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We Are All in the Same Boat: Cross-Border Spillovers of Climate Risk Through International Trade and Supply Chain

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Abstract

Are assets in a landlocked country subject to sea-level rise risk? In this paper, we study the cross-border spillovers of physical climate risks through international trade and supply chain linkages. As we base our findings on historical data between 1970 and 2018, we observe that globalization increased the similarity of countries' global climate risk exposures. Exposures to foreign climatic disasters in major trade partner countries (both upstream and downstream) lower the home-country stock market valuation for the aggregate market and for the tradable sectors. We also find that exposures to foreign long-term climate change risks reduce the asset price valuations of the tradable sectors at home. Findings in this paper suggest that climate adaptation efforts in a country can have positive externalities on other countries' macrofinancial performance and stability through international trade.

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I. INTRODUCTION

Are assets in landlocked countries subject to sea-level rise risk? Are financial sector valuation and risk in Latin American countries subject to typhoon risk in East Asia? These questions have become highly relevant in today's global economy. Globalization has brought about significant economic benefits to countries around the world, but has also fundamentally altered how the risks of nature, especially climate-related risks, are shared, allocated, and priced. Through the sophisticated international trade system, a climatic disaster that disrupts economic activities in any part of the global supply chain network can have non-negligible impact on the macrofinancial performance and stability of other countries that are connected to the network. Understanding the cross-border spillover of climate risks (that is, the likelihood of climatic disasters) helps assess the implications of long-term climate change on the macrofinancial stability in individual countries, and inform collaborative measures in climate adaptation due to their positive externalities through the supply chain¹.

The COVID-19 pandemic and associated government lockdown measures provide a recent example of how a disaster (a public health disaster in the case of COVID-19) in one country can disrupt global economic activities by putting a pause on the international flows of goods, services, and people. Applying a new machine-learning technique to the real-time Automatic Identification System signals sent by global cargo ships, Cerdeiro and others (2020) find that Chinese exports declined by 30 percent from late January to early March 2020, when China imposed the COVID-19 lockdown. They also observe a second wave of global trade decline starting in early April 2020, when the US and many European countries followed up to enforce lockdown measures. Baldwin and Freeman (2020) refer to these patterns as global supply chain “contagion and reinfection.” When cross-border flows of goods, capital, and people are disrupted by disasters (or necessary policy measures due to disasters), all countries connected to the international trade network incur negative economic effects. Even if a country is free from the virus or has brought the virus under control, it still suffers from the negative supply and demand shocks from the foreign countries currently battling the virus.

Climatic disasters may have similar implications on the global supply chains. Climatic disasters in one country can destroy local physical and human capital and shut down roads and factories. Meanwhile, they disrupt economic activities in other countries that rely on the disaster-hit country for imports and exports. The severe floods in Thailand in 2011, which claimed hundreds of lives and affected millions locally, effectively put a halt to automobile parts production and assembly in the country. As a result, Japanese carmakers that used Thailand as a key supplier in Southeast Asia had to pause their car production and sales globally. For instance, a report² finds that “Toyota’s three plants in eastern Thailand were unaffected by the weather, but production was halted due to parts shortages.” The Japanese headquarters was affected as well. Toyota claimed that it had to cut car production in Japan by a total of 6,300 vehicles due to the flood in Thailand, a sizable number even compared with the 37,500-unit direct loss from Toyota’s

¹ In our paper, which studies the propagation of shocks, we define “climate risk” broadly as the risk of climatic disasters, such as hurricanes and floods, occurring. “Climate change” could change the magnitude, frequency, and geographic allocation of climatic disasters and hence climate risk.

² See <https://www.cbc.ca/news/business/thai-flooding-disrupts-auto-supply-chains-1.1049854>.

damaged plant in Thailand³. Stock market returns of the Japanese automobile industry also reflected the impact of the disaster. The cumulative stock market return in the automobile sector in Japan was -8.7 percent, from 20 days before the Thai flood to 40 days after the Thai flood⁴.

As a second example, Cerdeiro and others (2020) also find that Hurricane Maria, which caused a severe landfall in Puerto Rico in 2017, reduced offloading vessel traffic in Puerto Rico by as much as 75 percent, disrupting international trade. It took about 10 days for the vessel traffic to recover to normal. These examples show that globalization increased the sophistication of the global supply chain and made firms and consumers highly connected globally and vulnerable to foreign risks. When evaluating a sector, firm, or country's financial risk related to climate change or assessing any associated policy measures, it becomes necessary to incorporate the exposures to foreign climate-related disasters and risks through international supply chain linkages.

This paper studies these questions by examining the spillover of climate risks across country borders through trade. We introduce a conceptual discussion on how to characterize the exposures to global climate risks through international trade, and empirically investigate how asset prices reflect these exposures. The paper proceeds in the following four steps: First, for each country (the home country), the paper constructs its upstream (that is, the countries that sell to the home country) and downstream (that is, the countries that buy from the home country) climate risk exposures, combining metrics of climate vulnerability (for example, historical damages, exposures to future climate change risks) and the country's trade patterns (upstream and downstream trade shares with all trade partners including the home country). With these exposure measures, we construct a pair of global spillover indexes of upstream and downstream climate risks. The spillover indexes capture the extent globalization reduces the cross-country dispersion in exposures to global climate risks. Intuitively, consider a landlocked country *a* in the high latitudes. If country *A* was a closed economy, it might have limited exposures to many climate-related risks, such as sea-level rise and tropical cyclones. In this case, opening to trade with the countries in the low-latitude Pacific countries would increase its global climate risk exposure. On the contrary, an island country *B* in the Pacific likely has high exposure to climate-related risks by itself, whereas opening to trade with other countries may diversify away its high exposure. Consequently, cross-country dispersion of climate risk exposures has decreased with globalization, suggesting that all countries are becoming similar over time in terms of global climate risk exposures.

Second, based on an event study approach and on historical climatic disasters, the paper studies empirically the stock market price response to foreign climatic disaster exposures by the aggregate market and individual sectors. We focus on the response in the disaster-hit country's

³ See <https://www.claimsjournal.com/news/international/2011/10/27/193931.htm> and <https://www.marketwatch.com/story/thailand-floods-hit-toyota-north-america-output-2011-10-27>. Toyota's Thai plants produced 630,000 vehicles in 2010. Therefore, the direct loss and the indirect loss in the Japanese headquarters from the Thai flood was about 6 percent and 1 percent of Toyota Thai plants' total output – a non-negligible fraction. The key point made with the calculations, though, is that the indirect loss from the cross-border spillovers is considerable compared with the direct loss.

⁴ The disaster date was documented as November 3, 2011, in EM-DAT. We compute the cumulative returns in the Japanese automobile sector stock price from October 7 to December 29. The cumulative return in the Japanese market index over the same period was -0.7 percent.

major exporting and importing partners. We find that the aggregate stock market is negatively affected by foreign climate shocks through both upstream and downstream trade linkages. On average, the aggregate stock market index experiences a drop of 0.5 percent from 20 trading days before to 40 trading days after a large foreign climatic disaster, in both upstream and downstream. The impact on sectoral stock returns varies across sectors and is significant for most typical tradable sectors. For the automobile sector, for instance, the negative impact can be as high as -2 percent immediately following a climatic disaster in the upstream foreign country. Note that these estimates reflect the effect of an average climatic disaster in the largest trade partner country. The total impact would be larger if we consider large foreign climatic disasters and if we add up the impact of disasters in all trade partner countries.

Next, we examine whether the size of the shock, the trade shares, and sector characteristics affect the degree of cross-border spillovers of climate shocks. We find that, for the average sector, the magnitude of foreign disaster exposure is indeed negatively associated with the stock market response at home. However, the association differs with respect to sectors, is negative and significant for most tradable sectors, but is not significant for most non-tradable sectors. Inspired by these observations, we formally show that the tradability of sectors (defined as the ratio of total value of imported inputs or total exports to the sector's total value-added) is a key determinant for the degree of cross-border spillovers. Given the magnitude of the disaster, the sectors that are more tradable in terms of importing respond more negatively to upstream disasters, and the sectors that are more tradable, in terms of exporting, respond more negatively to downstream disasters. These results further confirm that the spillover channel is through trade linkages. As the financial sector is often exposed to risks in all sectors, we also examine the effects of climatic shocks on financial sector stock prices and the role of institutional factors in the country, such as the degree of international trade guarantees and financial sector capitalization. We find that a higher degree of international trade guarantees for domestic firms and a higher ratio of total capital to risk-weighted assets seem to be associated with lower impact from climate risk spillovers.

Lastly, the paper examines whether exposures to future foreign climate change risks through international trade are reflected in countries' sectoral stock market valuations. Higher exposures of a sector to trading partners that have high climate risks (for example, a higher expected frequency of climatic disasters) imply greater risk to the operating cashflows and profitability of the sector. As a result, the stock market valuation of a sector with high cross-border climate risk exposure is likely lower. We empirically investigate this relationship by linking standard valuation metrics such as a price-to-earnings ratio (P/E ratio) at the sector level to exposures of foreign climate change risk. We find higher foreign climate change risk exposures are associated with lower P/E ratios. The relationship is particularly strong for tradable sectors. We separate the effects of getting more exposed to the high climate risk foreign countries from the effects of openness to trade with all foreign countries. We show that these results are not simply driven by openness to trade.

We assemble a comprehensive dataset for large climatic disasters, bilateral trade dynamics, and sectoral stock valuation and returns in a sample of 68 countries between 1970 and 2018. Among these countries, 34 are advanced economies, and the other 34 are emerging markets and developing economies. For climatic disasters, we include floods, storms (hurricanes), droughts,

wildfires, and extreme temperatures that were recorded by an international dataset for disasters Emergency Events Database (EM-DAT) and exclude small disasters below certain thresholds defined by the IMF⁵. For international trade relationships, we construct cross-country exposure to climate risks weighted by corresponding bilateral trade volumes/shares based on data from UN Comtrade. For sectoral stock prices and returns, we rely on daily sectoral stock returns and valuation metrics from Datastream. Our sample covers 26 sectors ranging from automobile, telecommunication, and banking sectors to retail, healthcare, and leisure/travel sectors.

We identify international trade as an important channel to propagate climate shocks, by focusing our analysis on largest trade partner countries and by distinguishing tradable sectors from other sectors. We effectively turn down other potential channels (such as financial spillovers through global capital flows, spread of natural disasters based on geographical proximity, among others) that do not have asymmetric effects between trade partner countries and other countries, as well as between tradable sectors and other sectors. Although they are unlikely the driving factors for the results found in this paper, we note that these other possible channels may exist—we leave them for future research.

This paper assumes the global trade partnership and network are resilient to climatic disasters in the short run⁶. This assumption is reasonable, as globalization in recent decades is a process (driven by, for example, better technologies of international trade, lower global tariffs, China's opening up, the end of the Cold War, and so on) most exogenous to considerations of climate change risks (more details about this assumption appear in Section I.B). Admittedly, climatic disasters and climate change risks, if they are severe enough, may affect international trade networks in the long run. For example, a country might deliberately decouple from climate risks by concentrating their supply chains on countries that are equally little affected by climate change⁷. Instead, this paper provides a partial equilibrium view of how climate risks are spilled over in the cross section of countries through a fixed global trade network.

Our paper contributes to the existing literature in a few ways. First, it focuses on the role of international trade in propagating climatic disasters and climate change risks across country borders. It provides a conceptual framework for examining the distribution of climate risks globally and the important role of international supply chain. Second, the paper provides

⁵ For a climate event to be considered a disaster, it has to satisfy at least one of the following criteria: (1) 10 or more deaths; (2) 100 or more people affected; or (3) the declaration of a state of emergency and/or a call for international assistance. Following the IMF Global Financial Stability Report (GFSR) and to exclude tiny disasters, we further restrict the sample to those that had a rate of affected population greater than 0.5 percent or damage greater than 0.05 percent of GDP.

⁶ This assumption allows that a downstream country may import less from the upstream foreign countries hit by a climate disaster or negatively impacted by climate change risks, and an upstream country may export less to the downstream foreign countries hit by a climate disaster or negatively impacted by climate change risks. In fact, the assumption is based on the gravity model of international trade (with more details in Section I.B). The assumption rules out, though, if a country deliberately decouples from a foreign country in perception of its higher climate risks or adjusts trade in ways that drastically depart from the predictions of the gravity model.

⁷ If this is the case, we may exaggerate the negative impact of foreign climate risks.

empirical estimates of the sectoral stock returns in response to foreign climatic disasters. Identification is further strengthened by conducting placebo tests on non-major trading partners and examining the roles of tradability to explain the heterogeneous sectoral returns. We also examine how financial sector capitalization and international trade guarantee have a role in determining the impact of foreign climate shocks on the domestic financial sector health. Last but not least, most previous works studying the propagation of climate shocks focus on the response in specific firms, whereas this paper finds that foreign climatic disasters and risk exposures affect aggregate stock market valuations on the country and country-sector level and have macrofinancial implications.

This paper also contributes to the important policy discussion surrounding climate change adaptation. It is often argued that a country's climate change mitigation efforts, such as decarbonization policies, in general could have positive externalities on other countries' resilience by slowing down global warming and the associated rising frequency and intensity of climatic disasters⁸. Critics of these policies, though, argue that decarbonization efforts in high-carbon economies (for example, with many fossil fuel producers), if implemented with international pressure or the introduction of carbon border adjustments by their main trade partners, are likely to have a severe contractionary effect on the home economy. The paper, however, shows that climate change adaptation efforts, such as enhancing a country's resilience of factories, roads, and ports against adverse climate shocks, also have significantly positive externalities on other countries by reducing the negative spillovers of climate risks through the highly connected and integrated global trade and supply chain networks. The contraction effects from adaptation efforts may not be as large as mitigation, and debt sustainability may be improved if the adaptation programs are partly or fully funded by the country's trade partners. The trade partners have the incentives because the monetary benefits for themselves could be substantial, given we find that exposures to foreign climatic disasters and foreign climate risk could undermine the valuations of the aggregate stock market and the tradable sectors in a significant and economically sizable way. There is a rationale to address climate change adaptation in a multilateral framework, as helping other countries, especially trade partners, to build resilience against climate shock also enhances home countries' climate resilience. In fact, from a global climate change adaptation perspective, because of the existence of cross-country spillovers documented in this paper, optimal adaptation efforts likely require collective action in a multilateral framework.

The paper complements the ongoing analytical work agenda of central banks and financial regulators (such as the Network of Central Banks and Supervisors for Greening the Financial System (NGFS)) on investigating the relationship between climate change and financial stability. While the paper focuses on physical climate risk, the conceptual framework and analytical method are applicable to the understanding of transition risk related to climate change. To study the spillovers of transition risk, the climatic disasters need to be replaced by climate transition shocks such as announcements of regulatory changes and policies related to carbon emissions. In addition to the expenditure shares of all goods and services, one would also need to incorporate the carbon intensity for each sector and in each bilateral trade relationship.

⁸ For example, see IMF (2019) *Fiscal Monitor* on the discussion of how carbon tax policies can help overcome externalities associated with carbon emissions internationally.

A. Literature review

Extreme climatic events, for example, climatic disasters such as storms, floods and wildfires, can have negative effects on economic growth, human capital accumulation, and productivity as well as asset prices. Using panel data between 1970 and 2006 for Caribbean countries, Hsiang (2010) studied the effect of cyclone intensity on GDP and finds that climatic disasters lower overall GDP, with more severe negative effects on several sectors, such as agriculture, retail, and tourism, and that the effect on economic growth can last several years. Based on data for the Philippines, Anttila-Hughes and Hsiang (2013) find that the average typhoon reduces household income by 6.6 percent in the short run and that these losses persist for several years. Hsiang and Jina (2014) find a similar negative and persistent effect of climatic disasters on GDP growth rates in a broad sample of countries. Strobl (2011) finds that a hurricane in the US on average lowers the annual growth rate of per capita income in the local county by 0.45 percent. On the economic effects of extreme temperatures, a direct consequence of climate change in many parts of the world, Dell, Jones, and Olken (2012) and Burke, Hsiang, and Miguel (2015) find that higher temperatures on average have negative effects on economic growth, especially for low-income countries. Kahn, Mohaddes, Ng, Pesaran, Raissi, and Yang (2019) find with a cross-country analysis that climate change reduces growth in real GDP per capita in the long run. There are also papers that suggest that the negative effects of climatic disasters can be partially offset. For example, based on a panel of European firms, Leiter, Oberhofer, and Raschky (2009) find that the effect of a major flood on firm-level activities possibly can be offset by increased labor and further increased investments in assets.

In addition, there is a component of the literature that examines how extreme climatic events affect asset prices, mostly domestically. At the sector level, Hong, Li, and Xu (2019) find that drought indexes can predict food sector returns in the country. Basing their findings on a sample of public firms in the US, Addoum, Ng, and Ortiz-Bobea (2018) observe that local extreme temperatures significantly impact earnings as well as stock prices in more than 40 percent of industries, and find that some industries are negatively affected by temperature shocks while other industries may benefit. Chapter 5 of the IMF Global Financial Stability Report (GFSR April 2020) documents the impact of large climatic disasters on the stock returns of domestic financial sectors. The chapter states that following a large climatic disaster, based on an event study approach, the domestic banking and insurance sectors lose on average about 1–2 percent in stock market valuation. At the aggregate stock market level, however, the chapter reveals that domestic valuation metrics (such as the price-to-earnings ratio for the entire market) overall are not strongly correlated with climate change vulnerability indexes in the cross section of countries.

The paper builds on the international trade literature on the propagation of shocks across space and stages of production. For example, di Giovanni, Levchenko, and Mejean (2018) find that a country's firms' performance correlates with the business-cycle-level fluctuations in the countries where the firms established international trade and multinational production relations. Korniyenko and others (2017) studied the spillover effects of supply shocks from the import of specific goods using a disaggregated international trade database and network analysis. Another line of this literature is more quantitative. For example, Caliendo, Parro, Rossi-Hansberg, and Sarte (2018), among others, use quantitative trade and macroeconomic models to show that

productivity, demand, and trade cost shocks hitting one region or sector could propagate to other parts of the economy and could have aggregate implications.

Despite a growing literature, fewer works have studied the propagation of climate shocks/risks through trade and input-output linkages. The paper most related to our work is Barrot and Sauvagnat (2016), who use a US firm-level database to find that natural disasters hitting specific input suppliers negatively reduce the sales growth and stock prices of their customers. Our paper differentiates from their work in a couple of notable ways. First, their work studies the transmission of natural disaster shocks within the US, whereas ours focuses on the cross-border spillovers with international trade, a linkage that is often omitted by climate scientists and economists. More importantly, their paper focuses on the impact of natural disasters on individual firms and their specific input to suppliers and customers. Yet ours finds strong evidence showing that climatic disasters have substantial aggregate implications for the hit country's trade partners, affecting their macrofinancial stability on the economy and sector level.

Other related works in this literature include Boehm, Flaaen, and Pandalai-Nayer (2019), who find that the 2011 Tōhoku Earthquake undermined the business performance of Japanese foreign affiliates abroad by disrupting the critical headquarters input supplies to subsidiaries. Carvalho, Nirei, Saito, and Tahbaz-Salehi (2016) examine the 2011 Tōhoku Earthquake as well, but focus on the supply chain disruptions within Japan. Dingel, Meng, and Hsiang (2019) find that climate change increases the global spatial correlation of productivities. This increases the correlation between a country's productivity and welfare, and in turn increases the cross-country welfare dispersion.

B. Data and variable construction

Our sample consists of the same set of 68 countries as those in the GFSR. Therefore, we ensure comparability between the results in the two publications. Thirty-four countries are advanced, and the other 34 countries are emerging markets and developing economies. The sample spans from 1970 to 2018⁹. Table 1 lists these countries and the countries covered by the international input-output databases we use in this study.

We introduce two sets of key international trade shares that guide our analysis throughout the paper. Define country n 's expenditure share on country i in year y , $\pi_{ni,y}$, as the ratio of the trade flows from i to n , divided by the total expenditure on final (consumption and investment) and intermediate goods by country n , $X_{n,y}$:

$$\pi_{ni,y} = \frac{x_{ni,y}}{X_{n,y}}$$

Given a buying country, the sum of its expenditure shares on all selling countries equals 1:
 $\sum_{i=1}^N \pi_{ni,y} = 1.$

⁹ Though the climate disaster and stock price data used by the GFSR cover years 1970–2019, the international trade data from UN Comtrade are only available until 2018. As a result, our sample ends in 2018, one year earlier than the GFSR's.

Define country i 's output share to country n , $S_{ni,y}$, as the ratio of the trade flows from i to n , divided by the total supply (gross output) of country i , $Y_{i,y}$:

$$S_{ni,y} = \frac{x_{ni,y}}{Y_{i,y}}$$

Given a selling country, the sum of its output shares to all buying countries equals 1:
 $\sum_{n=1}^N S_{ni,y} = 1.$

We get the information on country-bilateral total trade for the same set of countries and years from the United Nations Comtrade Database¹⁰. To compute the total expenditure and gross output in the denominators of the trade shares, we first get countries' annual GDP data from the United Nations National Account Database. Denote this number with $VA_{i,y}$. We get the value added to gross output ratio ($VAS_{i,y}$) for 42 of the 68 countries from 1970 to 2004 from the international input-output database constructed by Johnson and Noguera (2017). For 2005 to 2016, we get the variable from the Organisation for Economic Co-operation and Development Analytical Activity of Multinational Enterprises database (OECD AAMNE). Cadestin and others (2018) for 52 of the 68 countries. Some emerging market and developing economies and some advanced economies have their value added to gross output ratios missing from the international input-output databases. We use the average of the countries in the same category whose values are available in the same year to approximate them. We then get the gross output $Y_{i,y} = \frac{VA_{i,y}}{VAS_{i,y}}$, as well as the home sales $x_{ii,y} = Y_{i,y} - \sum_{j \neq i} x_{ji,y}$. The total expenditure then equals: $X_{n,y} = \sum_{i=1}^N x_{ni,y}$. With these we compute the expenditure shares, $\pi_{ni,y}$, and the output shares, $S_{ni,y}$.

Figure 1 plots the world trade-to-world GDP ratio overtime. This is the commonly used measure of globalization in international trade (Eaton and others 2016). The ratio was as low as about 0.07 in 1970, but it rose sharply in the 1970s, flattened in the 1980s, and returned to a strong upward trajectory in the 1990s and in the first half of the 2000s. The trend was clearly broken by the 2007-2009 Great Recession, when the world trade-to-world GDP ratio fell by 20 percent. This phenomenon is highlighted as the "Great Trade Collapse" by international trade economists. The ratio bounced back after the Great Recession, but never reached its pre-recession peak of about 0.25. After the recovery, it started to drop again. As of 2018, the world trade-to-world GDP ratio was about 0.20. It is unclear whether the post-recession dynamics was a short-run, business-cycle level pattern or the kick-off of a new, reversed trend.

A key assumption we maintain throughout the paper is that globalization is an exogenous process to climate change. In particular, we assume the expenditure shares, $\pi_{ni,y}$, are not affected by the

¹⁰ UN Comtrade sources raw data from national customs and covers only the trade in goods (most service trade does not pass through customs). Therefore, we are assuming that the expenditure and output shares of goods trade represent the respective shares of total trade. We believe this is a reasonable assumption given service trade accounts for only about 22 percent of world total trade as of 2018. (See https://ec.europa.eu/eurostat/statistics-explained/index.php/World_trade_in_services#:~:text=In%202018%2C%20services%20accounted%20for,growing%20part%20of%20world%20trade.)

climatic disasters that occur in the downstream country n in year y ¹¹. The output shares, $S_{ni,y}$, conversely, are not affected by the climatic disasters that occur in the downstream country i in year y ¹². This is supported by the international trade literature on the short-run stickiness of supply chains (for example, Antras and others 2017). The assumption is also supported by the gravity equation literature on international trade. Researchers find that, based on their estimated parameters, the expenditure shares increase in the size of the upstream economy, decrease in the bilateral distance, but are not significantly affected by the size of the downstream economy. Correspondingly, the output shares increase in the size of the downstream economy, decrease in the bilateral distance, but are not significantly affected by the size of the upstream economy¹³. Therefore, an upstream disaster that reduces the GDP in country i decreases downstream countries' expenditure shares on country i ($\pi_{ni,y}$), but does not significantly affect i 's output shares to downstream countries ($S_{ni,y}$). Correspondingly, a downstream disaster that reduces the GDP in country n decreases upstream countries' output shares to country i ($S_{ni,y}$), but does not significantly affect n 's expenditure shares on upstream countries ($\pi_{ni,y}$). With this assumption, an upstream climatic disaster reduces the upstream country's supplies to downstream countries proportionally, according to the annual output shares of the upstream country. A downstream climatic disaster reduces the downstream country's purchase from upstream countries proportionally, according to the annual expenditure shares of the downstream country.

The climate disasters data are from the same data source as the GFSR: the Emergency Events Database (EM-DAT)¹⁴. In order to have meaningful identification for our event study, we restrict our sample of climate-related disasters to those with an exact start date. In the database, the disaster damages are measured in three ways: total number of deaths, total number of people affected, as well as total monetary loss. We use $Damage_{i(d)}$ to denote the disaster damage from disaster d for the country hit by the disaster, i . We use $Damage_{i,y}$ to denote the total home-country disaster damage to i in year y . Among all the climatic disasters, Hurricane Katrina of 2005 caused the largest monetary damage to the host country in constant dollar terms (\$125 billion). The 2011 Thai floods caused the largest monetary damage relative to the host country's GDP (10.1 percent). Other disasters are less drastic in terms of magnitudes. The average disaster

¹¹ This assumption allows for $\pi_{ni,y}$ to be affected by disasters to upstream country i . If a disaster reduces the supplies from an upstream country, the downstream country will spend a smaller share on that country and larger shares on all other countries (including itself).

¹² This assumption allows for $S_{ni,y}$ to be affected by disasters to downstream country n . If a disaster reduces the expenditure from a downstream country, the upstream country will sell a smaller share to that country and larger shares to all other countries (including itself).

¹³ The gravity equation literature dates to Tinbergen (1962). They found that country-bilateral trade flows are characterized with $Trade_{A,B} \propto \frac{GDP_A^\alpha GDP_B^\beta}{Distance_{AB}^\gamma}$, where $\alpha, \beta, \gamma \approx 1$. Therefore, approximately, $\pi_{A,B} = \frac{Trade_{A,B}}{GDP_A} = \frac{GDP_B}{Distance_{A,B}}$, and $S_{A,B} = \frac{Trade_{A,B}}{GDP_B} = \frac{GDP_A}{Distance_{A,B}}$. Chaney (2018) provides a micro-foundation for the findings.

¹⁴ For a climate event to be considered a disaster, it has to satisfy at least one of the following criteria: (1) 10 or more deaths; (2) 100 or more people affected; or (3) the declaration of a state of emergency and/or a call for international assistance. Following the GFSR and to exclude tiny disasters, we further restrict the sample to those that had a rate of affected population greater than 0.5 percent or damage greater than 0.05 percent of GDP.

causes \$783 million monetary damage in current USD and 113 deaths, and affects 1.36 million people. On average, the monetary damage is 0.01 percent of the hit country's GDP (see Table 3 for the percentiles of the disaster damages).

To measure the climate change risks, the main data source we rely on is the Climate Change Exposure Index from Verisk Maplecroft. The index characterizes the degree to which countries are exposed to the physical impacts of future climatic disasters and climate changes. Climate change risks generally refer to a long-term view, measuring the likelihood of climatic disasters occurring in the future. Therefore, we fix a country's climate risk to its value in 2018¹⁵. The raw data use 0 to denote the highest risk and 10 to denote the lowest risk. Following the GFSR, we construct a climate change hazard index by subtracting the raw index from 10. We then normalize the measure such that it has a mean of 0 and standard deviation of 1, and an increase in the climate change hazard index is associated with higher climate risks. We denote the climate change hazard index with R_i ¹⁶.

To study the equity market response, we consider the following stock market variables: the stock index returns, price-to-earnings ratios, and earnings per share. We get the country-sector level, country-aggregate level, as well as global sector level information for these variables from Refinitiv Datastream. From the same data source, we also get three-month government bond yield data for the sample economies.

We refer to the country whose stock market is affected by foreign climate shocks as the home country. The countries that sell to the home country are the upstream countries. Climate shocks affecting the upstream countries are referred to as the upstream shocks. The countries that buy from the home country are the downstream countries. Climate shocks affecting the downstream countries are referred to as the downstream shocks.

To confirm international trade as the key propagation channel, we show that the tradable sectors in the home country respond more to foreign climate shocks. The sector level stock indexes from Datastream cover 26 sectors (Table 2a). However, Datastream does not provide information about how tradable these sectors are. We use the World Input-Output Database (WIOD) 2016 release (Timmer and others 2015) to compute sector tradability. To our knowledge, this international input-output database has the most granular sector classifications (a total of 56 sectors; Table 2). It allows matching with the sector level stock indexes on a more disaggregated level. WIOD 2016 release covers 2000–16. We use 2000 as the benchmark year to approximate the sector tradability for all years in the sample.

¹⁵ The Verisk Maplecroft data are only available during 2013–19. This makes an annual measure of country-level climate risks starting in the 1970s infeasible. In the years when the Verisk Maplecroft data are available, there are limited year-on-year changes in countries' climate risks.

¹⁶ We also consider specific types of climate risks as robustness tests, including the future heat stress risk, which measures the likelihood of extreme heat; the sea-level risk, which measures the physical threat of inundation of coastal areas due to the projected sea-level rise; an adaptive capacity index, measuring a country's ability to adjust to the possible consequences from climate change; and a climate change sensitivity index, measuring the susceptibility to future climate disasters and projected climate change. All these risk measures come from Verisk Maplecroft.

We consider both the exporting and importing tradability. A sector that is more tradable in terms of exporting should respond more to downstream climate shocks. Similarly, a sector that is more tradable in terms of importing should respond more to upstream climate shocks. Denote world total value added of sector s with VA^s , and world total export of sector s output with EX^s . Then the exporting tradability is constructed with:

$$TDEX^s = \frac{EX^s}{VA^s}$$

This is a sector level measure and could be considered an average across all countries. We use the ratio of world total export-to-world GDP as a measure of exporting tradability for the entire market:

$$TDEX^{mkt} = \frac{EX^{world}}{VA^{world}}$$

We construct importing tradability with the ratio of the sector's world total import in intermediate input used in the production of the sector's output, IIM^s , with respect to the sector's value added, VA^s :

$$TDIM^s = \frac{IIM^s}{VA^s}$$

IIM^s includes the imported input from all sectors, including sector s itself, that is used in the production of sector s output. As a result, $TDIM^s$ measures a sector's total exposure to upstream foreign shocks. The output of some sectors, for example, construction, may not be especially tradable. However, their input, in the case of construction may be tradable, and countries may import highly valued sand and stones from abroad. Therefore, these sectors might be subject to foreign upstream climate shocks as well.

The importing tradability measure is also sector level and could be considered an average across all countries. We use the ratio of world total imports (in intermediate input)-to-world GDP as a measure of importing tradability for the entire market:

$$TDIM^{mkt} = \frac{IIM^{world}}{VA^{world}}$$

The total factoring volume-to-GDP ratio and the bank regulatory capital-to-risk-weighted assets ratio are important institutional variables to explain the cross-country heterogeneity in the home-country financial sector's response to foreign climatic disasters (more details appear in Section IV.B). The country-year-level information for the two variables comes from the World Bank Global Financial Development Database. We report the summary statistics of the key variables used in this paper in Table 3¹⁷.

¹⁷ To be conservative and to reduce the impact of outliers on the results, we winsorized all variables at the top and bottom 1 percent.

II. A CROSS-BORDER CLIMATE SHOCK SPILLOVER INDEX

A. Exposures to global climate shocks

We refer to country n 's upstream exposure to global climatic disasters as how much the home country is exposed to its upstream countries according to the upstream countries' output shares. The upstream exposure in year y equals the weighted sum of the damages from climatic disasters, $Damage_{i,y}$, for any country i in the world selling to n , where the weights equal the output share of the selling country i to n , $S_{ni,y}$ (for exposures to global climate risks, replace $Damage_{i,y}$ with the country's climate change hazard index, R_i):

$$U_{n,y} = \sum_{i=1}^N S_{ni,y} Damage_{i,y}$$

We assume the disaster randomly destroys the output in country i . The losses in output then spillover to and are split among the hit country's downstream countries according to its output shares, $S_{ni,y}$. The loss in sales from i to n is therefore measured with $S_{ni,y} Damage_{i,y}$. Country n 's total upstream exposure adds up to the losses in sales from all countries that sell to n . As the home country n is also included in the summation, the upstream exposure measure captures all climate-disaster-related disruptions to both the home country's domestic and foreign suppliers.

We refer to country n 's downstream exposure to global climatic disasters as how the home country is exposed to its downstream countries, according to the downstream countries' expenditure shares. The downstream exposure in year y equals the weighted sum of climatic disaster damages to all countries in the world that buy from n , where the weights equal the expenditure share of the buying country on n , $\pi_{jn,y}$:

$$D_{n,y} = \sum_{j=1}^N \pi_{jn,y} Damage_{j,y}$$

In the context where the downstream country j is hit by climatic disasters, $Damage_{j,y}$ measures the losses in its income or total expenditure. We assume the disaster randomly destroys the purchasing power in country j . The losses then spill over to and are split among the hit country's upstream countries according to the expenditure shares, $\pi_{jn,y}$. As a result, the reduction in purchase from n by j could be measured with $\pi_{jn,y} Damage_{j,y}$. n 's total downstream exposure aggregates the reductions in purchase by all countries that are in n 's downstream. It includes the home country as well, to capture all climate-disaster-related disruptions to both the home country's domestic and foreign customers.

The two exposures measures of all countries add up to the total disaster damages in the world. Therefore, our constructed measures imply that international trade changes the disaster incidences allocated between countries, whereas it does not affect the global total damage caused by the disasters:

$$\sum_{n=1}^N U_{n,y} = \sum_{n=1}^N D_{n,y} = \sum_{n=1}^N Damage_{n,y}$$

We may normalize a country's upstream and downstream exposures with the world total climatic disaster damages:

$$Nor_U_{n,y} = \sum_{i=1}^N S_{ni,y} \frac{Damage_{i,y}}{\sum_{i=1}^N Damage_{i,y}}$$

, as well as

$$Nor_D_{n,y} = \sum_{j=1}^N \pi_{jn,y} \frac{Damage_{j,y}}{\sum_{j=1}^N Damage_{j,y}}$$

The normalized upstream and downstream exposures measure the fraction of world total disaster damages loaded on each country as soon as we take into consideration spillovers with international trade. The cross-country sum of the normalized exposures equals 1. Consider the normalized exposure measures under two knife-edge cases. In the first case, international trade is shut down and countries only buy and sell with themselves (autarky). The upstream and downstream exposures both reduce to the share of home-country disaster damage in world total disaster damage: $Nor_U_{n,y} = Nor_D_{n,y} = \frac{Damage_{n,y}}{\sum_{i=1}^N Damage_{i,y}}$. In the second case, countries spend the same share of their income and sell the same share of their output to all countries in the world. This implies countries perfectly share climatic disasters. All countries will have the same upstream and downstream exposures to global climate shocks: $Nor_U_n = Nor_D_n = \frac{1}{N}$. Generally, countries would differ in terms of their exposures to global climatic disasters and would have both a home-country disaster component and a component related to spillovers from foreign countries.

Like the upstream and downstream exposures to global climatic disasters, we may also construct the upstream and downstream exposures to global climate change risks by replacing the damage variables with the measures for risks. The exposure measures help us understand how globalization affects countries' exposures to global climatic disasters and climate risks. Our first application argues with globalization, the countries with low home-country risks have increased their global climate risk exposures, and the countries with high home-country risks have decreased their global climate risk exposures.

We illustrate the point with the examples of two (groups of) countries. Country *a* is a representative land-locked European country (or a group of countries) in a high-latitude and is generally considered to have low exposures to many sources (such as tropical cyclones) of

climate risks in the home country. In a hypothetical world with no international trade, country a would trade only with itself. Therefore, it was mostly exposed to home-country risks and had low exposure to global climate risks. Now, country a trades extensively with foreign customers and suppliers. Most foreign countries that country a buys from and sells to are likely to be exposed to relatively higher climate risks than country a itself. Country a should now face higher global climate risks associated with its customers and suppliers. As these risks are realized, country a is also hit with more climatic disasters in the upstream and downstream along the global value chain. One would thus predict that globalization increases country a 's exposure to global climate risks and disasters.

Country b , though, is a representative tropical coastline country (or a group of countries) in Asia Pacific and is subject to higher home-country climate risks than an average foreign country. As Country b opens to trade, most countries it trades with are likely to be exposed to lower climate risks. This should lead to a decline in global climate risks and disaster exposures with globalization for Country b .

To apply the concept to the data, we let country a refer to the group of countries that are among the bottom 10 percent of all countries, in terms of average annual deaths from home-country climatic disasters, or in terms of the home-country climate change hazard index if climate risks are concerned. Alternatively, we call country a the low home-country shock group. Correspondingly, we let country b refer to the group of countries that are among the top 10 percent of all countries, in terms of average annual deaths from home-country disasters or the home-country climate change hazard index. We may call country b the high home-country shock group.

To confirm the hypothesis, we plot the trend in the upstream and downstream exposures for the two groups of countries. But prior to that, we note that the home-country climate shocks may change differently among countries. This will lead to changes in the global exposure measures, even if there were no variations in the trade shares. To address this confounding factor, we first allow the year of the trade shares to be different from the year of the climate shocks. Specifically, we define the upstream and downstream exposures with the current global climate shocks, but with the expenditure and output shares fixed at benchmark year y_0 ¹⁸:

$$\begin{aligned} Nor_U_{n,y_0,y} &= \sum_{i=1}^N S_{ni,y_0} \frac{Damage_{i,y}}{\sum_{i=1}^N Damage_{i,y}} \\ Nor_D_{n,y_0,y} &= \sum_{j=1}^N \pi_{jn,y_0} \frac{Damage_{j,y}}{\sum_{j=1}^N Damage_{j,y}} \end{aligned}$$

Then we consider, for country groups a and b , the ratio of the exposure measures with current and benchmark shares. This takes out the component related to changes in the distribution of home-country climate shocks across countries. We call them the relative exposure measures:

¹⁸ We set $t_0 = 1971$, as more countries have their trade data missing for 1970.

$$Rel_U_{A,y_0,y} = \frac{\sum_{n \in A} Nor_U_{n,y,y}}{\sum_{n \in A} Nor_U_{n,y_0,y}}$$

$$Rel_D_{B,y_0,y} = \frac{\sum_{n \in B} Nor_D_{n,y,y}}{\sum_{n \in B} Nor_D_{n,y_0,y}}$$

The measures equal 1 in the benchmark year when $y = y_0$. If there were only changes in the climate shocks affecting individual countries, but no changes in the trade shares over time, the ratios would remain at 1.

The results are shown in Figure 2. The low home-country shock group (country *a*) experienced an increase in the global exposures to climatic disasters and climate risks from the 1970s to 2000s. The upstream (downstream) exposure to total climatic disaster-related deaths increased by about 25 (35) times¹⁹. The increase in risk exposures was more moderate. The upstream (downstream) exposure to climate risks increased by about 8 percent (4 percent). On both accounts, the global exposures of the low home-country shock group (country *a*) started to fall at approximately the same time as the Great Recession²⁰.

Meanwhile, the average country of the high home-country shock group (country *b*) had a decline in the exposures to climatic disasters and climate shocks from the 1970s to 2000s. The upstream (downstream) exposure to global climatic disasters dropped by about 8 percent (6 percent). The upstream (downstream) exposure to global climate risks dropped by about 20 percent (10 percent). Around the Great Recession, the high home-country shock countries (country *b*) began to increase their exposures.

These results show our methodology is useful for illustrating the evolution of climate risk distribution across countries and has policy relevance. They show that international trade patterns may have a significant impact on the global distribution of climate risk, assuming that the cross-border transmission of economic damages from climatic disasters are in proportion to respective trade shares. Economies in countries that used to have low climate risk exposures are no longer immune to extreme climatic shocks, due to their increasing trade linkages with countries with higher climate risk exposures.

Before we proceed to the second application of the exposure measures, we want to emphasize that the exposure measures are not only useful for the cross-border spillovers of physical climate risks, but may also be extended to study the transition risks. What one needs to do is replace the

¹⁹ On average, the low home-country shock group has 0.0002 climate disaster-related deaths per country per year. Conversely, the high home-country shock group has 0.1 climate disaster-related deaths per country per year. Therefore, the global exposures of climate disaster-related deaths would rise substantially for the low shock group once it starts to trade with the high shock group.

²⁰ During the sample period (1971–2018), Country *a* experienced 0.34 and 0.54 annual average increase in upstream and downstream exposures of global climate disaster-related deaths, and 0.15 and 0.06 percentage points increase in upstream and downstream exposures of climate risks. Country *b* experienced 0.07 and 0.08 annual average decline in upstream and downstream exposures of global climate disaster-related deaths, and 0.24 and 0.17 percentage points increase in upstream and downstream exposures of climate risks.

physical damages and risks of climate change with proper measures of the transition risk and regulatory shocks, or the implication of the transition, once a potential state is realized. The measures may also be extended to study the shock spillovers with other means of globalization, for example, multinational production. One needs to replace the trade shares with the respective multinational production shares. While the current project focuses on the spillovers of climate shocks across national borders, the same measurement and analysis techniques could be applied to firm-to-firm trade and within-firm trade as well.

B. The global spillover index of climate shock exposures

In the previous section we find that as globalization expands, the countries that have relatively few home-country climatic disasters and low home-country climate risks increase their exposures under the assumptions we made. Meanwhile, the countries that have relatively many home-country climatic disasters and high home-country climate risks decrease their exposures. Therefore, the cross-country dispersion of upstream and downstream exposures of global climate risks should have decreased with globalization. In this section, we study the dynamics of the cross-country dispersion in climate shocks by formally introducing a global spillover index of climate shock exposures. The index is defined as the ratio of the cross-country standard deviation of upstream/downstream exposures to the benchmark year expenditure shares, with respect to the cross-country standard deviation of upstream/downstream exposures with the current expenditure shares:

$$Spillover_up_{y_0,y} = \frac{sd_n(Nor_U_{n,y_0,y})}{sd_n(Nor_U_{n,y,y})}$$

$$Spillover_down_{y_0,y} = \frac{sd_n(Nor_D_{n,y_0,y})}{sd_n(Nor_D_{n,y,y})}$$

In the benchmark year with $y = y_0$, the global spillover indexes of both upstream and downstream exposures equal 1. As countries increasingly open to trade, the countries with high climate risks are exposed more to trading partners with relatively low climate risks, whereas the countries with low climate risks are exposed more to trading partners with relative high climate risks. One would expect that the cross-country dispersion in the exposures would decline. This is driven by the denominators of the spillover indexes, leading to a rise in the spillover indexes. Similar to the exposures to global climate shocks for individual countries, the cross-country dispersion in climate exposures is not only driven by opening to trade, but also is confounded by the rise and fall of cross-country variations in the climate shocks associated with individual countries. To take out the confounding component, we have in the numerator the cross-country standard deviation in climate shock exposures with current levels of climate shocks but with benchmark trade shares. If there are no changes in the trade shares over time, the spillover indexes will remain at 1. In the extreme case where countries perfectly share climate shocks, the spillover indexes will rise to infinity.

Figure 3 plots the time series of the spillover indexes for both upstream and downstream exposures to global climatic disaster damages and climate risks. The climatic disaster damages are measured with the number of deaths, and the climate risks are measured with the climate

change hazard index²¹. On the right axis, the figure plots the world trade-to-world GDP ratio. The trends of the two plots closely follow each other. This indicates that deepening globalization increases the spillovers of climatic disasters and climate risks across borders. When countries were trading less among each other, they were exposed to their own shocks. With the rise in international trade, high home-country climate shock countries (for example, country *b*) now have customers and suppliers that are hit by smaller disasters and face lower risks. Low home-country climate shock countries (for example, country *a*) now have customers and suppliers that are hit by larger disasters and face higher risks. As a result, globalization reduces the dispersion of climate shock exposures across countries. As globalization was on decline after the Great Recession, the spillover index fell as well. Again, the purpose of construction of this index, under the assumptions made earlier, is to illustrate that international trade could have significantly changed how climate risk is distributed across countries.

An alternative way to see the contribution by globalization is to investigate the fraction of the reduction in cross-country dispersion in climate shock exposures that could be explained by variations in trade shares and variations in climate shocks. Define the contribution by climate shocks alone (using the upstream exposures as an example) as the following:

$$Contribution_{climate} = \frac{sd_n(Nor_{U_{n,71,18}}) - sd_n(Nor_{U_{n,71,71}})}{sd_n(Nor_{U_{n,18,18}}) - sd_n(Nor_{U_{n,71,71}})}$$

The numerator computes changes in cross-country dispersion from 1971 to 2018 with the benchmark year (1971) trade shares with current climate shocks. Similarly, define the contribution by openness to trade alone as follows:

$$Contribution_{trade} = \frac{sd_n(Nor_{U_{n,18,71}}) - sd_n(Nor_{U_{n,71,71}})}{sd_n(Nor_{U_{n,18,18}}) - sd_n(Nor_{U_{n,71,71}})}$$

The numerator uses the benchmark year (1971) climate shocks and current trade shares. Note that the contribution by climate shocks alone and the contribution by openness to trade alone may not add up to 1, due to their correlations.

Taking the formula to the data shows that openness to trade alone explains 87.4 percent and 83.7 percent of the decline²² in cross-country dispersion in exposures to upstream and downstream, respectively, global climate disaster damages. Conversely, changes in the geographical distribution of climate disasters alone explain 35.9 percent and 29.7 percent of the decline for the upstream and the downstream, respectively. These results again highlight the importance of openness to trade in explaining the declines in cross-country differences in global climate shock exposures and indicate that they contribute much more than the changes in the spatial distribution of climate shocks themselves.

²¹ Other measures of climate disaster damages and climate risks show similar results.

²² From 1971 to 2008, the cross-country dispersion in global climate disaster damage exposures declined by 6.3% for upstream shocks and by 10.7% for downstream shocks, relative the respective levels in 1971.

Before we move on to estimate the stock market impact of foreign climate disasters, we want to mention the welfare implications of the cross-border spillovers with international trade. Our framework implies that globalization does not affect the world total monetary damage from climate disasters. Rather, it reduces the cross-country dispersion. This potentially leads to positive-sum global welfare gains if countries' aggregate utility functions are concave. In this case, it is beneficial, from a global point of view if the exposures to climate disasters are smoothed out within countries, and extreme losses from climate disasters are avoided. We will leave the modeling of welfare implications of the cross-border spillovers to future research²³.

III. EQUITY RETURNS AND FOREIGN CLIMATIC DISASTERS: EVENT STUDY

This section addresses whether exposures to foreign climatic disasters could affect the stock market valuation of the home country. We take an event study approach, designed as the following: consider the downward spillover of an upstream disaster. In the first step, for each disaster d in the ED-MAT database, we link the country hit by the disaster, $i(d)$, with the country to which $i(d)$ exports the largest value of output²⁴. We label this country $n_1(i(d))$. Using math,

$$n_D(i(d)) = \operatorname{argmax}_{n_D \neq i} S_{n_D i(d), y(d)}$$

We then study the impact of the disaster d on the stock market valuation responses in country $n_D(i(d))$, around the date disaster d hit $i(d)$. We use this as a quantification of the impact of upstream climatic disasters on the downstream stock market. Based on Section II, if the output share of country i to n is denoted $S_{ni(d), y(d)}$ and the disaster damage is denoted $Damage_{i(d)}$, the loss in sales from i to n is measured with $S_{ni(d), y(d)} Damage_{i(d)}$. Therefore, $n_D(i(d))$ should be the downstream foreign country that bears the largest value of damage from disaster d ²⁵. If we were not seeing a significant response to the disaster on n_D 's stock market, we likely are not going to see a significant response in i 's smaller exporting destinations, either²⁶. In fact, as a placebo test, we find that, on average, an upstream climatic disaster does not lead to a significant stock market response in the disaster-hit country's 35th largest (median) exporting destination.

We study the upward spillover of climatic disaster d hitting downstream country i in a similar way. We investigate the stock market response in the upstream country n_2 , from which country i imports the largest value:

²³ We note that global trade brings about economic benefits to all countries and enhances the level of climate resilience of all countries.

²⁴ Existence of dual listings could complicate our analysis. However, we argue that sectoral results are not affected if dual listing does not systematically confound with sectoral characteristics that we examine in the next section.

²⁵ On average, a country sells about 3.1% of its gross output to its largest exporting destination. See Table 3.

²⁶ Li and Souza (2020) use a similar approach to study the labor market implications of upstream and downstream tariffs through input-output linkages. They link the upstream tariffs with the downstream sector to which the tariffed sector sells the largest fraction of output, and the downstream tariffs with the upstream sector from which the tariffed sector buys the largest share of input.

$$n_U(i(d)) = \operatorname{argmax}_{n_U \neq i} \pi_{i(d)n_2, y(d)}$$

Remember, if the expenditure share of country i on n is $\pi_{i(d)n, y(d)}$ and the disaster damage is $\text{Damage}_{i(d)}$, the reduction in imports from n by i caused by disaster d could be measured with $\text{Damage}_{i(d)}$. Then $n_U(i(d))$ should be the upstream foreign country that bears the largest value of damage from the disaster²⁷. Therefore, it should respond significantly to the disaster. We also conduct a placebo test, showing that a downstream climatic disaster does not lead to a significant stock market response in the disaster-hit country's 35th largest (median) importing origin.

After we link each disaster d and the country it hits $i(d)$ with $i(d)$'s largest exporting destination $n_D(i(d))$ and importing origin $n_U(i(d))$ (from now on, we use n_D as the shorthand for $n_D(i(d))$ and n_U as the shorthand for $n_U(i(d))$), we conduct event studies of the disasters on the upstream and downstream countries' stock markets in the standard way. Here we illustrate the specification with n_D . We will get the specification for n_U if we replace every n_D with n_U .

This paper concerns the response of aggregate markets and the sector-level stock indexes. Use $RE_{n_D, t}^s$ to denote the stock index return of sector s (or the country-level aggregate market if $s = \text{mkt}$) in country n_1 on day t . Then the excess return is defined as: $re_{n_D, t}^s = RE_{n_D, t}^s - r_{n_D, t}^f$, where $r_{n_D, t}^f$ is the three-month government bond yield in country n_D . We estimate the expected return for individual sectors as follows:

$$re_{n_D, t}^s = \beta_{0, n_D}^s + \beta_{1, n_D}^s re_{global, t}^s + \beta_{2, n_D}^s re_{n_D, t}^{mkt} + \epsilon_{n_D, t}^s$$

, where $re_{global, t}^s$ is the excess return for sector s global stock index (in excess of the three-month Treasury bill yield by the US). $re_{n_D, t}$ is the country-level aggregate market excess return in country n_D (in excess of the three-month government bond yield in country n_D). The estimated coefficients $\widehat{\beta}_{0, n_D}^s, \widehat{\beta}_{1, n_D}^s, \widehat{\beta}_{2, n_D}^s$ associate the expected returns in individual sectors to the global sector returns and the country-level aggregate market level returns.

To estimate the expected return for aggregate markets, we use the following specification:

$$re_{n_D, t}^{mkt} = \beta_{0, n_D}^{mkt} + \beta_{1, n_D}^{mkt} re_{global, t}^{mkt} + \epsilon_{n_D, t}^{mkt}$$

We estimate the models on a window that starts 12 months before the date the disaster occurs ($t(d)$) and ends one month before the disaster. Using the estimated coefficients, we compute daily abnormal return in the event window. The event window is defined to start 21 trading days before the disaster occurs and end 60 trading days after the disaster occurred, so that any anticipation effect before the disaster occurs is also captured.

$$AR_{n_D, t}^s = re_{n_D, t}^s - \widehat{\beta}_{0, n_D}^s - \widehat{\beta}_{1, n_D}^s re_{global, t}^s - \widehat{\beta}_{2, n_D}^s re_{n_D, t}^{mkt}$$

²⁷ On average, a country spends about 2.7 percent of its total expenditure on its largest importing source.

$$AR_{n_D,t}^{mkt} = re_{n_D,t}^{mkt} - \widehat{\beta}_{0,n_D}^{mkt} - \widehat{\beta}_{1,n_D}^{mkt} re_{global,t}^{mkt}$$

The x -day cumulative abnormal return, in country n_D due to disaster d , is defined as: $CAR_{n_D,x}^s = \sum_{\tau=t(d)-21}^{t(d)+x} AR_{n_D,\tau}^s$ (with normalization $CAR_{n_D,-21}^s = 0$). We compute these for each disaster.²⁸ Then we compute the mean over all disasters: $\overline{CAR}_x^s$ and their 95 percent confidence intervals.

Figure 4 plots the cumulative abnormal returns for the spillovers of upstream climatic disasters on the downstream sectoral stock market indexes. Figure 5 plots the cumulative abnormal returns for the spillovers of downstream climatic disasters on the upstream sectoral stock market indexes. Figures 4(a) and 5(a) show the aggregate market-level cumulative abnormal returns to upstream and downstream climatic disasters from 21 trading days before the disaster to 40 trading days after the disaster were both about -0.5% and were marginally significant, at 95 percent confidence interval around 35 trading days after the disaster start dates. The magnitude is comparable to the finding for the home-country disaster's average impact on the stock market (about -1 percent) in the GFSR²⁹.

Figures 4 and 5 also show that the stock market responses to foreign disasters differ substantially with respect to sectors. For example, the cumulative abnormal returns in the chemicals sector are -0.8 percent for upstream disasters and -1 percent for downstream disasters. The cumulative abnormal returns in the automobiles sector are -1.8 percent for upstream disasters and -1.5 percent for downstream disasters. Conversely, the media sector and the telecommunication sector, among others, do not respond significantly to foreign disasters. An observation is that most sectors that are traditionally considered tradable have significantly negative cumulative abnormal returns from foreign disasters, while most sectors that are traditionally considered non-tradable do not. These first results raise the possibility that tradable sectors are affected more negatively than non-tradable sectors. We discuss the relationship between sector tradability and stock market valuation response to foreign disasters in Section IV.A.

We have been interpreting the impact of upstream climatic disasters on the downstream stock market as a negative supply shock, and the impact of downstream climatic disasters on the upstream stock market as a negative demand shock. However, the global supply chains are complicated, introducing confounding factors. For example, the upstream suppliers might compete with domestic suppliers. If the upstream competitors are impacted by their disasters, domestic suppliers might expand, leading to a gain in stock prices. The downstream consumers,

²⁸ We constrain our sample to large climate disasters, using the same selection criteria as the event study design in the GFSR. In the GFSR, large disasters refer to those that affect greater than 0.5 percent of the national population or cause damage greater than 0.05 percent of the country's GDP.

²⁹ The estimated stock market impact of the average foreign disaster refers to the response in the disaster-hit country's largest exporting and importing partner. If we want to get the aggregate effect of all foreign disasters to a country, we need to aggregate up all disasters that affect the country's trading partners. If we want to get the total foreign spillover of a disaster, we need to aggregate up the ripple effects in all foreign countries that trade with the disaster-hit country. Constrained by the computing power and as we are doing partial equilibrium analysis, we leave the add-up to future works. Therefore, we are providing an estimate for the upper bound of the impact of foreign disasters. The total effect, on both accounts, should be even more negative.

if impacted by a climatic disaster, may spend less due to an income loss, but, conversely, may also need to rebuild, which would have an expansionary effect on its expenditure on the upstream foreign country. The latter channel may increase the upstream stock price. Therefore, the two alternative channels should only bias our estimates upward, if there is any bias. Given that we find negative total effects from foreign disasters for the market and the tradable sectors, the two confounding stories in fact strengthen the main channels we propose.

To conclude the section, we perform a placebo test to emphasize international trade's key role in propagating climatic disaster damages across borders. We plot out the cumulative abnormal return in the event windows for the 35th largest (median) importing-exporting partner of the country hit by the disaster. The results are shown in Figure 6. The 35th largest importer-exporter's stock market, both market aggregate and on the sector level, does not respond significantly to the disaster.

IV. EQUITY RETURNS AND FOREIGN CLIMATIC DISASTERS: CROSS-SECTION ANALYSIS

Section III shows the cross-border spillovers of climatic disasters might reduce the country-level aggregate market returns and can significantly reduce the returns of many tradable sectors. Using a cross-section analysis on the disaster level, this section associates the stock market cumulative abnormal return with the magnitude of the disasters. It further shows that the cumulative abnormal returns are negatively associated with the sector tradability. The section also explores to what extent the spillovers matter for the stability of the financial sectors.

How should we measure the damage spillover of the upstream climatic disaster on the downstream economy? The EM-DAT data contain information about the direct monetary loss from the climatic disaster for the upstream country i . Denote this variable with $Damage_{i(d)}$. The loss in sales from i to n_D from this disaster is then measured with $S_{n_D i(d), y(d)} Damage_{i(d)}$, where $S_{n_D i(d), y(d)}$ refers to the output share of country i to country n_D in year $y(d)$. The stock market return is a relative measure with respect to the total valuation of the economy of interest. To get the monetary damage relative to the size of the economy, we further normalize the loss in sales with the GDP of country n_D to get the normalized damage of the upstream disaster:

$$nor_up_damage_{n_D(d), y(d)} = \frac{S_{n_D i(d), y(d)} Damage_{i(d)}}{GDP_{n_D, y(d)}}$$

Given the monetary loss in sales that spills over across borders, the larger is the size of home economy, the smaller is the upstream shock ripple in home country's stock market. Similarly, we construct the measure for normalized damage of a downstream. With the direct disaster loss for the downstream country measured in monetary values, $Damage_{i(d)}$, and the expenditure share $\pi_{i(d), n_U y(d)}$, the loss in purchase by i from n_U equals $\pi_{i(d), n_U y(d)} Damage_{i(d)}$. Then we normalize the loss with n_U 's GDP:

$$nor_down_damage_{n_U(d), y(d)} = \frac{\pi_{i(d), n_U y(d)} Damage_{i(d)}}{GDP_{n_U, y(d)}}$$

To study the association between the upstream climatic disaster magnitude and the cumulative abnormal return in the home country's stock market, we first consider the following specification (the specification of downstream disasters replaces n_D with n_U and the normalized upstream damage with the normalized downstream damage):

$$CAR_{n_D(d),40}^s = \alpha_1^s \text{nor_upstr_damage}_{n_D(d),y(d)} + \delta_{n_D}^s + \gamma_y^s + \epsilon_d^s$$

We regress trading day 40's (from 21 trading days before the disaster to 40 trading days after the disaster) cumulative abnormal return³⁰ in the home country, sector s (s refers to individual sectors or the country-level aggregate market) stock index, on the normalized upstream damage. We control for the home-country fixed effect to reflect that different countries might differ in their abilities to hedge the spillovers of foreign climate shocks. We also control for the year fixed effect. We cluster standard errors with two-way clustering on the stock market and year level to account for potential correlation within the same stock market and within the same year. We run this regression sector by sector, allowing for the coefficients, especially α_1^s , to be different across sectors.

Table 4 shows the results for upstream climatic disasters. The home-country stock market index return is negatively associated with the size of the upstream disaster. An increase in exposure to foreign upstream climatic disaster damage by 0.1 percent of the home country's GDP is associated with a 5.9 percent decline in the market-wide trading day 40's cumulative abnormal return. Table 4 also illustrates sector heterogeneity in the response to the size of upstream shocks. The impact on most tradable sectors, for example, automobile, basic materials, chemicals, food and beverages, food producers, industrial goods, and industrial producers, is negative and significant. An increase in foreign upstream damage by 0.1 percent of home-country GDP is associated with a more than 10 percent decline in the stock market valuations in automobile and chemical sectors. Conversely, the cumulative abnormal returns in most non-tradable sectors are not significantly affected by upstream damages. We investigate further the relationship between sector tradability and response to foreign climate shocks in Section IV.A.

The results for downstream climatic disasters are reported in Table 5. The correlation between cumulative abnormal return in the home-country market and the size of downstream disasters is also significant and negative. An increase in exposures to downstream foreign climatic disaster damage by 0.1 percent of home-country GDP is associated with a 3.7 percent decline in trading day 40's market-level cumulative abnormal return. Like the upstream results, the typical tradable sectors respond more negatively and more significantly to the magnitude of the downstream disasters than most non-tradable sectors.

A. Tradability and the cross-border spillover of climatic disasters

Next, we formally investigate the relationship between sector tradability and the cumulative abnormal return from foreign disasters. If climatic disasters propagate across country borders with international trade, we would expect that the sectors that are more tradable in terms of

³⁰ Trading day 40's cumulative abnormal return is defined as the sum of abnormal returns from 21 trading days before the disaster to 40 trading days after the disaster. See Section III for details.

importing respond more negatively to upstream climatic disasters. These sectors import a relatively larger share of input from abroad than the non-tradable sectors. Given the magnitude of the disaster, the input to these sectors should face larger damage than the sectors that import little input from abroad. Before we proceed to the main specification, we first consider a pooled regression of the previous sector-level regression. We control the home country, year, and sector fixed effects. By doing so, we recover the average association between the cumulative abnormal return and the normalized upstream damage:

$$CAR_{n_D(d),40}^S = \alpha \text{nor_upstr_damage}_{n_D(d),y(d)} + \delta_{n_D} + \gamma_y + \zeta^S + \epsilon_d^S$$

Table 6, Columns 1–2 show for the average sector, the cumulative abnormal return is negatively correlated with the size of the upstream and downstream disasters. An increase in upstream and downstream exposure by 0.1 percent of home-country GDP is associated with 4.7 percent and 3.3 percent declines in market cumulative abnormal return on trading day 40.

Remember, we use $TDIM^S$ to denote the importing tradability measure. We run a panel regression of cumulative abnormal return, on the level of the normalized upstream damage, and the variable interacted with the importing tradability (for the regression with normalized downstream damage, we should interact it with the exporting tradability, $TDEX^S$):

$$CAR_{n_D(d),40}^S = \mu \text{nor_upstr_damage}_{n_D(d),y(d)} + \lambda \text{nor_upstr_damage}_{n_D(d),y(d)} * TDIM^S + \delta_{n_D} + \gamma_y + \zeta^S + \epsilon_d^S$$

We control for the country fixed effect for the country hit by the disaster and the year fixed effect. We also control the sector fixed effect to take out the level effect of importing tradability on the cumulative abnormal return.

Column 3 of Table 6 shows that, as soon as we control for the interaction between the upstream damage and the importing tradability, the level effect of the upstream damage becomes insignificant. Meanwhile, the interaction between the upstream damage and the importing tradability is strongly significantly correlated with the cumulative downstream damage. Column 4 of Table 6 shows that, as soon as we control for the interaction between the downstream damage and the exporting tradability, the level effect of the downstream damage becomes insignificant as well, and the interaction term is significantly negative. These indicate that the negative impact of the upstream and downstream disaster damage for the average sector is entirely driven by the tradable sectors. The estimated coefficients imply that, for example, an increase in exposure to upstream foreign climatic disaster by 0.1 percent of home-country GDP is predicted to reduce the cumulative abnormal returns by 15.4 percent in the sector with the highest importing tradability (chemicals), 4.1 percent in the sector with the median importing tradability (food and beverages), and 0.98 percent in the sector with the lowest importing tradability (real estate). An increase in exposure to downstream foreign climatic disaster by 0.1 percent of home-country GDP is predicted to reduce the cumulative abnormal returns by 9.5 percent in the sector with the highest exporting tradability (automobile), by 2.2 percent in the sector with the median exporting tradability (media), and by 0.92 percent in the sector with the lowest exporting tradability (real estate).

B. Climatic disaster spillovers and the financial sector

The GFSR finds that the home-country climatic disasters reduce the valuation of the financial sector stocks. This indicates either the revenues of the financial sector decline or the risks associated with the financial sector rise. In either case, the financial stability of the home country is undermined. The GFSR also finds that insurance penetration and sovereign rating upgrade improve the financial sector valuations, holding fixed the magnitude of the disasters. The channels through which foreign climatic disasters undermine a country's financial stability are different from home-country disasters. The home-country disasters damage the infrastructure, properties, and personnel in the country, thus affecting the financial sector's operations directly and almost all clients of the financial sector. Foreign climatic disasters affect financial stability indirectly, as most implications of foreign climatic disasters are loaded on the tradable sectors.

In this section, we explore whether the impact of foreign disasters on financial sector valuation at home is heterogeneous across countries, and whether it is affected by country institutional factors. We examine whether the degree of international factoring, a form of protection for domestic exporters, affect the spillover effect of foreign climatic disasters on the domestic financial sector. Another factor that we examine is banking sector capitalization.

To measure banking capitalization, we use the standard variable: the ratio of the bank regulatory capital-to-risk-weighted assets³¹. Following the GFSR, we take a one-year lag of the institutional variables to alleviate potential endogeneity concerns. We consider the following specification for the downstream country (to study the association between banking capitalization and the financial sector cumulative abnormal return to downstream disasters, replace $CAR_{n_D(d),40}^{FIN}$ and $nor_upstr_damage_{n_D(d),y(d)}$ with their downstream counterparts):

$$CAR_{n_D(d),40}^{FIN} = \alpha nor_upstr_damage_{n_D(d),y(d)} + \beta regulatory_to_assets_{n_D,y(d)} + \epsilon_d^s$$

According to Columns 2 and 4 of Table 7, one percentage point increase in the bank regulatory capital-to-risk-weighted assets ratio is associated with about a 0.2 percent increase in the cumulative abnormal return from upstream and downstream disasters.

V. EQUITY PRICING OF FOREIGN CLIMATE CHANGE PHYSICAL RISK

Climate change poses increasing long-term risks of larger, more frequent climatic disasters (GFSR, Black Rock 2019, McKinsey 2020). The risks differ with respect to countries. For example, tropical countries may face a higher likelihood of heatwaves than countries in middle or high latitudes. Coastline countries may encounter larger sea-level rise and flood risks than inland countries. The major trading partners of these high-risk countries are more exposed to foreign climate risks through importing and exporting relationships as well. Forward-looking, rational investors should price these risks into valuation of their portfolios. If they have not priced in these risks (that is, mispricing of climate risk), correction of mispricing will happen in the future and could be associated with financial stability risks. Exposure to foreign climate

³¹ Find the definition here: <http://datahelp.imf.org/knowledgebase/articles/484367-in-financial-soundness-indicators-fsis-what-is>.

change risk would lead to a decline in stock market valuations at home if the home country imports and exports a lot with the countries that have a high degree of climate change risks (meaning more likely to be hit—and more likely to be hit frequently—by climatic disasters). The impact of home-country climate risks on stock valuations was studied in the GFSR. Here we investigate whether exposure to foreign climate risks is associated with lower stock market valuations at home.

To measure foreign climate risks exposures, we slightly adapt the measures for exposures to global climate risks introduced in Section II. We get a country's upstream foreign climate risk exposures by dropping the home-country trade shares from the measures:

$$U_{i,y} = \sum_{j \neq i} S_{ij,y} R_j$$

R_j denotes the climate risks associated with country j . As in previous sections, $S_{ij,y}$ denotes the output shares by j to i in year y . If $S_{ij,y} = 0, \forall j \neq i$, no foreign country sells to country i . In this case, $U_{i,y} = 0$, which implies that country i will not be exposed to upstream foreign climate risks at all. In our sample, all countries import from at least some foreign countries. Therefore, all countries are exposed to positive foreign upstream climate risks. Similarly, we get a country's downstream foreign climate risk exposures:

$$D_{i,y} = \sum_{j \neq i} \pi_{ji,y} R_j$$

$\pi_{ji,y}$ denotes the expenditure shares by j on i in year y . If $\pi_{ji,y} = 0, \forall j \neq i$, no foreign country buys from country i . In this case, $D_{i,y} = 0$, which implies that country i will not be exposed to upstream foreign climate risks. In our sample, all countries export to at least some foreign countries. Therefore, all countries are exposed to positive foreign downstream climate risks.

We consider the impact of exposures to foreign climate change risks on the home-country stock market P/E ratios. These ratios are a forward-looking measure for long-term stock performance. To implement the empirical strategy, we first take out the component in the P/E ratios that could be explained by standard known variables, including the interest rate ($r_{i,y}$, measured with the three-month government bond yield in the stock market country), the expected future earnings ($EXPFE_{i,y}$, measured with the mean annual growth of earnings per share over the past five years), as well as the equity risk premium ($ERP_{i,y}$, measured with the standard deviation of annual growth of earnings per share over the past five years). To get the variables on the year level, we take the average of the monthly observations in the raw data. We run the following regressions sector by sector, for individual sectors and with $= mkt$:

$$PE_{i,y}^s = a_0^s + a_1^s r_{i,y} + a_2^s EXPFE_{i,y} + a_3^s ERP_{i,y} + RPE_{i,y}^s$$

To ensure comparability with the GFSR, we use a regression design with a cross-section of countries, investigating whether the countries that are more exposed to foreign climate risks have

lower price-to-earnings ratios. We fix the year $y = 2018$. In the second step, we regress the residual P/E ratios in, RPE_i^S , on the upstream and downstream exposures to foreign risks with a pooled regression of all sectors. We control for sector fixed effects (we only show the regression for upstream exposures. The regression for downstream exposures is just to replace U_i with D_i):

$$RPE_i^S = b * U_i + \zeta^S + \epsilon_i^S$$

The results are presented in Columns 1–2 of Table 8. The home-country P/E ratio for the average sector is negatively associated with exposures to upstream and downstream foreign climate risks. One standard deviation increase in the exposures to upstream and downstream foreign climate risks corresponds to about 0.05 standard deviation decline in the P/E ratio. Inter-quartile increase in exposures to foreign risks is associated with a reduction in the P/E ratio by about 3.0 for upstream risks and about 3.7 for downstream risks.

We confirm that international trade is also the key spillover channel of foreign climate risks. We show that the tradable sectors are more negatively associated with the same foreign climate risks than the non-tradable sectors. We first look at a typical tradable sector: the industrial producers sector, and a typical non-tradable sector: the real estate sector. We consider the following regressions:

$$\begin{aligned} RPE_i^{S=INDUS} &= b_0^{S=INDUS} + b_1^{S=INDUS} * U_i + \epsilon_{i,t}^S \\ RPE_i^{S=RLEST} &= b_0^{S=RLEST} + b_1^{S=RLEST} * U_i + \epsilon_{i,t}^S \end{aligned}$$

Columns 3–6 of Table 8 show that the industrial producers sector's P/E ratios are strongly negatively correlated with upstream and downstream foreign climate risks. There is no significant correlation between the real estate sector's P/E ratios and foreign climate risks.

Next, we include the interaction between the importing tradability and the upstream exposures to foreign climate risks as the regressor. We consider the following specification (we use the exporting tradability to interact with the downstream exposures)³²:

$$RPE_i^S = b U_i + c TDIM^S * U_i + \zeta^S + \epsilon_i^S$$

We control for the sector fixed effect. Columns 7–8 show the results. Once the interaction term is introduced, the level effects of upstream and downstream foreign climate risks become insignificant. This indicates that the tradable sectors drive the negative association between foreign climate risk exposures and home-country P/E ratios for the average sector. For the sector at the 50th percentile of importing tradability (food and beverages), one standard deviation increase in exposures to upstream foreign risks is associated with 0.0488 standard deviation decline in the P/E ratio. For the sector with the 25th percentile importing tradability (travel and leisure), the number is 0.0286. For the sector with the 75th percentile importing tradability

³² We also run a similar regression by replacing the country-level upstream foreign climate risks with a country fixed effect. The estimated coefficient before the interaction term is similar across the two regressions. We stick to the current specification because we would like to compare the result to the level regression before. The current specification also helps us interpret the magnitude of the coefficients.

(industrial producers), the number is 0.0742. One standard deviation increase in the downstream foreign risk exposures is associated with 0.0075, 0.0169, and 0.1066 standard deviation declines for the sector at the 25th (insurance), 50th (media), and 75th (industrial producers) percentiles of exporting tradability, respectively.

The foreign climate risk exposure measures are a weighted sum of the trade shares and foreign climate risks. Therefore, holding fixed the foreign climate risks, openness to trade with all foreign countries can increase the foreign climate risk exposures, making it a confounding factor. We use a robustness test to show that the negative association between the P/E ratios and foreign exposures are not solely driven by openness to trade. We construct placebo upstream and downstream foreign risks by setting the placebo climate risks of all countries to $\frac{1}{N-1}$. A country's placebo upstream foreign climate risks then equal the following:

$$\tilde{U}_i = \frac{1}{N-1} \sum_{j \neq i} S_{ij}$$

$\tilde{U}_i$ denotes the average sales share by all foreign countries to country i . A larger $\tilde{U}_i$ means country i is more important as a global export destination. A country's placebo downstream foreign climate risks equal the following:

$$\tilde{D}_i = \frac{1}{N-1} \sum_{j \neq i} \pi_{ji}$$

$\tilde{D}_i$ denotes the average expenditure share by all foreign countries on country i . A larger $\tilde{D}_{i,t}$ means country i is more important as a global import origin.

The robustness tests concern the following regressions (for the regressions on downstream exposures, just replace $\tilde{U}_{i,t}$ with $\tilde{D}_i$ and $TDIM^S$ with $TDEX^S$):

$$RPE_i^S = \tilde{b} * \tilde{U}_{i,t} + \zeta^S + \epsilon_{i,t}^S$$

$$RPE_i^S = \tilde{c} TDIM^S * \tilde{U}_i + \delta_i + \zeta^S + \epsilon_i^S$$

Columns 9–10 of Table 8 shows that the placebo foreign exposures are not significantly correlated with the P/E ratios in the home country. If anything, the correlation is weakly positive. Columns 11–12 find the interaction between the placebo foreign exposures and the tradability measures is not significantly correlated with the P/E ratios in the home country, either. This shows that openness to trade alone cannot explain the negative association between the home-country P/E ratios and exposures to foreign climate risks. Rather, the key driver for the negative correlation is to trade with the countries that have high climate risk exposures.

In sum, in this section, we do not find strong correlation between exposure to foreign climate change risk and domestic stock valuations for non-tradable sectors; and we find some correlation for tradable sectors, although the magnitude is tiny. This result suggests that climate change risk

in trade partner countries has not become a major factor in asset valuations at home. However, as we find in the previous sections, the effect of foreign climatic disasters can be significant for tradable sector stock prices at home. As investors gradually incorporate foreign climate risks into domestic asset prices, even if a country is not subject to high degrees of climate change risks, domestic price correction could still happen, especially for tradable sectors due to trade linkages. This is a potential source of financial stability that is less emphasized in the current policy discussion.

VI. CONCLUSION

Climate change presents a major challenge to the economic wellbeing of all countries, and the economic effect of climatic disasters can be extremely devastating. Building resilience against climate shocks is important to enhancing macrofinancial stability. However, there is also a global aspect to climate risk: international trade and supply chain linkages can transmit climate risk across country borders. A climatic disaster that happens to any part of the sophisticated and interconnected global supply chain can have significant macrofinancial implications on other countries that share the same network.

In this paper, we find consistent evidence that foreign climatic disasters can have negative effects on the asset prices of the aggregate market and tradable sectors in trade partner countries. These results argue that enhancing resilience against climate risk through adaptation efforts is a common responsibility for all countries. We note that the exact financial stability implications from these effects on asset prices depend on many country-specific factors, such as the size of tradable sectors to the overall economy and the exposure of domestic banks to tradable sectors. Quantifying the effect on individual countries' financial stability requires further modeling assumptions calibrated to each country. We also acknowledge that many small island countries (for example, the Pacific and Caribbean island countries) might not have been fully integrated into the global supply chain, but are in fact often the most vulnerable to climatic disasters. For these countries, incorporating the cross-border spillovers through trade, which is documented in this paper, is an argument strong enough to induce sufficient adaptation efforts for this important part of the world. In other words, global climate change adaptation requires collective policy action internationally, in addition to domestic and cross-border economic incentives.

While this paper focuses on the physical climate risk, the conceptual framework and analytical method could be applied to understand the transition risk and decarbonization efforts in response to climate change as well. The framework is also readily applicable to the cross-border spillovers of other crises, for example, COVID-19, among others. The methodology may also be extended to study the shock spillovers with other means of globalization, for example, multinational production, remittance, tourism, and so on. We also note that other global supply chain characteristics, such as input-specificity, could also significantly affect the disaster transmission channel and that further empirical tests could be conducted using more granular data. While the current project studies the spillovers of climate shocks across country borders, the same techniques could be applied to a more regional setting, to firm-to-firm trade and within-firm trade as well. While the paper focuses on the asset price implications, more works could be done for the impact on the real economy, for example, the labor market, and so on. Going forward, we anticipate more academic and policy research to examine the role of the constantly evolving global supply chain in determining the cross-border implications of climate change. Lastly, the

analysis on differential P/E ratios could alternatively be used to back out the different levels of implied costs of capital across countries that are associated with climate risk. This methodology could be further used to evaluate and quantify the costs and benefits of infrastructure investments that enhance climate resilience.

Figure 1. World trade-to-world GDP ratio

This figure plots the world trade-to-world GDP ratio from 1970 to 2018.

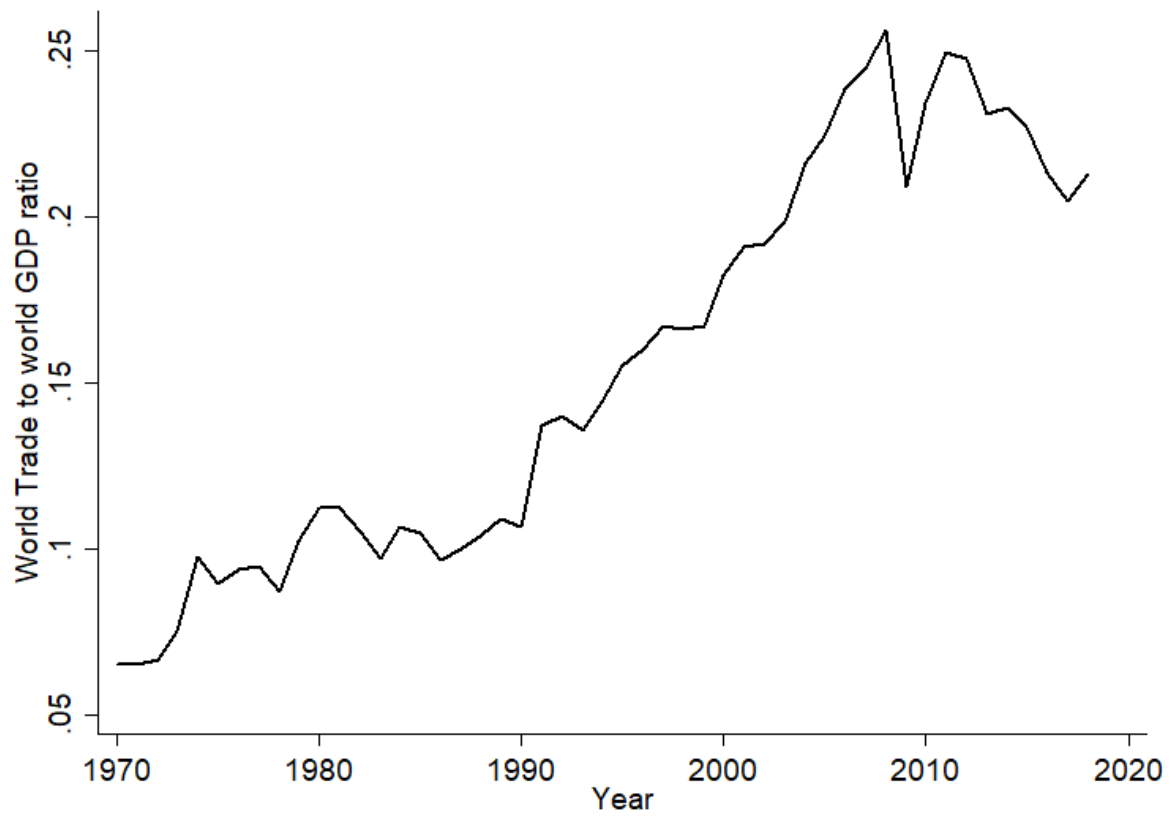


Figure 2. Exposures to global climate shocks for high/low home-country shock groups

The figures plot the upstream and downstream global climatic disaster (risk) exposures for the top/bottom 10 percent of the countries that have the highest/lowest annual average home-country disaster damages (climate risks). Disasters are measured with total deaths. Climate risks are measured with the climate change hazard index. Three-year moving average of the variables is plotted.

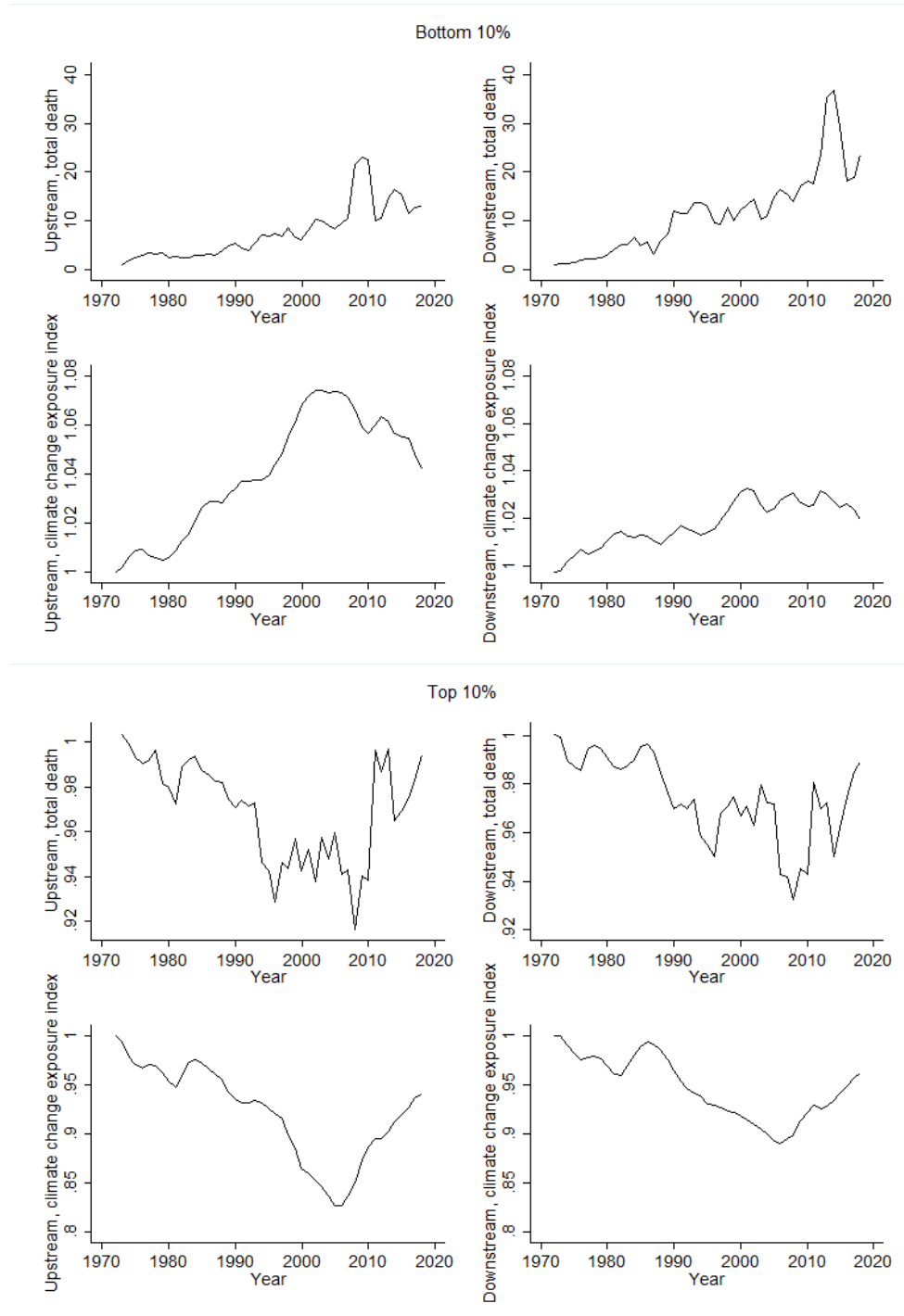


Figure 3. The global spillover index of climate shock exposures

The figures plot the global spillover index of exposures to climatic disasters and climate risks. Disasters are measured with total deaths. Climate risks are measured with the climate change hazard index. Variables take a three-year moving average. The vertical line marks year 2008—the financial crisis.

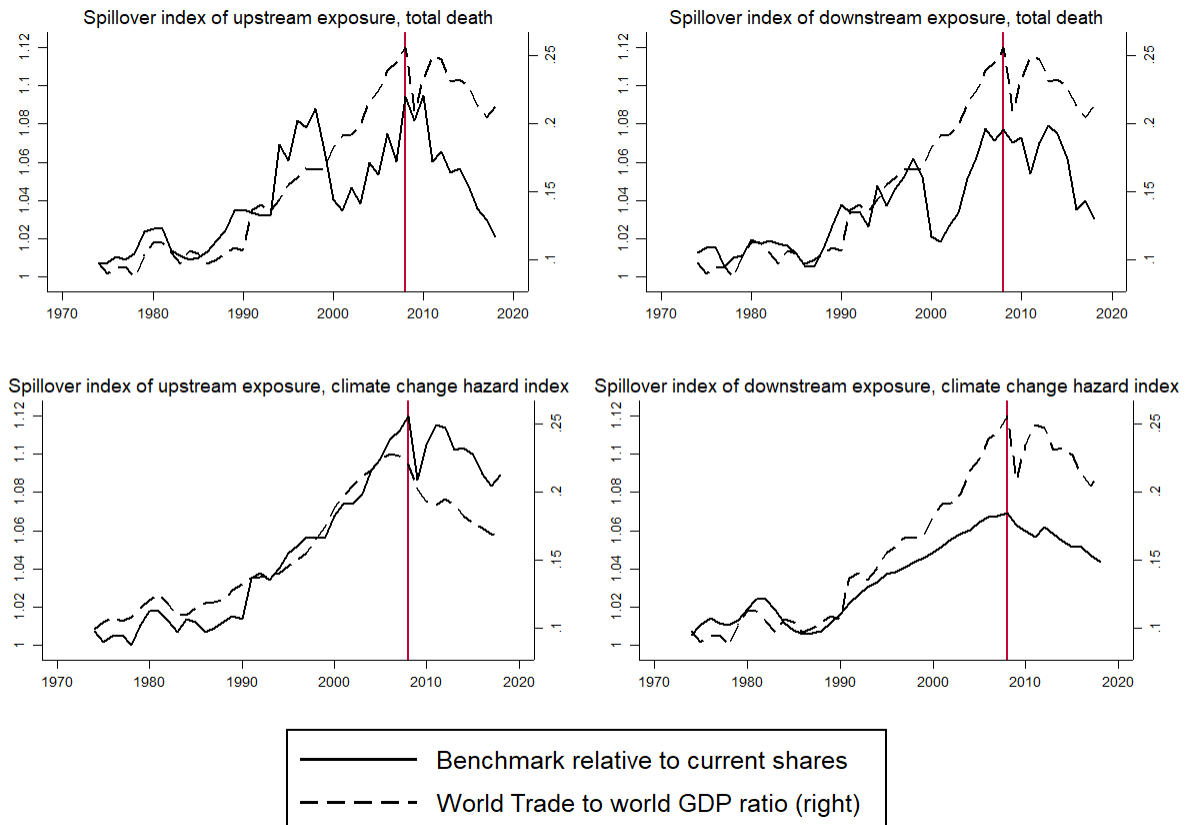


Figure 4. The spillover of upstream climatic disasters

The figures plot cumulative abnormal returns in the market and sector level stock indexes in response to upstream climatic disasters.

Figure 4(a): Market

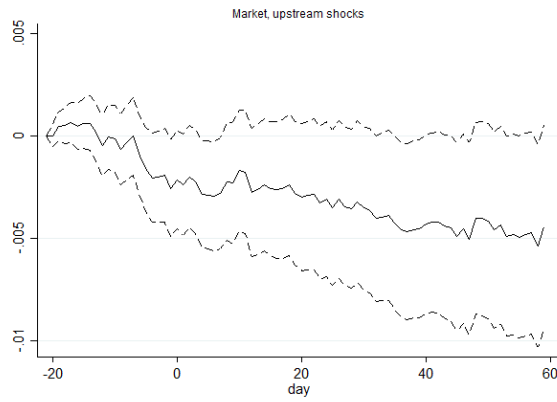


Figure 4(b): Automobiles and parts

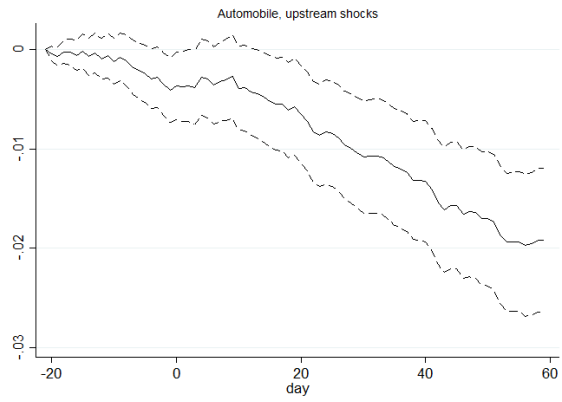


Figure 4(c): Banks

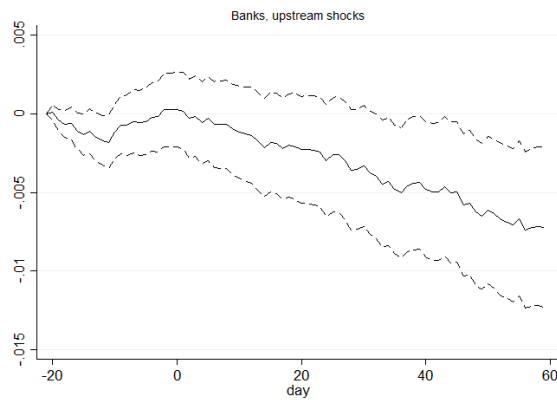


Figure 4(d): Basic materials

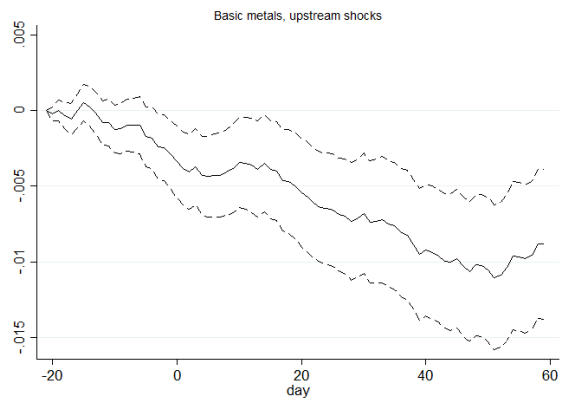


Figure 4(e): Basic resources

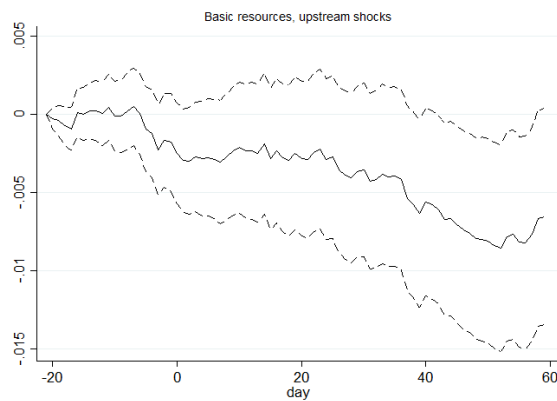


Figure 4(f): Chemicals

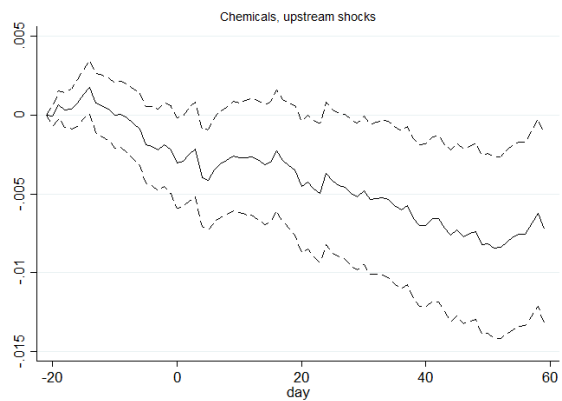


Figure 4(g): Construction and materials



Figure 4(h): Food and beverages



Figure 4(i): Financial services

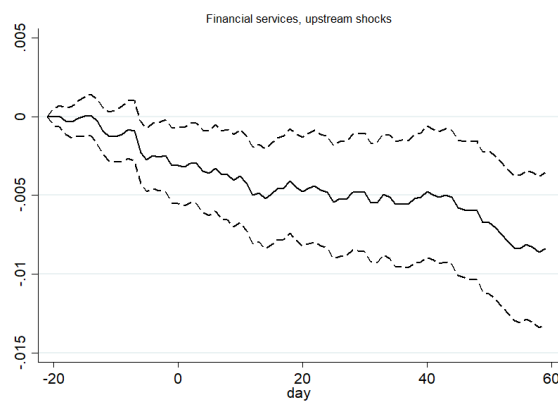


Figure 4(j): Food producers

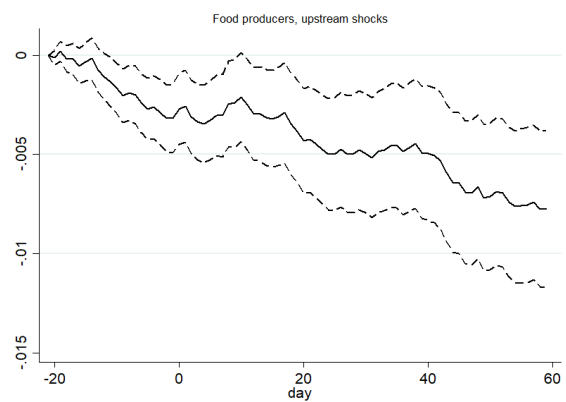


Figure 4(k): Household goods and home construction

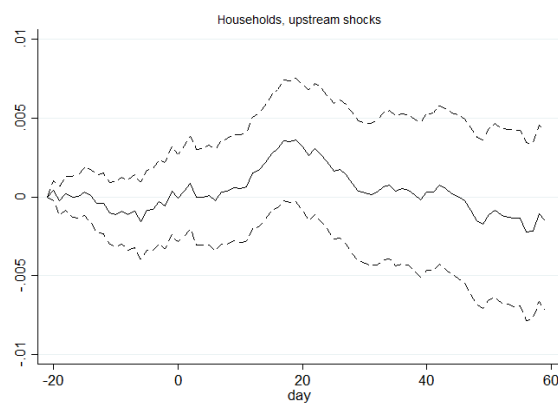


Figure 4(l): Utilities

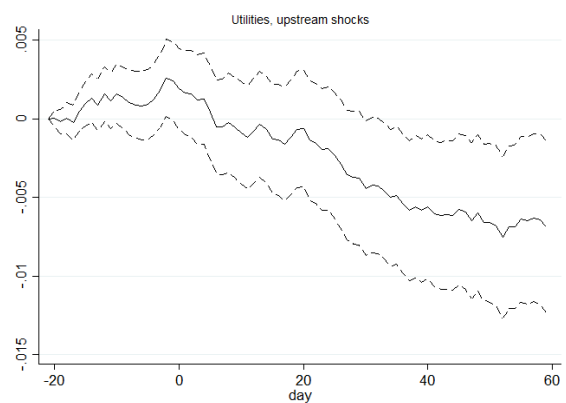


Figure 4(m): Industrial goods

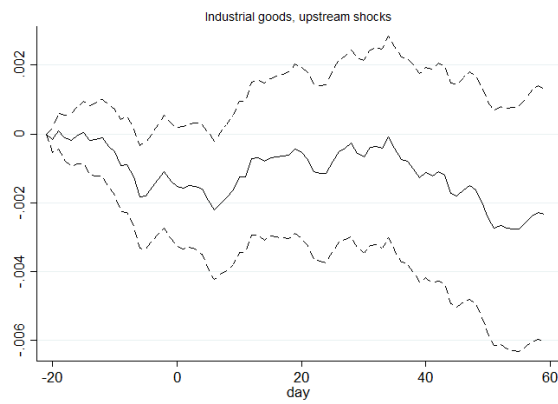


Figure 4(n): Industrial producers



Figure 4(o): Insurance

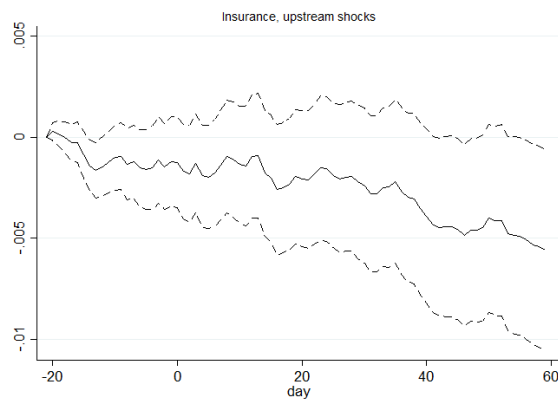


Figure 4(p): Life insurance

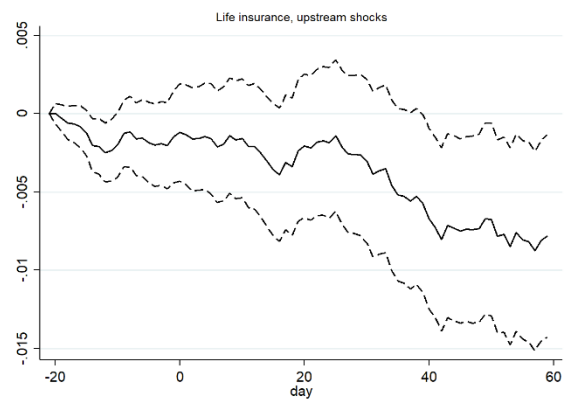


Figure 4(q): Media and communication sector

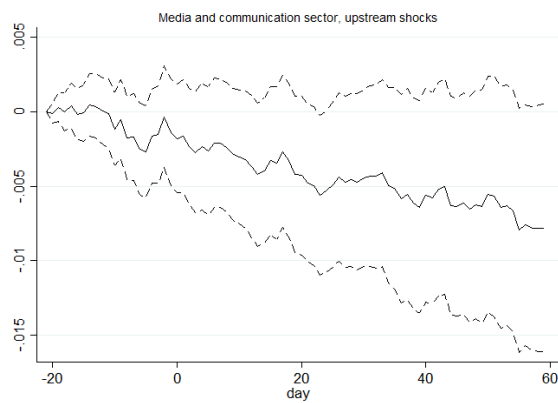


Figure 4(r): Non-life insurance

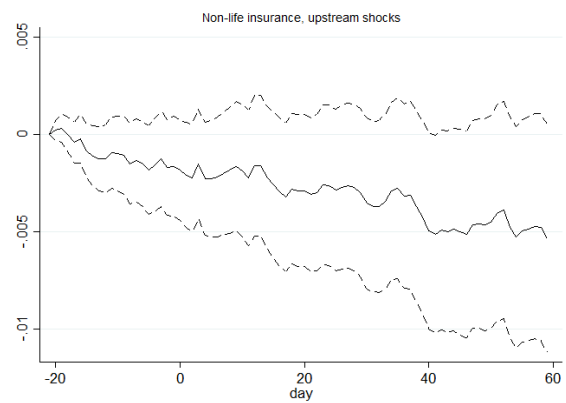


Figure 4(s): Property and casualty insurance



Figure 4(t): Reinsurance

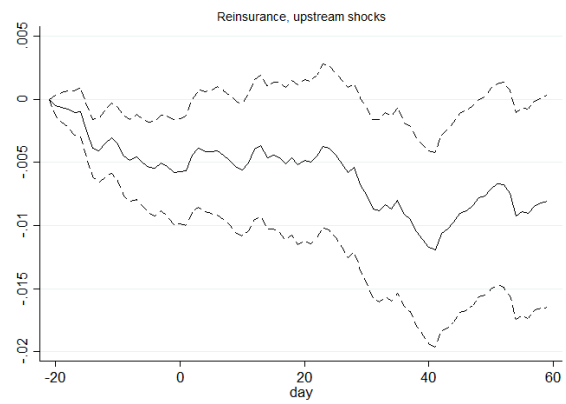


Figure 4(u): Real estate

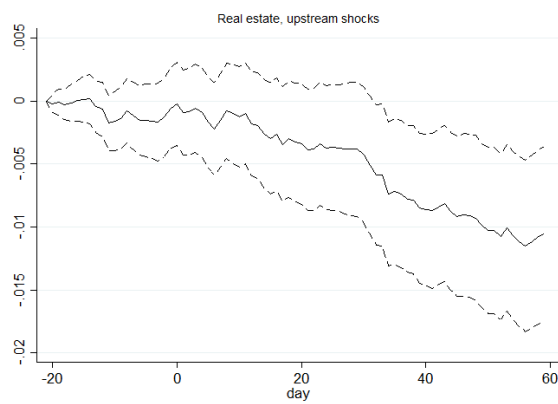


Figure 4(v): Retail

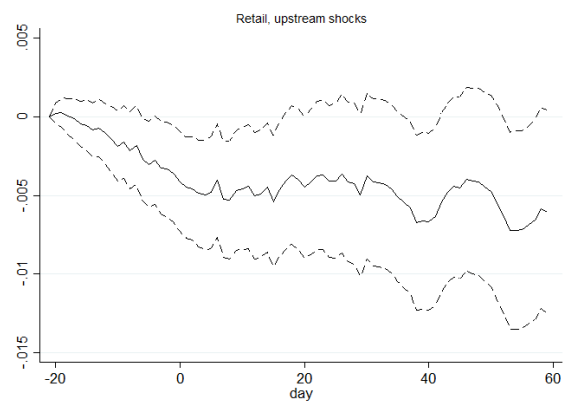


Figure 4(w): Technology

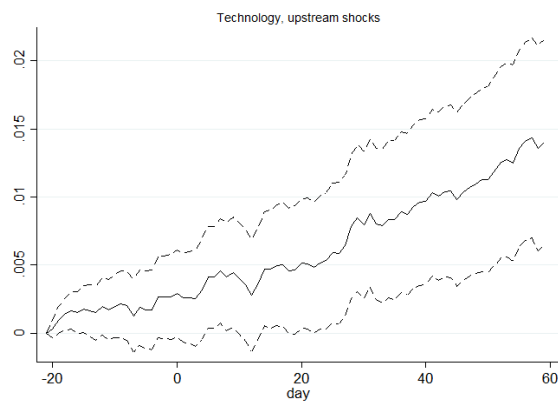


Figure 4(x): Telecommunications

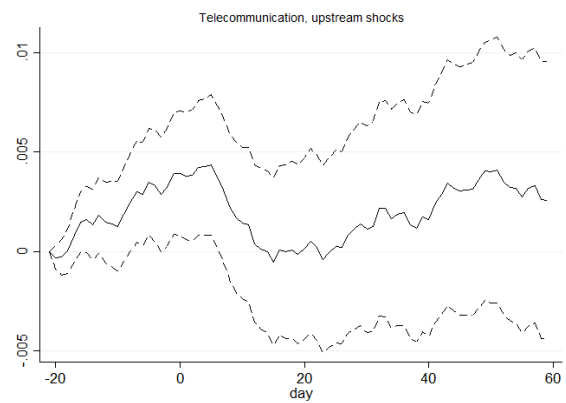


Figure 4(y): Travel and leisure



Figure 5. The spillover of downstream climatic disasters

The figures plot cumulative abnormal returns in the market and sector level stock indexes in response to downstream climatic disasters.

Figure 5(a): Market



Figure 5(b): Automobiles and parts

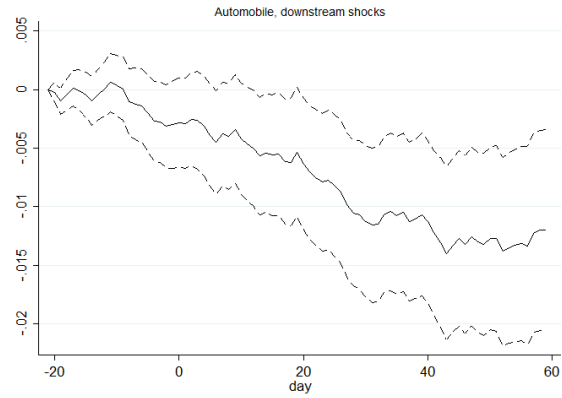


Figure 5(c): Banks

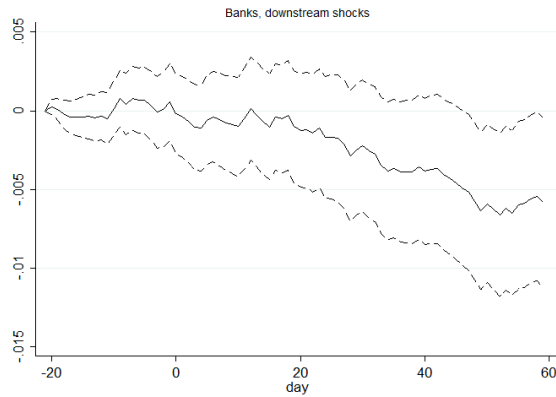


Figure 5(d): Basic materials

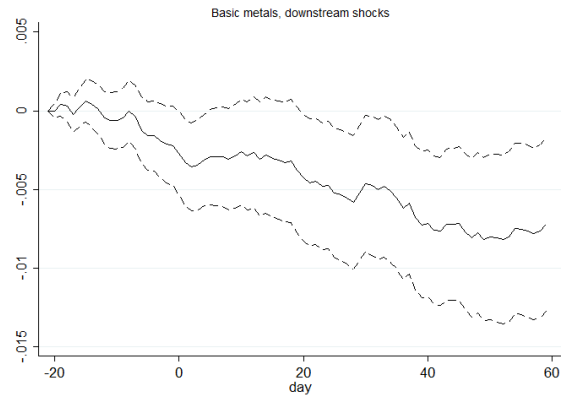


Figure 5(e): Basic resources

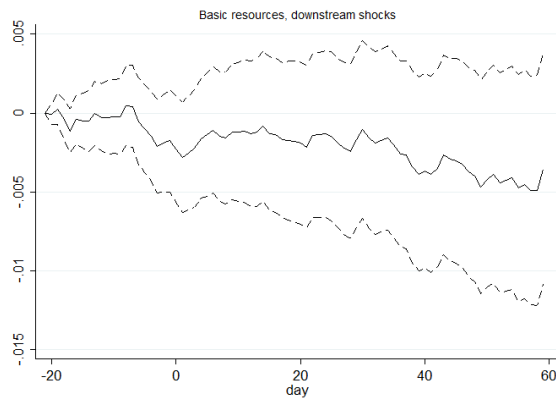


Figure 5(f): Chemicals

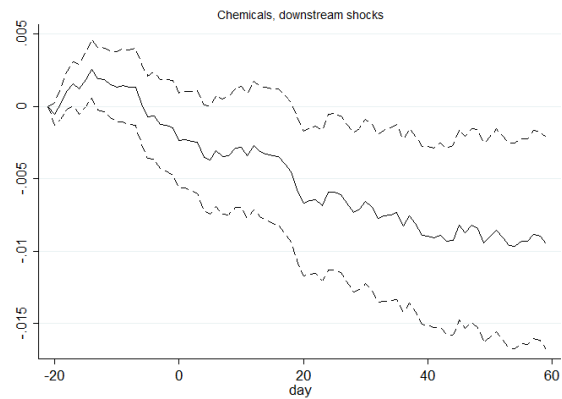


Figure 5(g): Construction and materials



Figure 5(h): Food and beverages

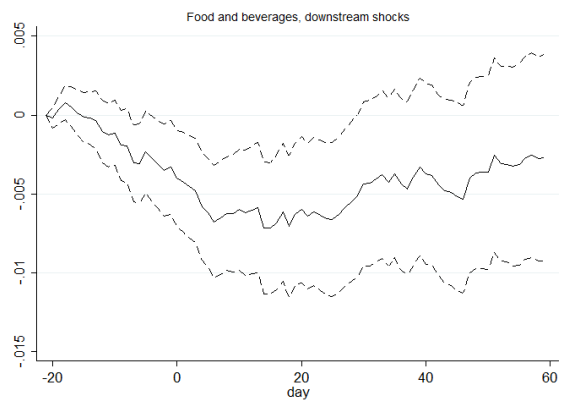


Figure 5(i): Financial services

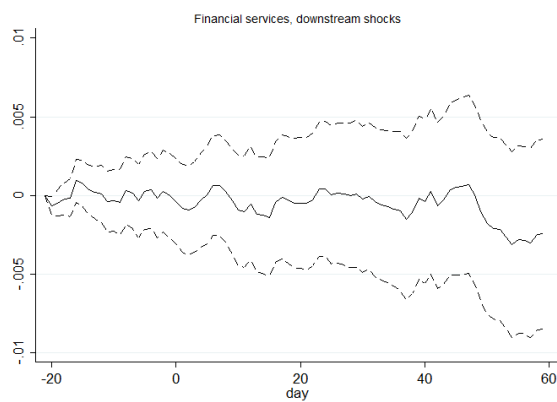


Figure 5(j): Food producers

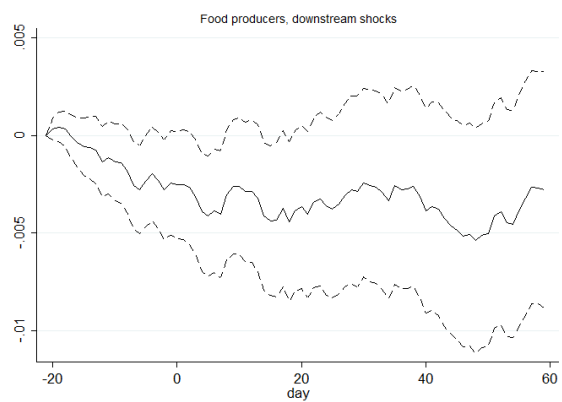


Figure 5(k): Household goods and home construction

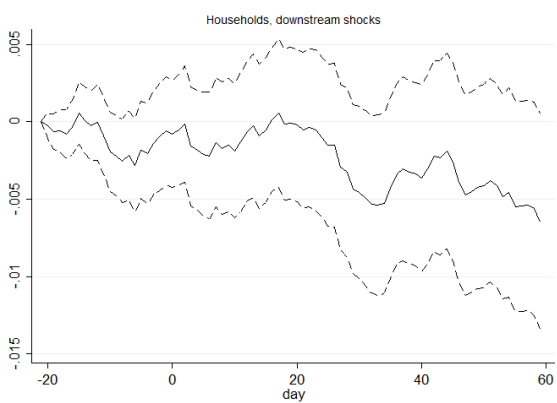


Figure 5(l): Utilities

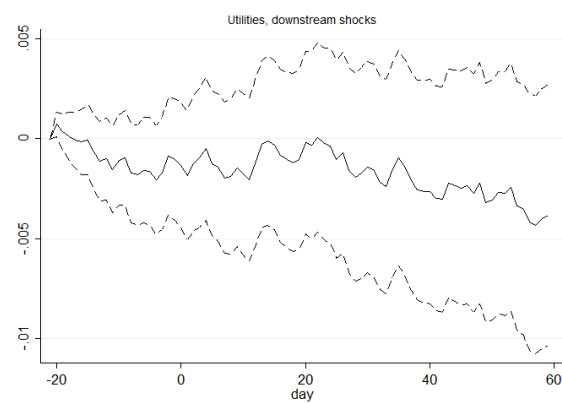


Figure 5(m): Industrial goods

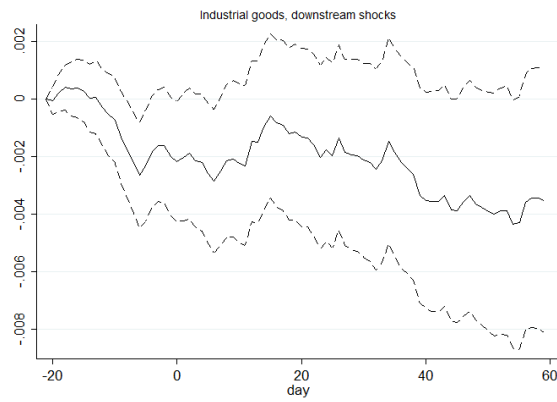


Figure 5(n): Industrial producers



Figure 5(o): Insurance

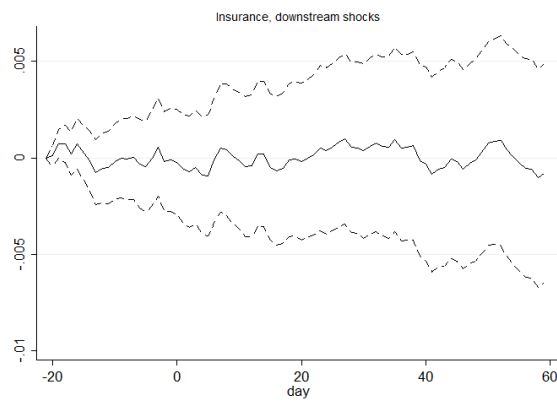


Figure 5(p): Life insurance



Figure 5(q): Media and communication sector

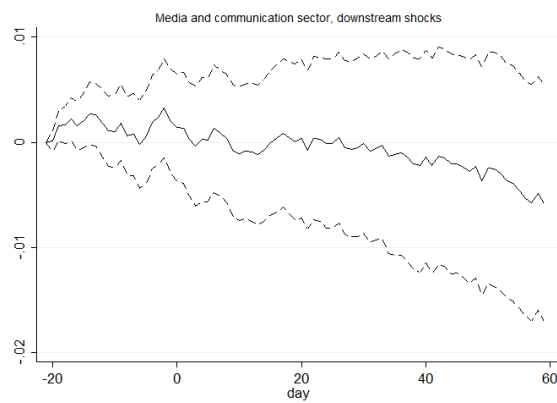


Figure 5(r): Non-life insurance

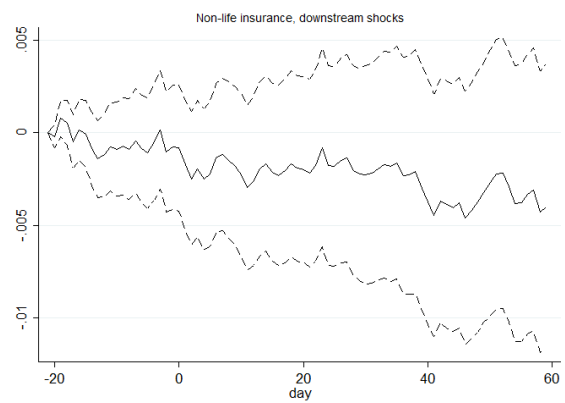


Figure 5(s): Property and casualty insurance



Figure 5(t): Reinsurance

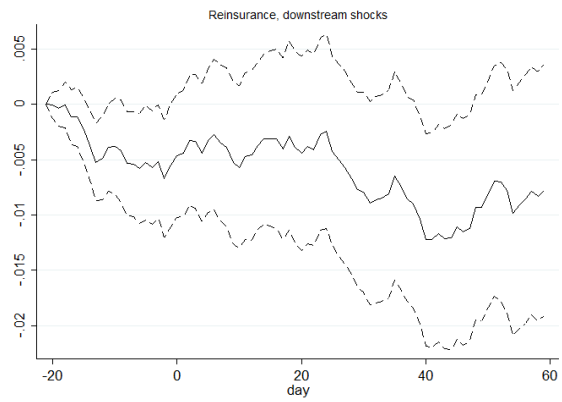


Figure 5(u): Real estate

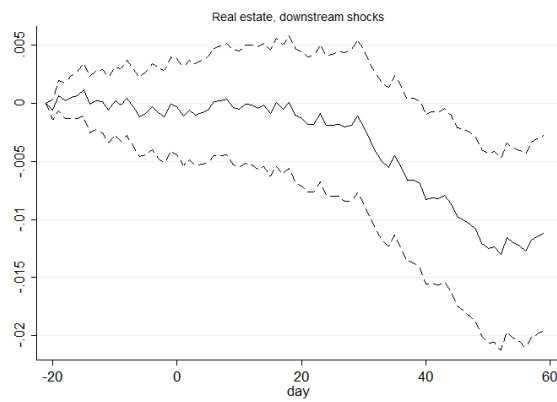


Figure 5(v): Retail



Figure 5(w): Technology

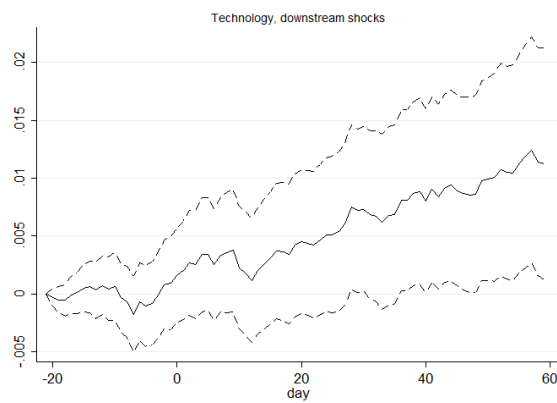


Figure 5(x): Telecommunications

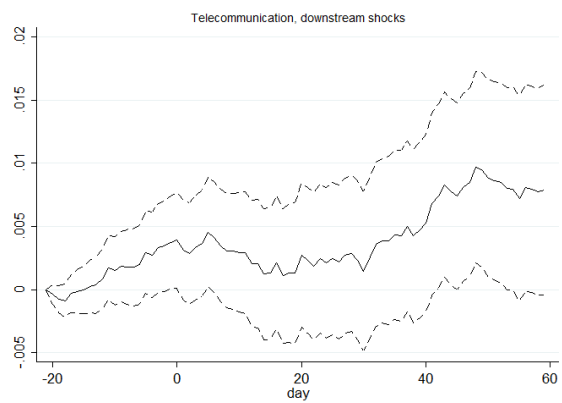


Figure 5(y): Travel and leisure

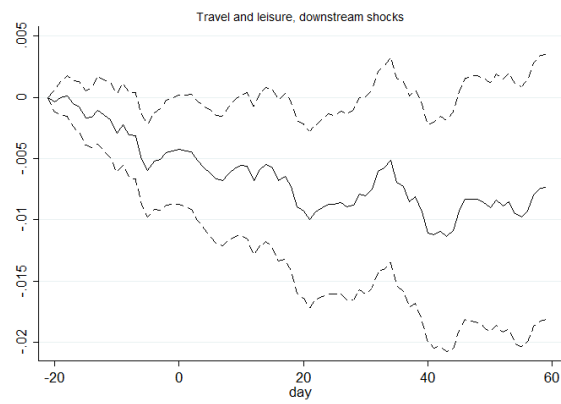


Figure 6. Non-major trade partner's stock market does not respond to the disaster

The figures plot cumulative abnormal returns in the market indexes of the 35th largest (median) exporting-importing partner of the disaster-hit country.

Figure 6(a): Placebo, upstream

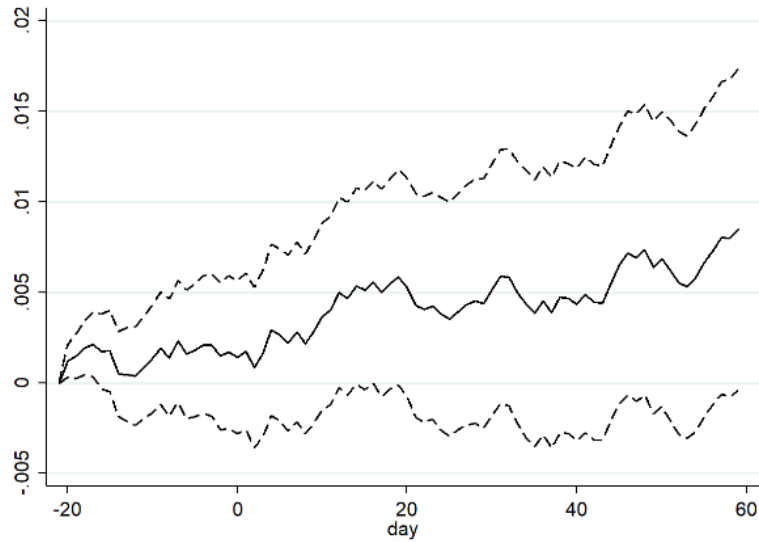


Figure 6(b): Placebo, downstream

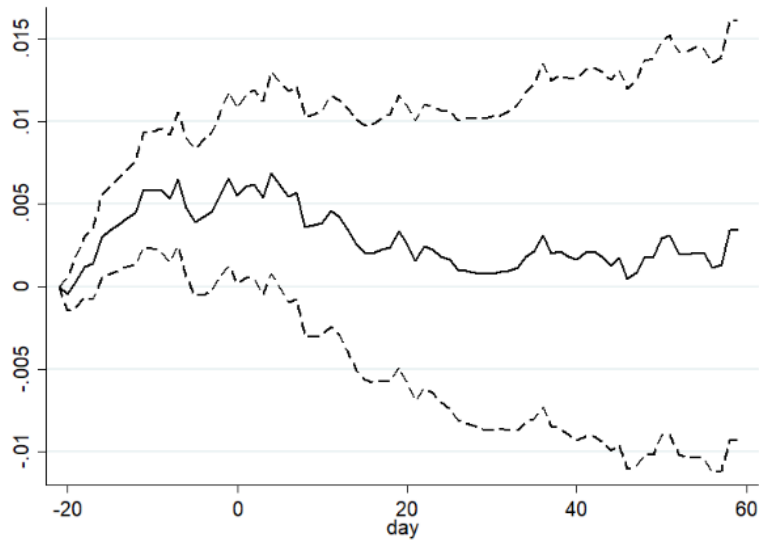


Table 1. Sample economies

This table shows the sample economies and whether these economies are included in other international input-output databases, including Johnson and Noguera (2017), the WIOD, and the OECD AAMNE. A “1” indicates that the economy is included in the column database. A “0” indicates that the economy is not included.

Advanced Economies				Emerging Market and Developing Economies			
Sample	Johnson and Noguera	WIOD	OECD AAMNE	Sample	Johnson and Noguera	WIOD	OECD AAMNE
AUS	1	1	1	ARE	0	0	0
AUT	1	1	1	ARG	1	0	1
BEL	1	1	1	BGR	0	1	1
CAN	1	1	1	BHR	0	0	0
CHE	1	0	1	BRA	1	1	1
CYP	0	1	1	CHL	1	0	1
CZE	1	1	1	CHN	1	1	1
DEU	1	1	1	COL	0	0	1
DNK	1	1	1	EGY	0	0	0
ESP	1	1	1	HRV	0	0	0
EST	1	1	1	HUN	1	1	0
FIN	1	1	1	IDN	1	1	0
FRA	1	1	1	IND	1	1	0
GBR	1	1	1	JOR	0	0	0
GRC	1	1	1	KWT	0	0	0
HKG	0	0	1	LKA	0	0	0
IRL	1	1	1	MAR	0	0	1
ISR	1	0	1	MEX	1	1	1
ITA	1	1	1	MYS	0	0	1
JPN	1	1	1	NGA	0	0	0
KOR	1	1	1	OMN	0	0	0
LTU	0	1	1	PAK	0	0	0
LUX	0	1	1	PER	0	0	0
MLT	0	1	1	PHL	0	0	1
NLD	1	1	1	POL	1	1	1
NOR	1	0	1	QAT	0	0	0
NZL	1	0	1	ROU	1	1	1
PRT	1	1	1	RUS	1	1	1
SGP	0	0	1	SAU	0	0	1
SVK	1	1	1	THA	1	0	1
SVN	1	1	1	TUR	1	1	1
SWE	1	1	1	VEN	0	0	0
TWN	0	1	1	VNM	1	0	1
USA	1	1	1	ZAF	1	0	1

Table 2(a). Concordance between the Datastream sectors and the ISIC sectors

Table 2(a): Concordance between the Datastream sectors and the aggregate sectors

Datastream sectors	Datastream sector names	Aggregate sectors
MRKTS	market	MRKTS
AUTMB	automobiles and parts	AUTMB
BANKS	banks	FINSV
BMATR	basic materials	BMATR
BRESR	basic resources	BRESR
CHMCL	chemicals	CHMCL
CNSTM	construction and materials	CNSTM
FDBEV	food and beverages	FDBEV
FINSV	financial services	FINSV
FOODS	food producers	FDBEV
HHOLD	household goods and home construction	HHOLD
HLTHC	healthcare	HLTHC
INDGS	industrial goods	INDUS
INDUS	industrial producers	INDUS
INSUR	insurance	INSUR
LFINS	life insurance	INSUR
MEDIA	media and communication sector	MEDIA
NLINS	non-life insurance	INSUR
PCINS	property and casualty insurance	INSUR
REINS	reinsurance	INSUR
RLEST	real estate	RLEST
RTAIL	retail	RTAIL
TECNO	technology	TECNO
TELCM	telecommunications	TELCM
TRLES	travel and leisure	TRLES
UTILS	utilities	UTILS

Table 2(b). Concordance between the WIOD 2016 release sectors and the aggregate sectors

The WIOD 2016 release sectors are based on ISIC Rev. 4 classifications.
Find details in Timmer and others (2015).

WIOD sector num	WIOD sectors	Aggregate sectors	WIOD sector num	WIOD sectors	Aggregate sectors
1	A01	FDBEV	29	G46	RTAIL
2	A02	BRESR	30	G47	RTAIL
3	A03	FDBEV	31	H49	INDUS
4	B	BRESR	32	H50	INDUS
5	C10-C12	FDBEV	33	H51	INDUS
6	C13-C15	HHOLD	34	H52	INDUS
7	C16	BRESR	35	H53	INDUS
8	C17	BRESR	36	I	TRLES
9	C18	MEDIA	37	J58	MEDIA
10	C19	CHMCL	38	J59_J60	MEDIA
11	C20	CHMCL	39	J61	TELCM
12	C21	HLTHC	40	J62_J63	TECNO
13	C22	CHMCL	41	K64	FINSV
14	C23	BMATR	42	K65	INSUR
15	C24	BMATR	43	K66	FINSV
16	C25	BMATR	44	L68	RLEST
17	C26	INDUS	45	M69_M70	Other
18	C27	INDUS	46	M71	TECNO
19	C28	INDUS	47	M72	TECNO
20	C29	AUTMB	48	M73	TECNO
21	C30	AUTMB	49	M74_M75	TECNO
22	C31_C32	HHOLD	50	N	Other
23	C33	AUTMB	51	O84	Other
24	D35	UTILS	52	P85	Other
25	E36	UTILS	53	Q	Other
26	E37-E39	UTILS	54	R_S	Other
27	F	CNSTM	55	T	Other
28	G45	RTAIL	56	U	Other

Table 3. Summary statistics

This table shows the summary statistics of the key variables used in the analysis. All variables are winsorized at top and bottom 1 percent to reduce the impact of the outliers on the results. Observations for variables damage, death, affected, damage_to_disaster_c_GDP, nor_up_damage, nor_down_damage, and CAR_MRKTS40 are on the climatic disaster level. Observations for TDIM and TDEX are on the aggregate sector level. Observations for the factoring-to-GDP ratio and the bank regulatory capital-to-risk-weighted assets ratio are on the country-year level. Observations for exposure, u_exposure, d_exposure, and RPE_MRKTS are on the country level.

Variable	N	mean	sd	1%	5%	25%
damage	5324	7.83E+05	4.01E+06	5.00E+01	8.55E+02	1.30E+04
death	5324	113	971	0	0	2
affected	5324	1.36E+06	1.04E+07	0.00E+00	0.00E+00	2.40E+01
damage_to_disaster_c_GDP	5324	9.14E-04	4.06E-03	1.47E-07	1.31E-06	1.96E-05
$S_{n_1 i(d), y(d)}$	5324	0.0313	0.0315	0.0036	0.0068	0.0107
$\pi_{i(d), n_2 y(d)}$	5324	0.0274	0.0273	0.0037	0.0061	0.0121
nor_up_damage	5324	1.23E-05	1.16E-04	4.02E-10	3.40E-09	7.58E-08
nor_down_damage	5324	1.29E-05	7.45E-05	4.31E-10	3.29E-09	8.92E-08
CAR_MRKTS40	4960	-0.0047	0.0605	-0.1965	-0.1012	-0.0334
TDIM	20	0.1804	0.1536	0.0123	0.0311	0.0624
TDEX	20	0.3181	0.3250	0.0027	0.0091	0.0830
factoring_to_gdp (%)	712	2.9	3.7	0.0	0.1	0.5
regulatory_to_assets (%)	651	14.4	3.6	8.2	10.3	12.2
exposure	57	0.0108	1.0400	-1.4100	-1.4000	-0.6818
u_exposure	57	-0.0055	0.1443	-0.5753	-0.1802	-0.0537
d_exposure	57	-0.0166	0.1312	-0.6636	-0.1825	-0.0634
RPE_MRKTS	57	-0.7805	3.7447	-8.5697	-6.4680	-2.7556
Variable	50%	75%	95%	99%		
damage	1.00E+05	4.50E+05	2.91E+06	1.16E+07		
death	11	41	283	1399		
affected	4.67E+03	1.05E+05	3.27E+06	2.46E+07		
damage_to_disaster_c_GDP	1.04E-04	4.90E-04	3.75E-03	1.17E-02		
$S_{n_1 i(d), y(d)}$	0.0188	0.0397	0.0981	0.1373		
$\pi_{i(d), n_2 y(d)}$	0.0178	0.0318	0.0854	0.1171		
nor_up_damage	4.50E-07	2.73E-06	3.04E-05	2.06E-04		
nor_down_damage	6.74E-07	3.98E-06	4.69E-05	2.22E-04		
CAR_MRKTS40	-0.0029	0.0255	0.0903	0.1438		
TDIM	0.1346	0.2555	0.5310	0.6004		
TDEX	0.1436	0.5651	0.9694	1.0251		
factoring_to_gdp (%)	1.4	4.0	10.4	13.8		
regulatory_to_assets (%)	13.6	16.2	20.3	25.1		
exposure	-0.2473	0.5402	1.9998	2.1949		
u_exposure	-0.0014	0.0164	0.2104	0.5777		
d_exposure	-0.0002	0.0214	0.1922	0.2920		
RPE_MRKTS	-1.0041	1.7640	6.6599	7.7028		

Table 4. Cross-section analysis: Association between trading day 40's sectoral cumulative abnormal return and the magnitude of the upstream climatic disaster

This table shows the association between the normalized upstream disaster damage and the sector level, 40 trading day cumulative abnormal return in the downstream stock market. The regressions control for the stock market country and year fixed effects. Standard errors are two-way clustered on the stock market country and year level.

Row Δsd refers to the changes in terms of standard errors of the dependent variable associated with one standard deviation increase in the independent variable. Row $\Delta interq$ refers to the changes in the magnitude of the dependent variable associated with increasing the independent variable from its 25th percentile to 75th percentile.

VARIABLES	(1) MRKTS	(2) AUTMB	(3) BANKS	(4) BMATR	(5) BRESR	(6) CHMCL	(7) CNSTM
nor_up_damage	-58.81** (21.61)	-195.9*** (60.71)	31.38 (28.03)	-79.00*** (9.482)	4.902 (27.33)	-132.0*** (24.42)	-51.23 (49.71)
Observations	4,959	4,932	4,937	4,959	4,950	4,957	4,938
FE	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Cluster	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Δsd	-0.0125	-0.0273	0.00699	-0.0171	0.000756	-0.0237	-0.00927
$\Delta interq$	-0.000156	-0.000520	8.33e-05	-0.000210	1.30e-05	-0.000350	-0.000136
VARIABLES	(8) FDBEV	(9) FINSV	(10) FOODS	(11) HHOLD	(12) HLTHC	(13) INDGS	(14) INDUS
nor_up_damage	-98.41** (43.88)	-32.35 (33.10)	-96.22* (52.50)	-34.81 (210.2)	-68.01 (41.90)	-42.11*** (13.55)	-69.95*** (13.77)
Observations	4,874	4,706	4,382	3,806	4,898	4,959	4,959
FE	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Cluster	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Δsd	-0.0198	-0.00754	-0.0210	-0.00700	-0.0133	-0.0122	-0.0199
$\Delta interq$	-0.000261	-8.58e-05	-0.000255	-9.24e-05	-0.000181	-0.000112	-0.000186
VARIABLES	(15) INSUR	(16) LFINS	(17) MEDIA	(18) NLINS	(19) PCINS	(20) REINS	(21) RLEST
nor_up_damage	-75.22 (46.12)	-70.93 (56.77)	33.58 (77.50)	-22.93 (58.01)	-58.24 (61.63)	-325.2 (299.6)	-54.24 (57.20)
Observations	4,937	4,517	4,753	4,887	4,766	2,719	4,859
FE	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Cluster	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Δsd	-0.0162	-0.0120	0.00482	-0.00431	-0.00879	-0.0568	-0.00860
$\Delta interq$	-0.000200	-0.000188	8.91e-05	-6.08e-05	-0.000155	-0.000863	-0.000144
VARIABLES	(22) RTAIL	(23) TECNO	(24) TELCM	(25) TRLES	(26) UTILS		
nor_up_damage	-42.62 (69.39)	42.05 (46.22)	91.11 (57.21)	-46.15 (37.86)	1.003 (29.42)		
Observations	4,937	4,503	4,860	4,755	4,858		
FE	n; y	n; y	n; y	n; y	n; y		
Cluster	n; y	n; y	n; y	n; y	n; y		
Δsd	-0.00737	0.00659	0.0157	-0.00630	0.000197		
$\Delta interq$	-0.000113	0.000112	0.000242	-0.000123	2.66e-06		

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 5. Cross-section analysis: Association between trading day 40's sectoral cumulative abnormal return and the magnitude of the downstream climatic disaster

This table shows the association between the normalized downstream disaster damage and sector level, trading day 40's (from 21 trading days before the disaster to 40 trading days after the disaster) cumulative abnormal return in the upstream stock market. The regressions control for the stock market country and year fixed effects. Standard errors are two-way clustered on the stock market country and year level. Row Δsd refers to the changes in terms of standard errors of the dependent variable associated with one standard deviation increase in the independent variable. Row $\Delta interq$ refers to the changes in the magnitude of the dependent variable associated with raising the independent variable from its 25th percentile to 75th percentile.

VARIABLES	(1) MRKTS	(2) AUTMB	(3) BANKS	(4) BMATR	(5) BRESR	(6) CHMCL	(7) CNSTM
nor_down_damage	-37.25* (20.57)	-133.4*** (26.29)	-0.854 (23.67)	-46.73** (20.77)	8.032 (46.50)	-115.9*** (12.17)	-24.88 (31.56)
Observations	4,414	4,364	4,404	4,414	4,401	4,391	4,385
FE	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Cluster	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Δsd	-0.00491	-0.0124	-0.000143	-0.00731	0.000951	-0.0132	-0.00317
$\Delta interq$	-0.000145	-0.000519	-3.32e-06	-0.000182	3.12e-05	-0.000451	-9.68e-05
VARIABLES	(8) FDBEV	(9) FINSV	(10) FOODS	(11) HHOLD	(12) HLTHC	(13) INDGS	(14) INDUS
nor_down_damage	-76.52** (34.06)	-48.79 (32.51)	-75.55* (38.41)	-179.8 (214.6)	20.34 (55.81)	-47.72* (23.75)	-73.54** (25.58)
Observations	4,330	3,976	3,398	3,000	4,354	4,414	4,407
FE	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Cluster	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Δsd	-0.0100	-0.00750	-0.0117	-0.0266	0.00249	-0.00859	-0.0131
$\Delta interq$	-0.000298	-0.000190	-0.000294	-0.000700	7.91e-05	-0.000186	-0.000286
VARIABLES	(15) INSUR	(16) LFINS	(17) MEDIA	(18) NLINS	(19) PCINS	(20) REINS	(21) RLEST
nor_down_damage	-56.41** (25.52)	-61.97* (31.33)	45.20 (70.58)	-40.17 (33.20)	-106.3* (51.90)	-715.3* (315.2)	-18.94 (43.18)
Observations	4,374	3,605	4,027	4,286	4,148	1,896	4,309
FE	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Cluster	n; y	n; y	n; y	n; y	n; y	n; y	n; y
Δsd	-0.00856	-0.00770	0.00349	-0.00464	-0.0101	-0.0932	-0.00196
$\Delta interq$	-0.000219	-0.000241	0.000176	-0.000156	-0.000414	-0.00278	-7.37e-05
VARIABLES	(22) RTAIL	(23) TECNO	(24) TELCM	(25) TRLES	(26) UTILS		
nor_down_damage	-18.27 (31.70)	76.44* (41.00)	61.64 (57.93)	-30.94 (46.45)	59.70 (55.24)		
Observations	4,339	3,634	4,301	4,194	4,332		
FE	n; y	n; y	n; y	n; y	n; y		
Cluster	n; y	n; y	n; y	n; y	n; y		
Δsd	-0.00196	0.00744	0.00683	-0.00267	0.00766		
$\Delta interq$	-7.11e-05	0.000297	0.000240	-0.000120	0.000232		

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Table 6. Cross-section analysis: Association between sector tradability and 40 trading day cumulative abnormal returns from foreign climatic disasters

This table shows the association between sector tradability and trading day 40's (from 21 trading days before the disaster to 40 trading days after the disaster) cumulative abnormal returns from foreign climatic disasters. Column 1 considers a pooled regression with all sectors on the normalized upstream damage. Column 2 considers a pooled regression with all sectors on the normalized downstream damage. Column 3 adds to column 1 an interaction term between the normalized upstream damage and the sector importing tradability. Column 4 adds to column 2 an interaction term between the normalized downstream damage and the sector exporting tradability. The regressions control for the stock market country, the year, and sector fixed effects. Standard errors are two-way clustered on the stock market country and year level. For columns 1–2, row Δsd refers to the changes in terms of standard errors of the dependent variable associated with one standard deviation increase in the independent variable. For columns 3–4, row Δsd refers to the changes in terms of standard errors of the dependent variable associated with one standard deviation increase in the normalized damage, for sectors with the median tradability. For columns 1–2, row $\Delta interq$ refers to the changes in the magnitude of the dependent variable associated with raising the independent variable from its 25th percentile to 75th percentile. For columns 3–4, row $\Delta interq$ refers to the changes in the magnitude of the dependent variable associated with raising the independent variable from its 25th percentile to 75th percentile, for sectors with the median tradability

VARIABLES	1 CAR40	2 CAR40	3 CAR40	4 CAR40
nor_up_damage	-47.20** (22.43)		-6.775 (30.80)	
nor_down_damage		-32.67* (16.37)		-8.964 (16.07)
nor_up_d * TDIM			-246.5*** (56.28)	
nor_down_d * TDEX				-83.74*** (18.96)
Observations	122,576	106,127	122,576	106,127
FE	n; y; s	n; y; s	n; y; s	n; y; s
Cluster	n; y	n; y	n; y	n; y
Δsd	-0.0653	-0.0251	-0.0473	-0.0143
$\Delta interq$	-0.000125	-0.000127	-9.07e-05	-7.21e-05

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Table 7. Cross-section analysis: Association between country institutional factors and trading day 40's cumulative abnormal returns from foreign climatic disasters in the financial sector

This table shows the association between country institutional factors and trading day 40's (from 21 trading days before the disaster to 40 trading days after the disaster) cumulative abnormal returns from foreign climatic disasters in the financial sector. The financial sector refers to the banking sector and other financial services (asset managers, consumer finance, specialty finance, investment services, and mortgage finance). The institutional factors we consider are total factoring volume-to-GDP (%), as well as bank regulatory capital-to-risk-weighted assets (%). Column 1 regresses trading day 40's cumulative abnormal returns in the financial sector on the normalized upstream damage and the one-year lag of the total factoring volume-to-GDP. Column 2 regresses trading day 40's cumulative abnormal returns in the financial sector on the normalized upstream damage and the one-year lag of the bank regulatory capital-to-risk-weighted assets ratio. Column 3 regresses trading day 40's cumulative abnormal returns in the financial sector on the normalized downstream damage and the one-year lag of the total factoring volume-to-GDP. Column 4 regresses trading day 40's cumulative abnormal returns in the financial sector on the normalized downstream damage and the one-year lag of the bank regulatory capital-to-risk-weighted assets ratio. Standard errors are two-way clustered on the stock market country and year level.

VARIABLES	1 CAR40	2 CAR40	3 CAR40	4 CAR40
nor_up_damage	-57.00 (210.3)	-148.7 (241.6)		
nor_down_damage			-9.707 (18.68)	-24.59 (22.60)
factoring_to_gdp (%)	0.00108** (0.000373)		0.00105** (0.000406)	
regulatory_to_assets (%)		0.00213*** (0.000559)		0.00250* (0.00141)
Observations	6,531	5,611	5,345	4,377
Cluster	n; y	n; y	n; y	n; y

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Table 8. Association between exposures to foreign climate risks and the home-country P/E ratios

This table shows the association between the home-country residual P/E ratios and the upstream and downstream exposures to foreign climate risks. Column 1 shows the impact of the upstream foreign climate risk exposures for the pool of all sectors. Column 2 shows the impact of the downstream foreign climate risk exposures for the pool of all sectors. Column 3 shows the impact of the upstream foreign climate risk exposure on the residual P/E ratio for the industrial producers sector. Column 4 shows the impact of the upstream foreign climate risk exposure on the residual P/E ratio for the real estate sector. Column 5 shows the impact of the downstream foreign climate risk exposure on the residual P/E ratio for the industrial producers sector. Column 6 shows the impact of the downstream foreign climate risk exposure on the residual P/E ratio for the real estate sector. Column 7 adds to column 1 the interaction between the upstream foreign climate risk exposures and the importing tradability. Column 8 adds to column 2 the interaction between the downstream foreign climate risk exposures and the exporting tradability. Column 9 presents the result with the placebo upstream foreign exposures. Column 10 presents the result with the placebo downstream foreign exposures. Columns 11–12 add the interaction between the placebo foreign climate risk exposures and importing and tradability measures. For columns 1–6 and 9–10, row Δsd refers to the changes in terms of standard errors of the dependent variable associated with one standard deviation increase in the independent variable. For columns 7–8 and 11–12, row Δsd refers to the changes in terms of standard errors of the dependent variable associated with one standard deviation increase in the normalized damage, for sectors with the median tradability. For columns 1–6 and 9–10, row $\Delta interq$ refers to the changes in the magnitude of the dependent variable associated with increasing the independent variable from its 25th percentile to 75th percentile. For columns 7–8 and 11–12, row $\Delta interq$ refers to the changes in the magnitude of the dependent variable associated with increasing the independent variable from its 25th percentile to 75th percentile, for sectors with the median tradability.

VARIABLES	(1) Up pooled	(2) Down pooled	(3) Up INDUS	(4) Up RLEST	(5) Down INDUS	(6) Down RLEST	(7) Up interaction
foreign_exp	-43.04*** (15.11)	-43.94** (20.06)	-16.63*** (5.364)	-5.683 (9.329)	-17.65*** (6.449)	-4.623 (9.691)	-9.687 (9.545)
foreign_exp * tradability							-200.3** (75.27)
Observations	1,084	1,084	49	46	49	46	1,084
FE	s	s					s
Cluster	n	n					n
Δsd	-0.0582	-0.0541	-0.176	-0.0558	-0.170	-0.0413	-0.0488
$\Delta interq$	-3.024	-3.731	-1.168	-0.399	-1.499	-0.393	-2.532
VARIABLES	8 Down interaction	9 Up placebo	10 Down placebo	11 Up placebo interaction	12 Down placebo interaction		
foreign_exp	8.901 (8.344)	3.755 (11.89)	2.318 (13.18)	-4.828 (4.717)	-7.013 (4.563)		
foreign_exp * tradability	-174.5** (76.28)			51.45 (53.43)	31.64 (57.97)		
Observations	1,084	1,084	1,084	1,084	1,084		
FE	s	s	s	s	s		
Cluster	n	n	n	n	n		
Δsd	-0.0169	0.00937	0.00614	0.00263	-0.00771		
$\Delta interq$	-1.166	0.552	0.430	0.137	-0.540		

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

REFERENCES

- Addoum, J., D. Ng, and A. Ortiz-Bobea, 2019. *Temperature Shocks and Industry Earnings News*. Available at SSRN 3480695.
- Anttila-Hughes, J.K., and S.M. Hsiang, 2013. *Destruction, Disinvestment, and Death: Economic and Human Losses Following Environmental Disaster*. Available at SSRN 2220501.
- Antras, P., T.C. Fort, and F. Tintelnot, 2017. “The Margins of Global Sourcing: Theory and Evidence from US Firms, *American Economic Review*, 107(9), 2514-64.
- Auboin, M., H. Smythe, and R. Teh, 2016. *Supply Chain Finance and SMEs: Evidence from International Factoring Data*.
- Baldwin, R., and R. Freeman, 2020. “Supply Chain Contagion Waves: Thinking Ahead on Manufacturing ‘Contagion and Reinfection’ from the COVID Concussion,” VoxEU. org.
- Barrot, J.N., and J. Sauvagnat, 2016. “Input Specificity and the Propagation of Idiosyncratic Shocks in Production Networks,” *The Quarterly Journal of Economics*, 131(3), 1543-92.
- BlackRock, 2019. “Getting Physical: Scenario Analysis for Assessing Climate-Related Risks,” BlackRock Investment Institute, <https://www.blackrock.com/ch/individual/en/insights/physical-climate-risks>.
- Burke, M., S.M. Hsiang, and E. Miguel, 2015. “Global Non-Linear Effect of Temperature on Economic Production,” *Nature*, 235-39.
- Cadestin, C., K. De Backer, I. Desnoyers-James, and others, 2018. “Multinational Enterprises and Global Value Chains,” OECD AAMNE Database.
- Caliendo, L., F. Parro, E. Rossi-Hansberg, and others, 2018. “The Impact of Regional and Sectoral Productivity Changes on the US Economy,” *The Review of Economic Studies*, 85(4), 2042-96.
- Carvalho, V.M., M. Nirei, Y. Saito, and others, 2016. “Supply Chain Disruptions: Evidence from the Great East Japan Earthquake,” Columbia Business School Research Paper, (17-5).
- Cerdeiro, D.A., A. Komaromi, Y. Liu, and others, 2020. “World Seaborne Trade in Real Time: A Proof of Concept for Building AIS-Based Nowcasts from Scratch,” IMF Working Paper No. 20/57.
- Chaney, T., 2018. “The Gravity Equation in International Trade: An Explanation,” *Journal of Political Economy*, 126(1), 150-77.
- Dell, M., B.F. Jones, and B.A. Olken, 2012. “Temperature Shocks and Economic Growth: Evidence from the Last Half Century,” *American Economic Journal: Macroeconomics*, 4(3), 66-95.

- Di Giovanni, J., A.A. Levchenko, and I. Mejean, 2018. “The Micro Origins of International Business-Cycle Comovement,” *American Economic Review*, 108(1), 82-108.
- Dingel, J.I., K.C. Meng, and S.M. Hsiang, 2019. “Spatial Correlation, Trade, and Inequality: Evidence from the Global Climate,” National Bureau of Economic Research, No. w25447.
- Eaton, J., S. Kortum, B. Neiman, and others, 2016. “Trade and the Global Recession,” *American Economic Review*, 106(11), 3401-38.
- Hong, H., F. Li, and J. Xu, 2019. “Climate Risks and Market Efficiency,” *Journal of Econometrics*, 208(1), 265-281.
- Hsiang, S.M., 2010. “Temperatures and Cyclones Strongly Associated with Economic Production in the Caribbean and Central America,” proceedings of the National Academy of Sciences of the United States of America 107:15367–72.
- Hsiang, S.M., and A.S. Jina, 2014. “The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence from 6,700 Cyclones,” National Bureau of Economic Research, No. w20352.
- International Monetary Fund, 2020. *Global Financial Stability Report: Markets in the Time of COVID-19*. Washington: International Monetary Fund.
- International Monetary Fund, 2019. *Fiscal Monitor: How to Mitigate Climate Change*. Washington: International Monetary Fund.
- Johnson, R.C., and G. Noguera, 2017. “A Portrait of Trade in Value-Added Over Four Decades,” *Review of Economics and Statistics*, 99(5), 896-911.
- Kahn, M.E., K. Mohaddes, R.N. Ng, and others, 2019. “Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis,” . National Bureau of Economic Research, No. w26167.
- Korniienko, M.Y., M. Pinat, and B. Dew, 2017. “Assessing the Fragility of Global Trade: The Impact of Localized Supply Shocks Using Network Analysis,” IMF Working Paper 17/30.
- Kouvelis, P., and F. Xu, 2019. *A Supply Chain Theory of Factoring and Reverse Factoring*. Available at SSRN 3241484.
- Li, H., and G. Souza, 2020. *The Aggregate Labor Market Consequences of Anti-Dumping Tariffs*. University of Chicago mimeo.
- Leiter, A.M., H. Oberhofer, and P.A. Raschky, 2009. “Creative Disasters? Flooding Effects on Capital, Labour and Productivity Within European Firms,” *Environmental and Resource Economics* 43:333–50.

McKinsey, 2020. “Climate Risk and Response: Physical Hazards and Socioeconomic Impacts.” January.

Strobl, E., 2011. “The Economic Growth Impact of Hurricanes: Evidence from US Coastal Counties,” *Review of Economics and Statistics* 93:575–89.

Timmer, M.P., E. Dietzenbacher, B. Los, and others, 2015. “An Illustrated User Guide to the World Input–Output Database: The Case of Global Automotive Production,” *Review of International Economics*, 23(3), 575-605.

Tingergen, J., 1962. *Shaping the World Economy, An Analysis of World Trade Flows*. New York: Twentieth Century Fund.