



Source: Definitions for ND-Gain Index see text. Economic size captured by GDP from the World Bank data (<https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?view=chart>). Interconnectedness indices correspond to the geometric average of the degree and strength of the network (see Porter et al, 2022). All figures expressed as deviation from sample average. Each dot represents a country.

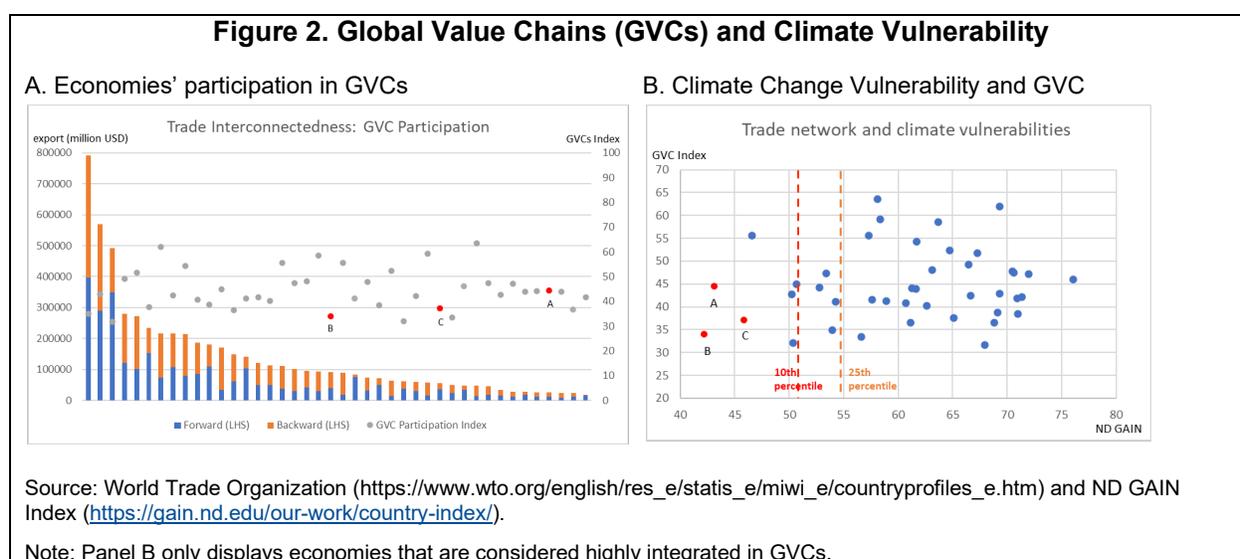
C. Identify Vulnerable Economies to Climate Change

We aim to identify large and highly interconnected economies that are vulnerable to climate change. Our sample includes 63 economies representing about 80 percent of 2018 global GDP. Figure 1 displays a scatter plot of the climate change vulnerability (as captured by the ND-Gain index) vis-à-vis (i) economic size (as captured by GDP); (ii) financial interconnectedness (as captured by a measure of the multilayered density of FDI, portfolio, and interbank positions); and (iii) export and import (as captured by a multilayered density of the bilateral flows of goods and services) interconnectedness.¹⁰ As shown in Panel A, we identify six large economies that are highly vulnerable to climate change (red dots). These economies are over the 75th percentile of the distribution of the ND-Gain Index and above the 90th percentile of economic size in the sample. Panels B

¹⁰ The measures of interconnectedness used here capture both the degree and strength of a network. See Porter et al, 2022 for a detailed discussion. For data sources, see Annex.

through D show that of these six economies, three—labeled as A, B, and C—display a substantial degree of financial and trade interconnectedness.¹¹

Based on this analysis, the remaining of the paper will focus on these three economies. Together these economies are large, representing about 5 percent of global GDP. They are also substantially interconnected, and as a result have the potential to amplify climate change-related shocks, triggering spillovers and contagion across the world via trade and financial channels.¹² These three countries represent 4 percent of world total imports. Furthermore, over 30 percent of their trade is directly linked to global value chains (GVCs), much of which corresponds to intra-regional GVC activities (WTO et al., 2019).¹³ Hence, in these economies, climate change-related shocks that adversely affect sectors linked to trade, in particular to GVCs, can reverberate and be amplified across the world (Figure 2).



IV. Climate Change and External Financing Needs-at-Risk

Building on the financial literature on value-at-risk and its applications to macroeconomic outcomes—e.g., the IMF's growth-at-risk (IMF, 2017)—it is possible to estimate the external financing needs-at-risk of an economy and how these are affected by climate change shocks.¹⁴ This forecasting methodology estimates the full

¹¹ See Annex for robustness check using alternative indicators of climate change vulnerability. For market sensitivity reasons, country names are anonymized.

¹² The Covid-19 crisis has shown how interconnectedness amplifies shocks through global value chains. Bonadio et al. (2020) found that about one-third of the total real GDP downturn in global economy after the Covid-19 outbreak was due to transmission through global supply chains.

¹³ List of the WTO's statistical profile, "the trade in value-added and global value chain."

¹⁴ External financing needs are calculated as short-term debt plus the amortization of medium- and long-term debt minus the current account balance.

conditional probability distribution of external financing needs (EFNs) at different forecast horizons as a function of domestic and global conditions, including climate change. Since the methodology provides the full distribution of countries' EFNs, it allows to distinguish between normal and extreme circumstances (e.g., tail risks).

To implement the methodology, we use quantile regressions to estimate the conditional density of the forecast distribution of each economy's EFNs as a function of climate change, current domestic variables, and global macroeconomic and financial conditions. Formally,

$$Q(EFN_{j,t+h}^q | \{X_{j,i}, C_{j,i}\}_{i \in P}) = a_j^q + \sum_i \beta_{j,i}^q X_{j,i,t} + \sum_j \gamma_{j,i}^q C_{j,i,t}$$

where $Q(EFN_{j,t+h}^q | \{X_{j,i}, C_{j,i}\}_{i \in P})$ is the conditional quantile (q) of the forecast distribution of the EFNs for each country j , h periods-ahead, as a function of current EFNs and current economic and financial conditions (X), and climate change indicators (C). The C block captures the economies' vulnerability to climate change proxied by the ND-GAIN climate vulnerability index and by the Germanwatch global climate risk index. In addition, we control for (i) domestic macroeconomic conditions using real GDP growth, inflation, fiscal deficit-to-GDP ratio, public debt-to-GDP ratio, external debt-to-GDP ratio, and the credit-to-GDP gap; (ii) financial conditions using the financial stability index used by the IMF Global Financial Stability Report (GFSR), the Chicago Board of Options Exchange (CBOE) volatility index (VIX), credit-to-GDP ratio, and real effective exchange rate; and, finally, (iii) global conditions are captured using world real GDP growth, U.S., and China's real GDP growth, and oil prices. All these variables are obtained from the IMF's International Financial Statistics, the IMF's World Economic Outlook database, the IMF's GFSR, and Haver Analytics.

The conditional quantiles are then sufficient to obtain an empirical estimate of the full conditional cumulative distribution function (cdf) of the external financing needs-at-risk ($F@R$). The probability distribution function (pdf) is then derived from the cdf, using the parametric skewed t-distribution. This allows to stay agnostic about the shape of the distribution of future EFNs and decide whether the climate change is assessed to be a macro-critical factor that might push the country in question to default. All estimates are obtained using a sample for the period 1999q1-2019q4, and the density forecast is estimated for four quarters-ahead (For an illustration of quantile regression results see Annex 3).

A. Econometric Results

Having identified which economies are vulnerable to climate change, we now aim to quantify the extent to which climate change-related shocks can affect their external financing positions. The four-quarter ahead $F@R$ density estimates for economy A and B are reported in Figure 3 (blue line). As shown, the EFNs of these economies—absent the effects of the COVID-19 pandemic—are forecasted to be relatively small, if any. According to our estimates, under the baseline estimate EFNs in economy A and B have a 50 percent probability of exceeding \$ 2 billion and \$ 25 billion, which is equivalent to 0.5 percent and 0.9 percent of GDP, respectively. We also estimate that should historical conditions remain in place there is only a 5 percent probability that these external financing needs will exceed \$ 16 billion and \$ 161 billion, i.e., 4.2 percent of GDP and 5.6 percent of GDP, respectively.

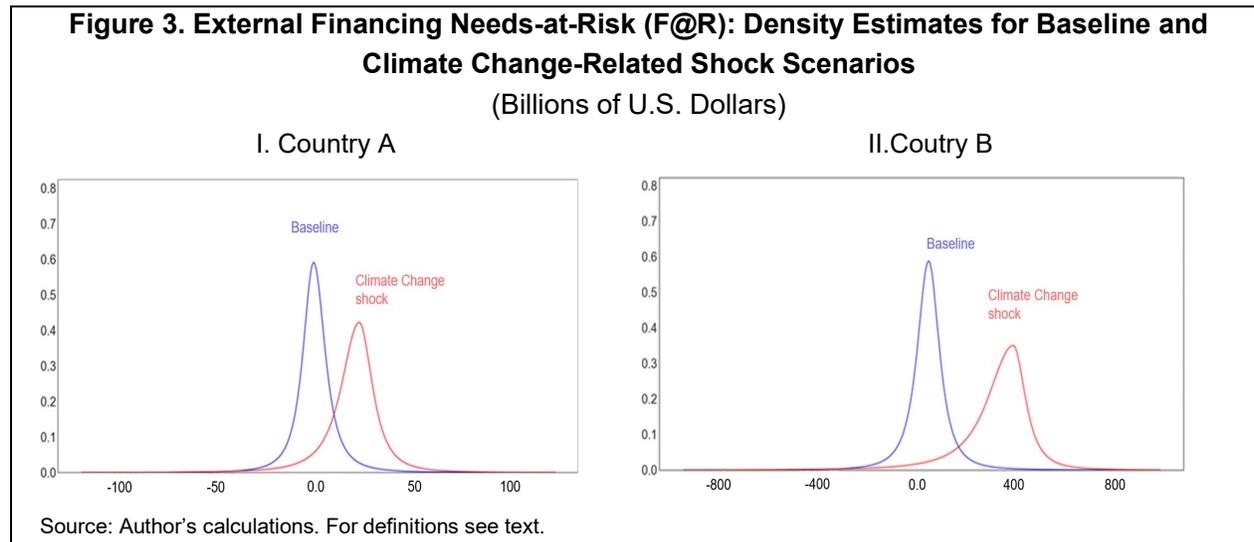


Figure 3 also reports the forecasted density following a two-standard deviation on the climate change-related shock (red line).¹⁵ The shock is applied to the ND-GAIN climate vulnerability index, implying the economy is becoming more vulnerable to climate change *ceteris paribus*.¹⁶ As shown, the shock induces a substantial shift in the distribution. The results indicate that following the climate change-related shock there is a 50 percent probability that external financing needs in country A would exceed \$19 billion and \$342 billion in country B, equivalent to 5.0 percent and 11.9 percent of GDP respectively.¹⁷ Estimates also suggest that there is only a 5.0 percent probability that EFNs will exceed \$ 40 billion in economy A and US\$ 494 billion in economy B, i.e., 10.6 percent of GDP and 17.2 percent of GDP.^{18,19}

¹⁵ The motivation using standard deviation to build the severity of adverse scenarios based on historical volatility of climate change shock. After applying the two-standard deviation, the values are still within the range of observed values in the sample.

¹⁶ Specifically, since the ND-Gain index is defined as $(Readiness - Vulnerability + 1) * 50$, then it is immediate to see that the shock to the index can be interpreted as being directly proportional to an economy's vulnerability to climate change affecting food, water, health ecosystem services, human habitat, or infrastructure (which are the key sectors of vulnerability in the index). In this respect, it is also worth highlighting that the Intergovernmental Panel of Climate Change (IPCC, 2021) has warned that economy B will suffer more frequent and intense heat and humid waves, extreme rainfall events and erratic monsoons, as well as cyclonic activities, among other weather-related calamities in the coming decades. For further details, see also the [World Bank Climate Knowledge Portal](#).

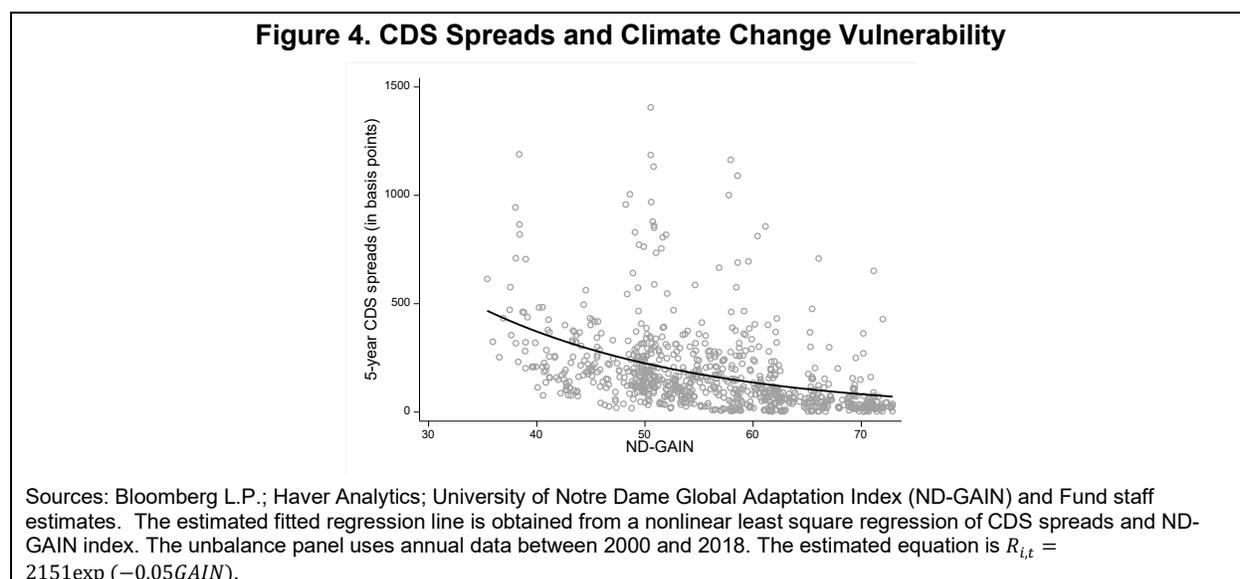
¹⁷ It is worth noting that that Floods are the single source of annual losses in economy B, costing about \$7 billion every year. Also, that a single weather-related event in economy A in 2013, killed more than 6,000 people, devastated nine regions, damaged 1.1 million homes, and triggered agricultural and infrastructure damages of \$802 million. See World Bank Climate Change Portal.

¹⁸ We must highlight that economy C's strong external position resulted in a positive external financing position and, therefore, its external position is not found to be vulnerable to a climate change-related shock as to trigger significant spillovers.

¹⁹ Climate change vulnerability for economies A and B have improved over the past decades according to the ND-GAIN index. See Annex 1 for more details.

V. Stress Testing the Global Economy to Climate Change-Related Shocks

So far, we have shown that economies A and B are large and interconnected and have external financing positions that are vulnerable to climate change-related shocks. That is, we have shown that their F@R can be substantial following a climate change-related shock. Existing studies have provided support to these findings. For instance, evidence shows that natural disasters in economy A could lead to high risks to debt sustainability. Besides lowering real GDP, climate-related events have damaged the country's fiscal capacity and worsened the current account (IMF, 2020b). Recent studies have also shown that sovereign risk and natural disasters are interwoven, and extreme weather has often played a prominent role in sovereign default episodes (Mallucci, 2020).²⁰ Extreme climate-related event reduces government's ability to issue debt and further restricts government's access to financial markets. The estimated non-linear relationship between sovereign spreads and climate change risk shows that the increase in sovereign risk premium would be particularly large for countries that are more vulnerable to climate change (Figure 4). Deterioration in market access can also impair countries' ability to meet its external debt obligations. In a highly interconnected economy, such an event can trigger spillovers and contagion, adversely affecting the global economy.



Our model explicitly captures the impact of a climate change-related shock induced default in country A and B and quantifies its systemic impact through global losses of international reserves. Specifically, we simulate the balance of payments dynamics as captured by the country's trade, net foreign asset, and liability positions (see IMF, 2017, Porter et al., 2022; Ramadiah et al., 2022). To adequately capture the systemic impact of climate change-related shock on the world economy, we also consider the external financing provided by the global

²⁰ This is especially true where climate-related events are particularly disruptive to the economy and affect a vast portion of the territory, or where the economic activity is concentrated in areas that are prone to extreme weather events, for instance, in many South and South-East Asian economies.

financial safety net (GFSN). That is, we consider any financial assistance provided by the GFSN as captured by bilateral swap lines, regional financial arrangements (RFAs), and the IMF.²¹

Formally, changes in foreign reserves, ΔR_i , in country i reflects the dynamics of trade revenues, net interest payments on foreign assets and foreign liabilities, exchange rate changes and net external financing from the GFSN:

$$\Delta R_{i,t} = \underbrace{\sum_{j \neq i} TB_{ij}(e_{ji,t-1})}_{\text{Trade revenues}} + \underbrace{\sum_{j \neq i}^{\in ND_t} a_{ij} r_{j,t} e_{j,t}}_{\text{Return on net foreign Assets}} - \underbrace{\sum_{j \neq i} a_{ji} r_{i,t} e_{i,t}}_{\text{Return on net foreign liabilities}} + \underbrace{EF_{it}}_{\text{GFSN financing}}$$

where a_{ij} denotes country i 's asset holding against country j , $r_{j,t}$ is country j 's specific interest rate on its liabilities, $e_{j,t}$ denotes the nominal effective exchange rate and EF_{it} is the external financing provided by the GFSN.

For each economy, changes in net foreign assets and liabilities and the trade balance can create liquidity needs. These can become solvency crises when economy h (or a set of economies) is unable to fulfill its external payment obligations.

In the setup, the cascading effect is triggered by the inability of economy A and B to fulfill their external obligations.²² This in turn affects the external revenues of its creditors, which see a decline in reserve levels.²³

Should the reserves level of an economy decline below a certain threshold, the economy would have to default on its external debt. This in turn, will impair other economies' ability to pay their external obligations. In our analysis, we assume that when reserves reach 80 percent of the IMF's assessed reserve adequacy (ARA) metric the economy stops servicing its debt.^{24,25} The total loss in international reserves across in each economy is equivalent to its exposure to the debt service amount that is not serviced, that is:

$$\Delta R_i = -a_{ih} r_{h,t} e_{h,t}$$

²¹ Given the country sample in this paper, the IMF financing refers to that provided by the General Resources Account (GRA) and would encompass financing instruments such as the Stand-by Arrangements (SBA), the Extended Fund Facility (EFF), the Rapid Financial Instrument (RFI), the Flexible Credit Line (FCL), and the Precautionary Liquidity Line (PLL).

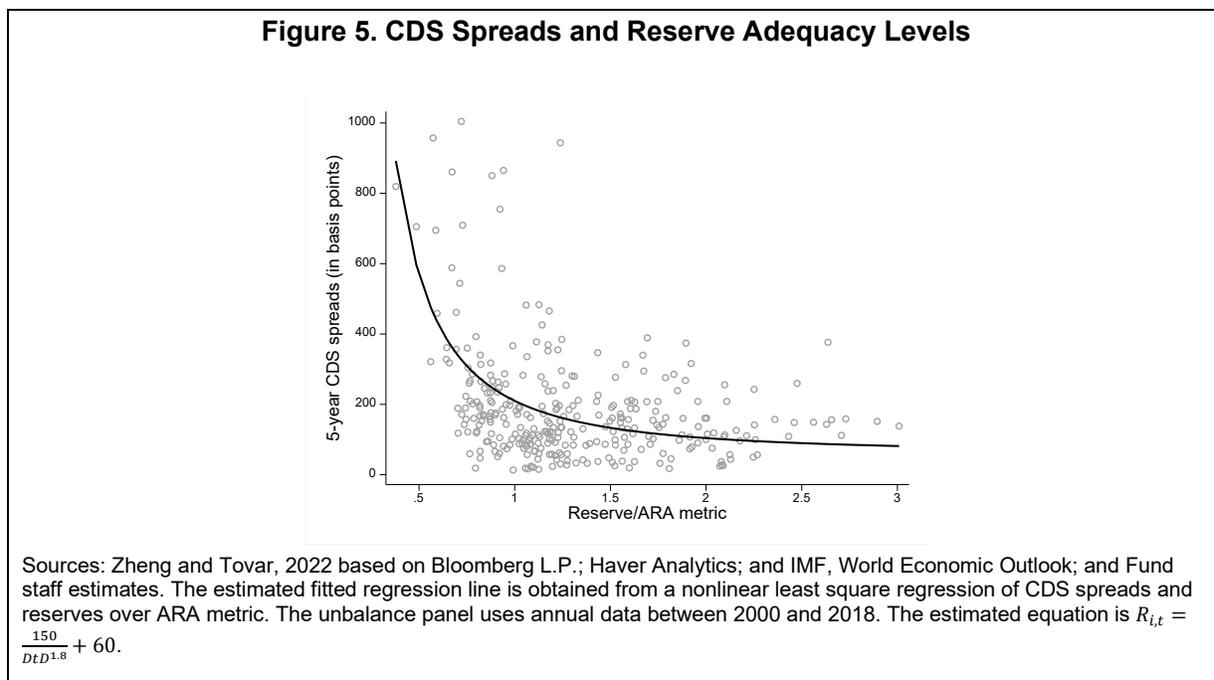
²² The impairment to meet external obligations is evident from the analysis showing that climate change-related shocks shift the distribution of external financing needs towards worse outcomes (Figure 3). Underlying this is a widening of the current account (e.g., due to a worsening of exports) or an increased debt burden. These factors also undermine access to international financial markets through their impact on sovereign debt spreads.

²³ Creditors have crossholdings of assets and liabilities with economy A and B.

²⁴ The ARA metric is designed to measure the balance of payments vulnerabilities that might arise if an economy were subject to an exchange market pressure (EMP) event. The metric captures vulnerabilities arising from four possible sources: (i) lower export income (X); (ii) lower rollover rates of short-term debt (at remaining maturity) (STD); (iii) non-resident capital outflows proxied by longer-term debt and equity liabilities (OL); and (iv) resident capital flight proxied by broad money (M2). See IMF, 2011, 2013, and 2015.

²⁵ Using a panel nonlinear least squares regression based on a sample of 81 economies between 2000 and 2018, we have found that sovereign risk premia increase rapidly as the ratio of reserves to ARA metric approaches 80 percent. For details on how the sovereign risk premium reacts to this measure of distance-to-default, see Zheng and Tovar (2022).

The banking stress testing literature has shown that direct exposures are not sufficient to assess the vulnerability of a banking network to external shocks (Porter et al., 2022). Therefore, the model also incorporates several amplification mechanisms operating through the risk premium. Specifically, we allow the risk premium to react to the *distance-to-default*, as captured by how far an economy's stock of international reserves is from the IMF's ARA metric. Figure 5 plots the non-linear relationship between economies' reserve adequacy and sovereign spreads based on a nonlinear least square regression. As shown, the increase in sovereign risk premium would be large for countries with inadequate reserve levels.



In addition, the model allows contagion to occur via asset price co-movements. Specifically, we allow the risk premium to react in a stepwise manner to changes in asset prices in economies falling into default. If an economy is financially distressed, markets may charge a higher risk premium to economies with similar risk profiles. This contagion mechanism has gained relevance as the international financial market has become more integrated and interconnected (for example see Balduzzi et al., 2001; Bae et al., 2003; Forbes and Rigobon, 2002). In this paper, this channel is calibrated according to the maximum changes in the sovereign risk premia during the 2013 Taper Tantrum episode.²⁶ To incorporate domestic policy responses, we allow currencies to depreciate by up to 10 percent per year and to carry out a fiscal adjustment program equal to 0.7 percent of GDP over two years. This is in line with the average observed adjustments in IMF programs prior to the COVID-19 crisis.²⁷ Multilateral policy responses are captured by the financing provided by the GFSN. Access to the GFSN is calibrated economy-by-economy. At the bilateral level, economies can access swap lines established bilaterally among economies. At regional level, economies can gain protection coming from

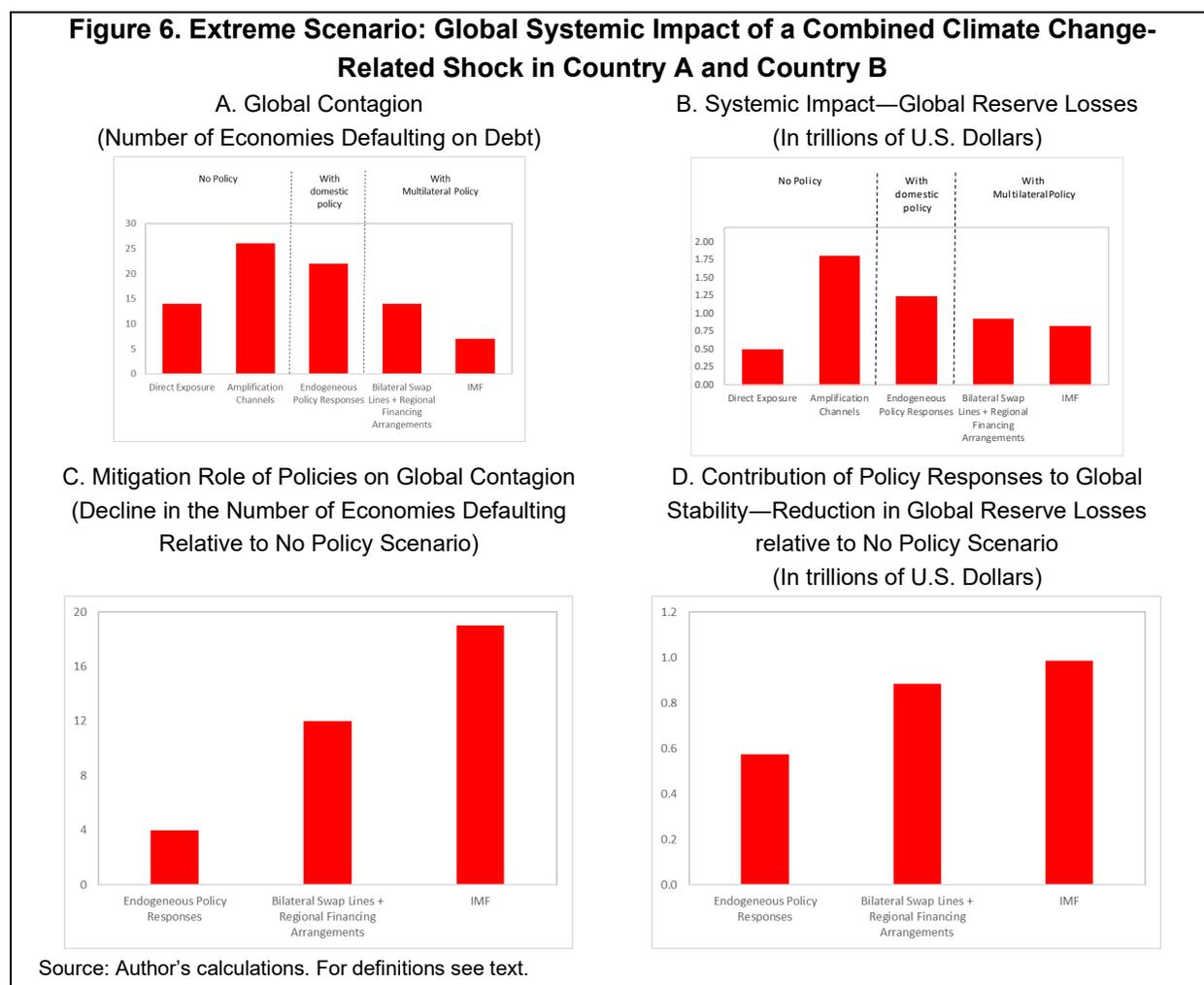
²⁶ For this exercise, we identify the correlation between 10-year bond yields, and we assume that if yields are highly correlated, there will be an increase in the interest rates equal to the maximum credit default swap (CDS) spread of the country involved in that period.

²⁷ It is important to keep in mind that domestic policy response and the design of adjustments vary according to each country's fundamentals, domestic institutional settings, and availability of external financing among others, including whether the country is under an IMF program or not.

RFAs. And finally, the IMF provides financing as a financial backstop without exceeding the economies' access limit.²⁸

A. Simulations Scenario Using the Multilayered Network Model

We now report simulations a tail risk scenario in which an extreme climate change-related shock triggers a default on economy A and B's external debt. For presentational purposes, the results are reported sequentially (Figure 6).



To keep track of spillovers and contagion, Panel A displays the number of economies that may be forced to default on payments, while Panel B reports the global reserve losses following the shock. In addition, we report the contribution from domestic and multilateral policies. Panel C shows the decline in the number of economies defaulting relative to the 'no policy' scenario and Panel D shows the reduction in global reserve losses relative to the 'no policy' scenario.

²⁸ For details of the network model, please see Annex 4 and Porter et al., 2022.

To describe the simulation results we start by considering the simplest contagion channel, i.e., economies' direct exposures. In this case, global reserve losses are relatively small (Panel B, first bar). However, these losses increase once we introduce other amplification channels. Reserve losses surge once the distance-to-default and asset price co-movement channels are in place (Panel B, second bar). We refer to this scenario as the '*no policy*' outcome. Due to the absence of the policy responses, contagion and the systemic impact of the shock are at their peak. In this scenario, 26 economies may default on their debt service, and reserve losses would reach \$ 1.8 trillion.

However, we would expect authorities in different economies to react to the economic and financial spillovers from economies A and B. Such policy response helps mitigate contagion (Panels A and C, third bar). Moreover, global reserve losses decline by about US\$ 0.6 trillion compared to the '*no policy*' scenario (Panels B and D).

Financing from the GFSN further contributes to the reduction of contagion and spillovers and reduces the systemic impact of the shock on the global economy. We find that financing provided by GFSN except the IMF would help reduce global reserve losses by over US\$ 0.3 trillion (Panel C, second bar). The IMF also significantly helps reduce contagion. This is evident in the substantial decline in the number of economies in default and global reserves losses relative to the '*no policy*' scenario (Panel C and D, third bar).

Climate change-related shocks can be costly and undermine global financial stability if they lead to sovereign defaults in large and interconnected economies. An extreme climate change-related shock in economies A and B could push seven other economies into default and trigger a global reserves loss of US\$ 800 billion even after all other financing avenues (domestic and external) have been utilized. This highlights the importance of interconnectedness and contagion when considering costs of climate change. Also, that economies need to pursue adequate adaptation and mitigation policies to climate change while ensuring sustainable macroeconomic policies that provide sufficient policy space to deal with spillovers.

VI. Conclusion and Policy Implications

Extreme climate change-related shocks have become more frequent and will do so in the future. These shocks are not only deadly but can also have deep economic implications. Moreover, to the extent that actions are not taken to revert global warming, climate change-related shocks in a more interconnected world will compound to amplify the effects of these and other shocks with underlying economic vulnerabilities.

While there are already many studies providing evidence of the negative macroeconomic impact of climate change, few assess the indirect effects of climate change through economic and financial spillovers and contagion. This paper contributes to the understanding of the impact of climate change-related shocks on the global economy by showing how in large and interconnected economies, climate change-related shocks can result in spillovers and contagion and have global systemic effects—even if its physical impacts are confined within individual economies.

Our simulations show that an extreme climate change-related shock in large and interconnected economies could have a systemic economic and financial impact on the global economy. In the absence of appropriate domestic and multilateral macroeconomic policy responses, the scenario results indicated that global losses as measured by the decline in global aggregate international reserve could reach \$ 1.8 trillion. To put these results

in perspective, these losses would be equivalent to nearly four times the size of the bailout packages for Greece, Portugal, and Ireland during European debt crisis.²⁹

However, our analysis highlights the importance of ensuring an adequate use of domestic macroeconomic policies and support from the global financial safety net. When fully deployed, these policies together can reduce the global reserve losses due to the climate change-related shock, by more than a half, to about \$ 800 billion.

Our analysis also suggest that current macroeconomic estimates are underestimating the potential losses due to climate change-related shocks that could arise from the indirect effects of spillovers and contagion and their feedback effects due to the interconnectedness of the global economy. This suggests that the global benefits arising from multilateral and individual economies' efforts on mitigation and adaptation to climate change are likely to be much larger than currently thought, as they would not only reduce the vulnerability of individual economies, but also reduce the likelihood of events that could trigger economic and financial spillovers. Moreover, a set of common global principles and disclosure standards would also help strengthen the assessment of climate risks and help in controlling cross-country spillovers (Ferreira et al, 2021).

Policies to mitigate and adapt to climate change policies are global public goods, and these warrant global collective efforts to help vulnerable countries build capacity to strengthen their readiness for climate events. Enhancing global safety nets can also contribute to limiting global losses.

²⁹ The size of the total bailout packages amounted to EUR 440 billion. See page 4 in <https://ieo.imf.org/~media/IEO/Files/evaluations/completed/07-28-2016-the-imf-and-the-crises-in-greece-ireland-and-portugal/eac-full-report.ashx>.

Annex I. Data Source

We use cross-country imports and exports as reported by Direction of Trade Statistics (DOTS), and each economies' balance sheet position against the rest of the world from: (i) interbank asset and liabilities positions as reported by the BIS Locational International Banking Statistics; (ii) portfolio investment positions from the International Monetary Fund's Coordinated Portfolio Investment Survey (CPIS); and (iii) foreign direct investment positions from the International Monetary Fund's Coordinated Foreign Direct Investment Survey.

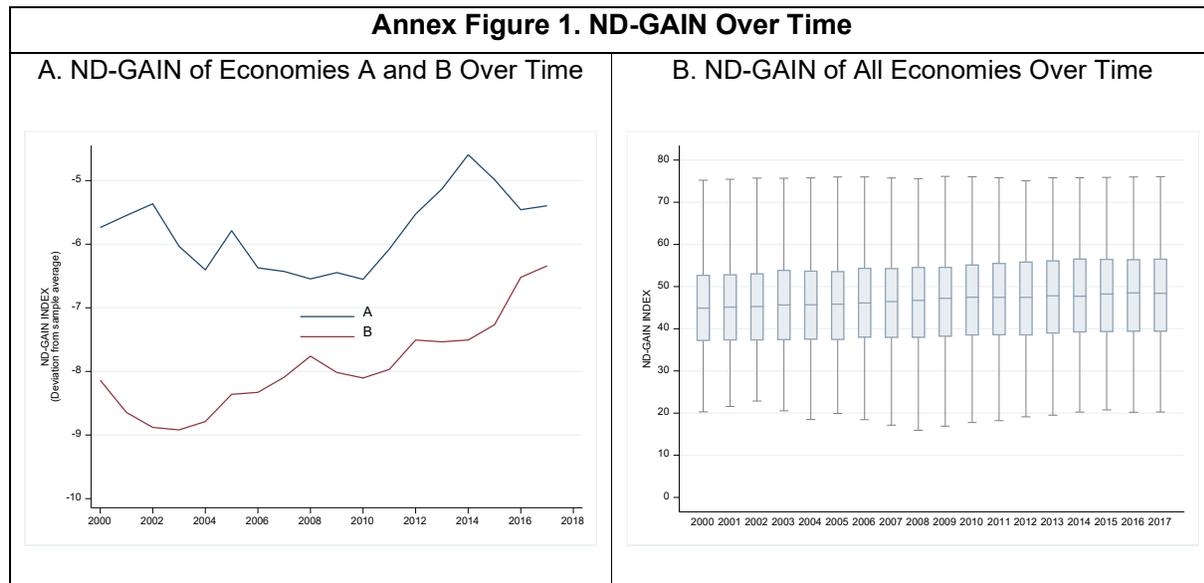
Annex Table A.1. Vulnerable Economies Identified by Various Studies

ND GAIN (89 Economies)	Global Climate Risk Index (98 Economies)	IMF (64 Economies)
Advanced		
None	Australia, Austria, Belgium, Canada, Taiwan Province of China, Czech Republic, France, Germany, Greece, Italy, Japan, Republic of Korea, Latvia, Netherlands, New Zealand, Portugal, Puerto Rico, Slovenia, Spain, Switzerland, United Kingdom, United States.	None
Emerging Market		
Algeria, Angola, Antigua and Barbuda, Belize, Bolivia, Botswana, Central Africa, Cuba, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Gabon, Guatemala, Guyana, India, Indonesia, Iraq, Lebanon, Libya, Libyan Arab Jamahiriya, Micronesia, Namibia, Pakistan, Paraguay, Philippines, Samoa, Seychelles, Sri Lanka, Suriname, Swaziland, Syrian Arab Republic, Tonga, Turkmenistan, Vanuatu, Venezuela.	Antigua and Barbuda, Argentina, Belize, Bolivia, Bosnia and Herzegovina, Brazil, Bulgaria, Chile, China, Colombia, Costa Rica, Croatia, Dominica, Dominican Republic, El Salvador, Fiji, Grenada, Guatemala, Hungary, India, Indonesia, Iran, Jamaica, Mexico, Micronesia, Mongolia, Namibia, Oman, Pakistan, Paraguay, Peru, Philippines, Poland, Romania, Russia, Samoa, Serbia-Montenegro-Kosovo, South Africa, Sri Lanka, St. Lucia, St. Vincent and the Grenadines, Thailand, The Bahamas, Tonga, Ukraine, Uruguay, Vanuatu, Venezuela.	Fiji, Indonesia, Maldives, Micronesia, Palau, Philippines, Samoa, Sri Lanka, Tonga, Tuvalu, Vanuatu, Antigua and Barbuda, The Bahamas, Belize, Chile, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Guyana, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Angola, Cabo Verde, Eswatini, Mauritius.

Annex Table A.1. Vulnerable Economies Identified by Various Studies (Concluded)

ND GAIN (89 Economies)	Global Climate Risk Index (98 Economies)	IMF (64 Economies)
Low-income and Developing		
Afghanistan, Bangladesh, Bhutan, Cambodia, Lao People’s Democratic Republic, Myanmar, Nepal, Papua New Guinea, Solomon Islands, Timor-Leste, Vietnam, Haiti, Honduras, Nicaragua, Djibouti, Somalia, Sudan, Tajikistan, Uzbekistan, Yemen, Benin, Burkina Faso, Burundi, Cameroon, Chad, Comoros, Democratic Republic of Congo, Republic of Congo, Cote D’Ivoire, Eritrea, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Madagascar, Mozambique, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Tanzania, Togo, Uganda, Zambia, Zimbabwe.	Afghanistan, Bangladesh, Burundi, Cambodia, Djibouti, Ethiopia, Haiti, Honduras, Kenya, Lao People’s Democratic Republic, Madagascar, Malawi, Mauritania, Moldova, Mozambique, Myanmar, Nepal, Niger, Nicaragua, Yemen, Sierra Leone, Solomon Islands, Tajikistan, Gambia, Uganda, Vietnam, Zimbabwe.	Afghanistan, Bangladesh, Cambodia, Kiribati, Myanmar, Nepal, Papua New Guinea, Solomon Islands, Timor-Leste, Vietnam, Haiti, Honduras, Nicaragua, Djibouti, Sudan, Tajikistan, Benin, Burkina Faso, Cameroon, Chad, Comoros, Gambia, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Mali, Mozambique, Niger, Sao Tome and Principe, Senegal, Sierra Leone, Zimbabwe.

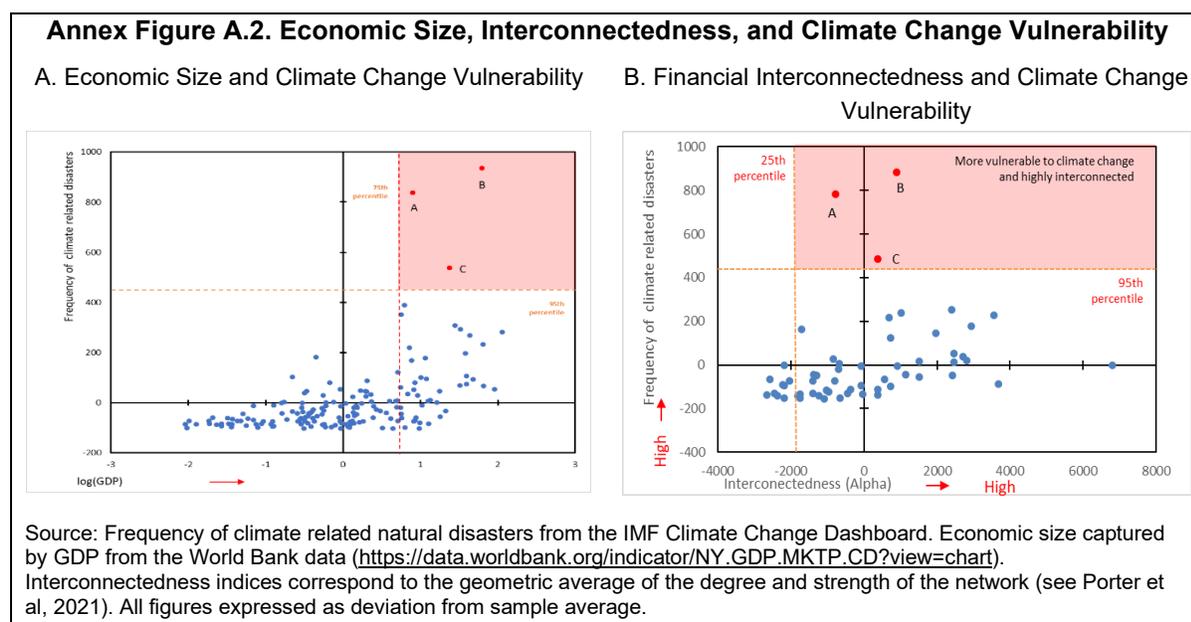
Annex Figure 1. ND-GAIN Over Time



Sources: University of Notre Dame Global Adaptation Index (ND-GAIN) and IMF staff calculations.

Annex II. Robustness Check

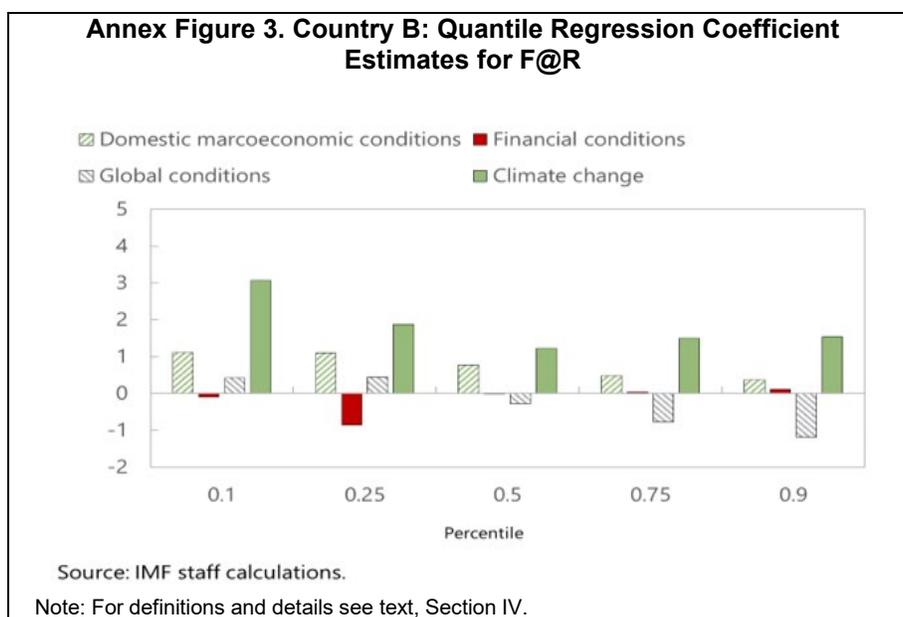
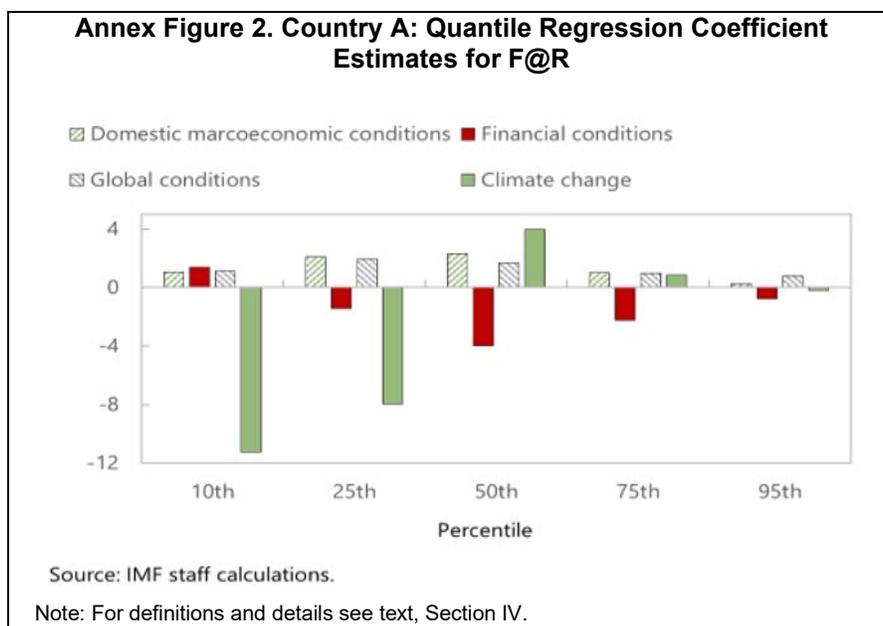
We use the frequency of climate related natural disasters from the IMF Climate Change Dashboard as an alternative indicator to ND-GAIN to capture economies' vulnerability to climate change. The dataset covers annual frequency economy level data on major natural disasters including drought, extreme temperature, flood, landslide, and storm. We investigate all types of natural disasters and compute the annual average number of natural disasters for each country. With this, we replot Figure 1 using number of climate related natural disasters instead of ND-GAIN.



As Figure A.1 shows, three large economies A, B, and C are highly vulnerable to climate change. These economies are large in economic size measured by GDP and are over the 95th percentile of the distribution of the number of natural disasters. Panel B show that of these three economies, also display a substantial degree interconnectedness, confirming the robustness of the results using ND-GAIN.

Annex III. External Financing Needs-at-Risk Quantile Regressions

This section reports the results of quantile regressions for the external financing needs-at-risk (F@R) for Country A and B, respectively.



Annex IV. Multilayered Network Model

This annex provides details of the multilayered network model.

The model allows to examine how economic and financial contagion spread through the global economy once an economy or group of economies deemed as highly vulnerable are subject to an exogenous shock to the return on their external liabilities. Spillovers to their counterparts' external financing needs emerge from direct trade and financial exposures and are amplified through changes in risk premia and asset price comovements, triggering cascading effects. To mitigate the contagion, the economies affected can implement domestic monetary and fiscal policies and tap into the layers of GFSN.

Formally, each economy (node in the network) i is endowed with foreign exchange reserves at $t = 0$ in an amount of R_{i0} dollars. Balance of payments dynamics—and hence the stock of foreign exchange reserves at any moment in time—in economy i are given by its trade and net foreign asset and liability positions against all its counterparts. The change in foreign exchange reserves of economy i at time t ($\Delta R_{i,t}$) can be described by the following expression:

$$\Delta R_{i,t} = \underbrace{\sum_{j \neq i} TB_{ij}(e_{ji,t-1})}_{\text{Trade revenues}} + \underbrace{\sum_{j \neq i}^{\in ND_t} a_{ij} r_{j,t} e_{j,t}}_{\text{Return on net foreign Assets}} - \underbrace{\sum_{j \neq i} a_{ji} r_{i,t} e_{i,t}}_{\text{Return on net foreign liabilities}} + \underbrace{EF_{it}}_{\text{GFSN financing}}$$

where a_{ij} denotes economy i 's asset holdings against economy j ,¹ $r_{j,t}$ is economy j 's specific interest rate on its liabilities, $e_{i,t}$ is the nominal effective exchange rate, and $EF_{it} = EF_{BSA;i,t} + EF_{RFA;i,t} + EF_{IMF;i,t}$ is the external financing provided by the various layers of the GFSN.

In the network, a liquidity crisis emerges when economy h (or a set of countries) is hit by a shock to its external liabilities and, in an extreme case, it is unable to fulfill interest payments due, $a_{ih,t}r_{h,t}$. This implies that international reserves decline for all economies with exposure to economy h . Assuming an economy remains current on its obligations with others ($i \in ND_t$)—which denotes the set of non-defaulting economies—the initial financing need, fulfilled by the drawdown of available foreign exchange reserves is equivalent to its exposure to the 'defaulted' amount, $\Delta R_{i,t} = -a_{ih,t}r_{h,t}$.² If reserves are depleted or fall below a certain threshold, the economy fails to fulfill some of its payments on external liabilities. This means that economy's external financing needs exceed its available resources (stock of foreign exchange reserves above the established threshold). In such case, it can resort to other layers of the GFSN. Once accessing those resources (the catalytic role of the IMF), the residual constitutes a potential call for Fund resources.

¹ Economy i 's asset holdings and liabilities denoted by a_{ij} include FDI, portfolio investment, and cross-border interbank positions (see further details on the data description section below).

² As in IMF (2017), we assume for simplicity that the trade balances of all countries are in equilibrium initially, consistent with stable net foreign asset positions and reserves. This implies that a default does not trigger additional reserve losses through the trade channel. This assumption is relaxed once we introduce endogenous policy responses through exchange rate and fiscal adjustment (see Porter et al., 2022).

The model incorporates two amplification mechanisms that compound direct contagion effects: sovereign risk premia, and asset price comovements. The first amplification mechanism aims to capture the observation that borrowing costs are a function of an economies' capacity to repay (or, more broadly, its economic fundamentals). In the model, risk premia are sensitive to an economies' *distance-to-default*, captured by the difference between its stock of international reserves and its reserve adequacy (ARA) metric. As an economies' reserves approach the ARA threshold, its sovereign risk premium increases, making borrowing more costly. The second amplification mechanism mimics the observation that occurs when economies under financial distress trigger increases in the risk premia of other economies with similar risk profiles as perceived by investors. In the model, this is calibrated using interest rate correlations and CDS shifts during periods of financial stress driven by exogenous shocks (e.g., the so-called Taper Tantrum).

The model allows for economies to tighten monetary policy and implement fiscal consolidation measures aimed at mitigating contagion effects. It also accounts for the Fund's catalytic role by incorporating other layers of the GFSN. On monetary policy, it allows for currencies to adjust by up to 15 percent cumulatively during the first two years in which an economy sees its counterparts not servicing their debt obligations. On fiscal policy, the model allows economies to carry out a once-and-for-all fiscal adjustment program equal to 1 percent of GDP. The fiscal adjustment improves the trade balance by 0.5 percent of GDP through reduced imports, and partially offsets the amplification effects. Finally, the model allows for economies to draw from the GFSN (EF_{it}) to support their liquidity needs. The first sources of financing correspond to bilateral swap lines ($EF_{BSA,i,t}$) and RFAs ($EF_{RFA,i,t}$), when available. Drawdowns on these credit lines support reserve accumulation up to a limit determined by the economies' maximum access in each layer of the GFSN. RFAs included in the analysis are: European Stability Mechanism, European Financial Stability Facility, European Financial Stabilization Mechanism, EU Balance of Payments Assistance Facility, Chiang Mai Initiative Multilateralization, BRICS Contingent Reserve Arrangement, Latin American Reserve Fund, Arab Monetary Fund, Eurasian Fund for Stabilization and Development. The demand for Fund resources is a residual after accounting for these sources of external financing.

Data and Coverage of the Network Model

The network model uses 2019 data for 63 economies (36 advanced and 27 emerging market) representing about 85 percent of global GDP on: (i) cross-economy imports and exports as reported by *Direction of Trade Statistics* (DOTS); (ii) interbank asset and liability positions as reported by the *BIS Locational International Banking Statistics*; (iii) portfolio investment positions from the International Monetary Fund's *Coordinated Portfolio Investment Survey* (CPIS); and (iv) foreign direct investment positions from the International Monetary Fund's *Coordinated Foreign Direct Investment Survey*. The last three sources summarize each economy's balance sheet position against the rest of the world. The model also employs cross-economy data on nominal bilateral exchange rates, sovereign spreads, interest rates, foreign exchange reserves, as well as access to bilateral swap lines, RFAs, and Fund financing. The data are obtained from various sources, including Haver, Bloomberg, the International Monetary Fund's International Financial Statistics, the U.S. Federal Reserve System, and RFAs websites.

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