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A Parsimonious Model

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Trade Openness and Extreme Events: A Parsimonious Model

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Abstract

Are trade-open economies more vulnerable or less so to extreme events? Extreme events, such as natural disasters, financial crises, and war, are infrequent but have large negative effects on economies. This paper presents a new, parsimonious model of trade openness and extreme events, showing that an economy's vulnerability to extreme events is a nonlinear function of its trade openness. This relationship depends on the probability that a home country experiences extreme events; the probabilities that foreign countries experience the extreme events that have negative effects on trade with the home country; the effect sizes of these extreme events; and the capacity of the home country to minimize the cost from failing to capitalize on comparative advantage. The nonlinear nature is exemplified by Monte Carlo simulation exploring 810 combinations of parameter values and using Irish macroeconomic data as inputs.

JEL Classification Codes: F410, F620

Keywords: extreme event, trade, globalization, simulation, Occam's razor

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1 Introduction

Extreme events, also known as "Black Swan" events (Taleb 2007), are the events that occur only infrequently but have large negative impacts on economies. Examples include natural disasters, financial crises, and war. Most recently, the COVID-19 pandemic and the War in Ukraine have brought renewed attention as to whether trade-open economies are more vulnerable, or less so, to extreme events (e.g., see Baldwin and Freeman 2022; Brunsden and Peel 2020; Clancy, Valenta, and Smith 2023; OECD 2020; Pisani-Ferry, Mauro, and Zettelmeyer 2024).

This paper presents a new, parsimonious model showing that the relationship between the degree of trade openness and the vulnerability to extreme events is nonlinear – the "trade and extreme event" model hereafter. The relationship depends on (1) the probability of a home country experiencing extreme events; (2) the probabilities that foreign countries experience the extreme events that have negative effects on trade with the home country; (3) the effect sizes of these extreme events; and (4) the capacity of the home country to minimize the cost from failing to capitalize on opportunities for efficiency gains through trade, i.e., comparative advantage.

The previous research presents mixed views. Some suggest that less trade openness makes countries economically more vulnerable to extreme events (e.g., Caselli et al. 2020; Clancy, Valenta, and Smith 2023; Grossman, Helpman, and Lhuillier 2021; OECD 2020), while others imply the opposite (e.g., di Giovanni and Levchenko 2009, 2012; Kose, Prasad, and Terrones 2003). The aim of this paper is not to judge the *findings* of these previous studies. Instead, the novelty of its trade and extreme event model is a simple, parsimonious design to facilitate an intuitive understanding of how the nonlinear relationship could, *in theory*, arise between trade openness and the vulnerability to extreme events. Indeed, the previous findings can be accommodated by the trade and extreme event model; they are a reflection or realization of specific parameter values of the model. This paper is an attempt to advance a theoretical understanding, in terms of the scientific principle of Occam's razor: if there are several models, all of which can explain the same point, the simplest one should be selected (e.g., see Rasmussen and Ghahramani 2000).

To illustrate the nonlinearity substantively, the paper utilizes a Monte Carlo simulation. The simulation implements 810 combinations of parameter values, and runs 1,000 iterations per parameter combination to capture the stochastic occurrence of extreme events. The purpose of the simulation is not to examine what the effects of extreme events have been in the past; that would be an empirical study (e.g., see Carvalho et al. 2021). Instead, the simulation is here used as a thought experiment to explore the detailed implications of the theory of the trade and extreme event model. Yet, to make the simulation more realistic, the paper uses as inputs macroeconomic data from the small open economy of Ireland, whose trade-to-GDP ratio has been over 200% since 2014 (and till 2023, the latest time point at the time of writing).[1] Note that the trade and extreme event model is general and applicable to any country or even to a supranational economic entity such as the European Union.

The results of the simulation give detailed insights into the nonlinear relationship between trade openness and the vulnerability to extreme events. Given the parameter combinations employed, there is a greater possibility that a trade reduction policy (modelled to be implemented prior to extreme events) can decrease the loss to the home country compared to no reduction policy, as (1) the cost of lost comparative advantage opportunities becomes smaller or (2) the effect sizes of foreign extreme events become larger. In addition, the results imply that reducing trade can cause a greater loss *in expectation*, but at the same time result in a smaller loss under an *extreme case* of extreme events, than keeping the status quo.

The paper does not aim to give any concrete policy recommendations. Yet, it has two implications. First, the relationship between trade openness and the vulnerability to extreme events is not as simple as linear or even monotonic. It is therefore necessary to do a case-by-case analysis, before deciding whether to keep openness or increase self-

[1]The figures were calculated using the data from the Central Statistics Office (2024b).

sufficiency for reducing the vulnerability to extreme events. Second, given that there seems to be a growing effect of political divisions on international economic relations (Aiyar, Ilyina, et al. 2023), policymakers might be compelled to reconfigure, and reduce, some of the existing trade relationships. While the literature argues that such "geoeconomic fragmentation" leads to economic inefficiency in general (Aiyar, Ilyina, et al. 2023; Javorcik et al. 2023; Goes and Bekkers 2023), the trade and extreme event model points to what implications such fragmentation might have for the vulnerability of a national economy to extreme events in particular.

The rest of the paper is structured as follows. The next section explains how reducing the imports or the exports may affect the national economy, operationalized by the gross domestic product (GDP), and why it is not simple addition or subtraction of the entire value of the reduced parts. It is followed by the presentation of the trade and extreme event model consisting of three steps and clarifying the nonlinear relationship between trade openness and the vulnerability to extreme events. Afterwards, the paper explains the Monte Carlo analysis and discusses its results.[2] Finally, concluding remarks are stated.

2 Effects of Trade Reduction on GDP

This section explains how reducing the imports or the exports may affect a country's GDP. The expenditure measure defines GDP as the sum of personal consumption, net government expenditure, capital spending/investment, and exports, minus imports (Central Statistics Office 2022). Then, at first glance, it might seem that reducing the exports by a certain value lowers the GDP by the same value, while reducing the imports by a certain value increases the GDP by the same value. These are not the necessary consequences, however. The *effect* of trade reduction on the GDP is much more complicated than simple subtraction (for export reduction) or addition (for import reduction).

[2] All computation was done in the statistical programming software, R (R Core Team 2024), and the graphs were generated by the ggplot2 package (Wickham 2016).

First, the export aspect is considered. Assume that a company sold a car abroad. The value of the car would be part of the exports in the GDP. Now imagine the counterfactual state where the company did not sell a car of the same type abroad. Would the counterfactual value of the GDP be the original GDP value minus the value of the car?

The answer is: Not necessarily. If all other things remained the same in the domestic economy (i.e., the "ceteris paribus" assumption), the GDP would indeed reduce by the value of the car. However, if the ceteris paribus assumption did not hold, it would generally be incorrect to assume that the counterfactual GDP would be the original GDP minus the value of the car. For example, in the counterfactual state, the company might be able to sell the car in the domestic market, albeit at a different (probably lower) price. Then, the GDP in the counterfactual state would be the original GDP minus the value of the car in the original state plus the value of the car in the counterfactual state. Yet, this calculation still assumes that the domestic customer buying the car has no impacts on any other aspects of the domestic economy. It might be the case that the domestic customer would spend the money in the counterfactual state that would have been used for another purpose if the company had sold the car abroad. In short, the chain reaction of export reduction is complex and may have many causal processes.

Next, the import aspect is considered. Assume that a company bought a raw material to produce its own final product from a foreign distributor. Because it paid the foreign distributor rather than a domestic distributor, the price paid would be considered as an import and, therefore, part of the imports in the GDP. Now imagine the counterfactual state where the company did not buy the part from the foreign distributor. Would the value of the counterfactual GDP be the original GDP value plus the price of the raw material?

The answer is again: Not necessarily. If the company bought the same material at the same price from a domestic producer, and if this change of behavior had no impacts on any other parts of the domestic economy (again, the ceteris paribus assumption), then the counterfactual GDP would indeed be the original GDP plus the original price paid. However, if the ceteris paribus assumption did not hold, it would generally be incorrect to assume that the counterfactual GDP would be the original GDP plus the original price paid. For example, a domestic producer might sell the material at a different (probably higher) price than what the company would have paid the foreign distributor. Then, the company might need to raise the price of the product, which in turn might affect its sales. Or, there might be no domestic distributor that sells the material, in which case the company would be unable to produce its final product. As in the case of export reduction, the chain reaction of import reduction is complex and may have many causal processes.[3]

The above considerations are only a few examples to show that the effect of reducing the imports or the exports on the GDP is not simple addition or subtraction of the entire value of the reduced parts.[4] The key point is that it is necessary to parameterize the effects of reducing the imports and the exports, to model how much reducing the imports or the exports by a certain value translates to a change in the original GDP. The next section explains how the trade and extreme event model of this paper does it.

3 Trade and Extreme Event Model

This section explains the trade and extreme event model consisting of the following three steps: (1) a trade reduction policy prior to extreme events, (2) the stochastic occurrence of extreme events, and (3) the loss given these two. The imports from, and the exports to, a foreign country i in values are denoted by m_i and x_i respectively. The paper measures the national economy from an expenditure perspective and denotes the

[3]There is another interesting point regarding import reduction. It is reasonable to assume that economies decide to import goods and services in the first place because they think it is more efficient than producing them domestically. Yet, it is less clear whether import reduction may revert the economy to the previous state. Trade embedded in global value chains tends to promote knowledge transfers and growth in general (World Bank 2020). Then, the economy may be able to provide formerly imported goods and services by itself more efficiently than before it started to import them.

[4]For more advanced treatments, see, for example, Bai et al. (2024), Hakobyan, Meleshchuk, and Zymek (2023), and Javorcik et al. (2023).

home country's GDP by s.

3.1 Trade reduction policy

As explained in section 2, reducing trade can affect GDP. The following equation block defines the gross and net fixed costs of comparative advantage opportunities being lost (c and c^*), and the revised GDP (s^*), given a trade reduction policy and (part of) the former trade being domestically compensated for:[5]

$$
\begin{aligned}
c &= \sum_{i=1}^{n-1}((\pi_i m_i - \pi_i m_i \eta_i)\tau_i + (\phi_i x_i - \phi_i x_i \theta_i)),\\
s^* &= s + \sum_{i=1}^{n-1}\pi_i m_i - c,\\
c^* &= s - s^*,
\end{aligned}
\tag{1}
$$

where n is the total number of countries in the world (so $n-1$ is the number of all foreign countries from a home country's perspective); π_i is the policy size of import reduction, measured as a percentage change in the value of the imports from a foreign country i ($0 \leq \pi_i \leq 1$); η_i controls how efficiently the former imports are compensated for by the domestic economy ($0 \leq \eta_i \leq 1$, where 0 is perfect inefficiency while 1 is perfect efficiency); τ_i governs how much value could have been added on the former imports that could not be compensated for by the domestic economy (i.e., the counterfactual contribution to the GDP under no import reduction); ϕ_i is the policy size of export reduction, measured as a percentage change in the value of the exports to i ($0 \leq \phi_i \leq 1$); θ_i controls how efficiently the former exports are compensated for by the domestic economy ($0 \leq \theta_i \leq 1$, where 0 is perfect inefficiency while 1 is perfect

[5]The term, "compensated for," is used, to mean more general ideas than producing former imports in, and reorienting former exports to, the domestic economy. The formerly imported goods or services might not be produced domestically, yet the home country might increase its GDP by diverting the money that used to be spent on these former imports to other areas of the economy. Similarly, the formerly exported goods or services might not find an alternative domestic market, yet the home country might minimize the reduction in GDP by instead producing alternative goods or services for a domestic market.

efficiency).[6]

The upper bound of 1 is assumed for η_i and θ_i, given the standard macroeconomic argument of comparative advantage. In other words, it is assumed that trade reduction does not result in greater efficiency. $(\pi_i m_i - \pi_i m_i \eta_i)\tau_i$ is the loss in GDP given an import reduction policy, where $\pi_i m_i \eta_i$ captures an addition to GDP after part of the former imports ($\pi_i m_i$) is compensated for domestically; $\phi_i x_i - \phi_i x_i \theta_i$ measures the loss in GDP given an export reduction policy, where $\phi_i x_i \theta_i$ captures an addition to GDP after part of the former exports ($\phi_i x_i$) is compensated for domestically. Thus, under perfect efficiency ($\eta_i = 1$ and $\theta_i = 1$), no costs are incurred from trade reduction: $(\pi_i m_i - \pi_i m_i \eta_i)\tau_i = 0$ and $\phi_i x_i - \phi_i x_i \theta_i = 0$.[7]

The second line of equation block 1 can be interpreted as follows. First, if an import reduction policy were implemented and the former imports were compensated for by the domestic economy with perfect efficiency, it would add to GDP (i.e., $+\sum_{i=1}^{n-1} \pi_i m_i$); τ_i is unnecessary here because if these former imports were intermediate goods and services, the value added of the final goods and services using them is already accounted for within the original GDP. Second, if an export reduction policy were implemented and the former exports were compensated for by the domestic economy with perfect efficiency, the original GDP figure would hold (as the total exports are part of the original GDP). Third, if an import reduction policy were implemented and the former imports were compensated for by the domestic economy with inefficiency, the loss in GDP would be captured by $-\sum_{i=1}^{n-1}(\pi_i m_i - \pi_i m_i \eta_i)\tau_i$. Finally, if an export reduction policy were implemented and the former exports were compensated for by the domestic economy with inefficiency, the loss in GDP would be captured by $-\sum_{i=1}^{n-1}(\phi_i x_i - \phi_i x_i \theta_i)$.

The net cost from the lost comparative advantage opportunities (c^*) is simply the orig-

[6]The degree of efficiency depends partly on what time horizon one intends to capture in the model; generally, a longer time horizon implies greater efficiency (see Baqaee et al. 2024).

[7]The model could be expanded to disaggregate the imports and exports from a foreign country, and their parameters, for individual items (such that, for example, $\pi_i m_i \eta_i$ becomes $\pi_{ik} m_{ik} \eta_{ik}$, where k indexes an individual category of the imports). Such granularity would be useful to simulate micro-level dynamics but would significantly increase the number of parameters to set. The purpose of this paper is, as stated in the introduction, to provide a parsimonious model and leaves this disaggregation aspect for future research.

inal GDP minus the GDP after a trade reduction policy. It might be a positive or negative value. A negative net cost means that GDP becomes greater after trade reduction (i.e., $s^* > s$). From the second line of equation block 1, it is clear that such a case is possible if and only if $\sum_{i=1}^{n-1} \pi_i m_i > c$.

The trade and extreme event model is agnostic about the exact mechanisms whereby trade reduction propagates to the national economy. While modelling such mechanisms helps illustrate how trade reduction could propagate to the national economy, it is difficult (or probably impossible) to model *all* mechanisms of the true data generating process. The literature on structural causal modelling suggests that misspecifying at least one mechanism can make the model generate an incorrect estimate and simulation of the *total* effect of a causal factor on an outcome (Pearl 2009). Appendix A exemplifies this point.

3.2 Stochastic occurrence of extreme events

Home and foreign extreme events, y and w_i, are coded as binary variables and drawn from the Bernoulli distributions:

$$\begin{aligned} y &\sim Bern(p), \\ w_i &\sim Bern(q_i), \end{aligned} \tag{2}$$

where p is the probability of a home country experiencing an extreme event and q_i is the probability of a foreign country i experiencing an extreme event. y and p are scalar values as they are for the home country, while w_i and q_i are an $n-1$ length of vectors.

The model assumes only the foreign extreme events in i that have a negative effect on i's trade with the home country in particular. While some foreign extreme events could bring economic benefits to the home country, such cases are beyond the scope of this paper.[8]

[8]For example, an extreme event in a foreign country might accelerate rather than dampen

The paper denotes the effect size of home extreme events on the home country's GDP by α; the effect size of extreme events in a foreign country i on the home country's imports from it by β_i; and the effect size of extreme events in a foreign country i on the home country's exports to it by γ_i. All of these effects are modelled as being measured on the proportional scale (i.e., between 0 and 1).

Home extreme events can occur for purely domestic reasons, or as a result of the spillover effects of foreign extreme events (di Giovanni, Levchenko, and Mejean 2024; Hernandez and Valdes 2001; Kim, Kim, and Lee 2015; Mensi et al. 2016); α is considered to capture either case.[9] Thus, β_i and γ_i represent the effect sizes of foreign extreme events on the home country's GDP, in the cases where these foreign extreme events do not cause an extreme event in the home country and affect the home country's GDP only through reducing the bilateral trade.

3.3 Loss given a trade reduction policy and extreme events

Given a trade reduction policy and extreme events as modelled in the previous two subsections, the loss incurred by a home country is:

$$l = y\alpha s^* + \sum_{i=1}^{n-1} w_i(\beta_i m_i^* \tau_i + \gamma_i x_i^*) + c^*, \tag{3}$$

where m_i^* and x_i^* are the imports and exports after a trade reduction policy (i.e., $m_i^* = m_i - \pi_i m_i$ and $x_i^* = x_i - \phi_i x_i$).[10] As a reminder, s^* and c^* are the revised GDP and the net cost of lost comparative advantage opportunities respectively, after a trade reduc-

the inflow of investment, if investors decided to move capitals from that foreign country.

[9]The model does not separate these two types of home extreme events for the following reason. While it may be easy to parameterize theoretically, it is challenging to empirically identify how much of the effect of a home extreme event is attributable to purely domestic reasons compared to spillover effects and, therefore, it is difficult to define empirically plausible parameter values.

[10]For simplicity, the value added on the imports was modelled by the same parameter τ_i, for the former imports that were not compensated for domestically (in equation block 1), and for the imports that were lost because of foreign extreme events (in equation 3). For the latter, the setup implies the case where both the goods/services to be imported and the money spent on these would be lost because of foreign extreme events.

tion policy. In other words, it is modelled that a trade reduction policy is implemented prior to stochastically occurring extreme events of concern.

From equation 3, it is possible to see that the vulnerability to extreme events is not a linear function of the degree of trade openness. In other words, keeping the current level of trade, or reducing it, as a policy can result in a greater or smaller loss, depending on the parameter values. For example, even if β_i and γ_i are large, the loss can be smaller or greater when trade is reduced prior to the onset of extreme events, depending on the size of α and c^* and the relative frequency of y and w_i. These nonlinear aspects are explored further through the Monte Carlo analysis in the next section.[11]

3.4 Summary

In summary, the trade and extreme event model consists of three steps: (1) a trade reduction policy prior to extreme events, (2) the stochastic occurrence of extreme events, and (3) the loss given these two.

The trade and extreme event model accommodates the findings by previous research. For example, holding c^* constant, it is possible to observe the result that less trade openness makes countries economically more vulnerable to extreme events, if, relative to the loss from home extreme events (which is a function of the parameters α and p), the loss from foreign extreme events is small (which is a function of the parameters η_i, β_i, q_i, and τ_i when the imports from i are reduced; θ_i, γ_i, and q_i when the exports to i are reduced). The opposite result is also possible, if, relative to the loss from home extreme events, the loss from foreign extreme events is large.

While the trade and extreme event model does not directly parameterize the reaction of the home country to an extreme event to mitigate its negative effect (e.g., finding an alternative source or market), it can indirectly capture that. Computation ignor-

[11] It is also possible to see from equation 3 that reallocating trade into fewer trade partners prior to extreme events, e.g., as a result of friend-shoring – "sourcing inputs from economies that share similar values"(Javorcik et al. 2023, 2), implies nonlinear effects in a similar way. If the home country reduces trade with a partner i and instead trades more with another partner j, it can increase or decrease the loss, depending on how efficient the trade reallocation is and how β_i, τ_i, γ_i, and q_i are different from β_j, τ_j, γ_j, and q_j, for all i and j, $i \neq j$.

ing such a reaction results in the *gross* effect, i.e., what would be the loss to the home economy if all other conditions remained the same; computation modelling the reaction produces the *net* effect. Both types of computation are possible by setting α, β_i, and γ_i differently. The net effect of home extreme events could be modelled by setting a smaller value for α than the gross effect. The net effects of foreign extreme events in a trade partner i could be modelled in two ways. First, as in the case of the net effect of home extreme events, smaller values could be used for β_i and γ_i than the gross effects, if the home economy were able to mitigate the negative effect of the lost trade domestically.[12] The other way would be to assume that when a trade partner i experiences an extreme event, the home economy will be able to increase trade with another country j, such that β_i and γ_i take positive values while β_j and γ_j are assigned negative values.[13]

4 Monte Carlo Analysis

4.1 Setup

In the Monte Carlo simulation analysis, p and q_i are the source of stochasticity. The analysis uses Ireland's 2021 annual GDP data taken from the Central Statistics Office (2023b). The simulation employs Ireland's 2021 annual goods trade data with other countries taken from Eurostat (2024), assuming that a foreign extreme event disrupts a supply chain of goods.

In terms of the parameter setup, for simplicity the analysis uses the same value for all i for the parameters q_i, π_i, η_i, ϕ_i, θ_i, τ_i, β_i, and γ_i; therefore, the index i is dropped hereafter. The values for π, η, β, and γ are varied, while p, q, ϕ, θ, τ, and α are fixed at

[12] How much smaller values for α, β_i, and γ_i should be depends on how easily and quickly the home economy could mitigate the negative effects, and on what time horizon one intends to capture (e.g., see Baqaee et al. 2024). For example, one could empirically estimate the effects of extreme events in different time horizons. Since it takes some time for the home country to recover the economy or find an alternative source or market, a short-term horizon should proxy the gross effect of extreme events while a long-term horizon should estimate their net effect.

[13] Note that in a loss function, a negative value denotes a benefit.

Parameter	Values	Explanation
π	$\{0, 0.025, 0.05, 0.075, 0.1\}$	Import reduction policy size
η	$[0, 1]$	Efficiency for import reduction policy
ϕ	0	Export reduction policy size
θ	NA	Efficiency for export reduction policy
τ	2.00	Value added on the imports
p	0.048	Probability of home extreme events
q	0.048	Probability of foreign extreme events
α	0.073	Effect of home extreme events on GDP
β	$\{0.652, 0.752\}$	Effect of foreign extreme events on imports
γ	$\{0.664, 0.764\}$	Effect of foreign extreme events on exports

Table 1: Parameter values.

constant values, to simulate different scenarios while keeping the number of scenarios at a manageable level. In particular, ϕ is fixed at zero, i.e., the scenario where the policy is to keep the exports as they are; therefore, θ is redundant. In other words, the simulation examines only an import reduction policy by the home country. Yet, by the design of the trade and extreme event model, the conclusion of this paper is unaffected with respect to the relationship between the openness of trade in general and the vulnerability to extreme events, even if the exports rather than the imports are modelled to be reduced as a policy (e.g., as a result of export control measures).[14] Table 1 summarizes the parameter setup.

π is set at one of 0, 0.025, 0.05, 0.075, and 0.1 as possible values, to simulate scenarios where the imports are reduced to different degrees as a policy decision. η is varied from 0 to 1 by an increment of 0.01. Nishimizu and Robinson (1984) find that import substitution is generally associated with lower total factor productivity. However, it may vary across contexts how much capacity the home country has to compensate for the former imports domestically. τ is set at the value equivalent to the ratio of the total output to the intermediate consumption, based on the 2021 data from Central Statistics Office

[14]The results from the analysis swapping the parameter values between π and ϕ and between η and θ are available in Figure 3 in Appendix B. The key difference in the results is that, even though the effect size of foreign extreme events on the exports (γ) is similar to that on the imports (β), an export reduction policy produces a greater loss than the status quo at a much smaller size of inefficiency (i.e., a larger value of θ). This is most probably because, by the design of the trade and extreme event model, an import reduction policy can increase the GDP if the domestic compensation is efficient enough, while the efficiency of domestic compensation for the former exports after an export reduction policy can only mitigate the negative impact of the lost exports on the GDP and cannot increase the GDP ever.

(2023a).

The probability of extreme events is set at 0.048, the median country-year probability of a GDP contraction of at least 5% between 1960 and 2022, calculated based on the data from the World Bank (2023). This value is used for both p and q.

α is set at 0.073, β at 0.652, and γ at 0.664. $\alpha = 0.073$ is a GDP contraction rate, based on the outturn annual real GDP growth rate of -0.045 in 2008 (calculated based on data from the Central Statistics Office 2023c), the year of the Global Financial Crisis, and the forecast figure of 0.03 for the same year from January 2008 (as reported in the Central Bank of Ireland 2008), a time point prior to the Crisis hitting the global and Irish economy hardest.[15] In other words, this value of effect size is based on the assumption that if the Global Financial Crisis had not taken place, Ireland's GDP growth rate would have been what was forecasted by the Central Bank of Ireland. Given its short time horizon, the value may be considered as more the gross effect than a net effect.

$\beta = 0.652$ and $\gamma = 0.664$ are based on the annual changes in real values in Ireland's goods imports from, and exports to, Ukraine between the annual sum from February 2021 to January 2022 and the one from February 2022 to January 2023, calculated based on goods trade data from Eurostat (2024) and the Harmonised Index of Consumer Prices from the Central Statistics Office (2024a).[16] In other words, these values of effect size are based on the assumption that Ireland's goods imports from, and exports to, Ukraine in this period would have been the same as in the previous corresponding one-year period, if the War in Ukraine had not taken place. As additional scenario analysis, 0.1 is added to β and γ, simulating the case where the trade partners experience greater effect sizes of extreme events. The simulation does not model the reaction of the home country to a foreign extreme event. Thus, these parameter values may be considered to capture the gross effects of foreign extreme events.

[15] Formally, $0.073 \approx ((1 - 0.045) - (1 + 0.03))/(1 + 0.03)$.

[16] The effect of Brexit on EU-UK trade would be another interesting case to use for these parameter values; its empirical estimate is available from Kren and Lawless (2024).

These parameter values for the probability and effect sizes of extreme events are, though empirically informed, not necessarily precise empirical estimates or most likely values. Instead, these values are placeholders for the simulation; as noted in the introduction, the simulation is a thought experiment to explore the detailed implications of the theory and not an empirical study. While an empirical estimate is a useful reference point for parameter tuning, it should not be dogmatic at least for the analysis of the effects of extreme events, for two reasons. First, it may be difficult to identify the *typical* effect size of an extreme event empirically; different extreme events may well have different effect sizes. Second, extreme events are often seen as extreme because they exceed one's expectations. If the expectation of extreme events is based on what the data indicate (whose time period is usually limited), it means that the parameter values are restricted within the empirically observed range. However, if an extreme event can take place whose scale is something that has never been observed (within the time period of the data used), it is also beneficial to set parameter values beyond the empirical range in the simulation, to explore what could happen.

It is also worth noting that the conclusion of this paper itself is generally insensitive to the parameter values. Different values only change the crossover point where the baseline loss becomes greater or smaller than the one given a trade reduction policy. There can be no crossover point (i.e., a trade openness or trade reduction policy always dominates the other), only if some extreme parameter values are used (e.g., $\beta = 0$ and $\gamma = 0$).

The parameter setup results in 810 unique combinations. The simulation is run 1,000 times for each of these 810 parameter combinations. Each iteration returns the total loss incurred by the home country, l. The loss is standardized as the ratio of l to s (the original GDP figure). The results from the 1,000 iterations are summarized by the mean and the mean plus two standard deviations ("+2SD value" hereafter), to present both the expected value and an extreme value. Figure 1 presents the distribution of 1,000 simulated values from the baseline scenario of no import reduction policy, indi-

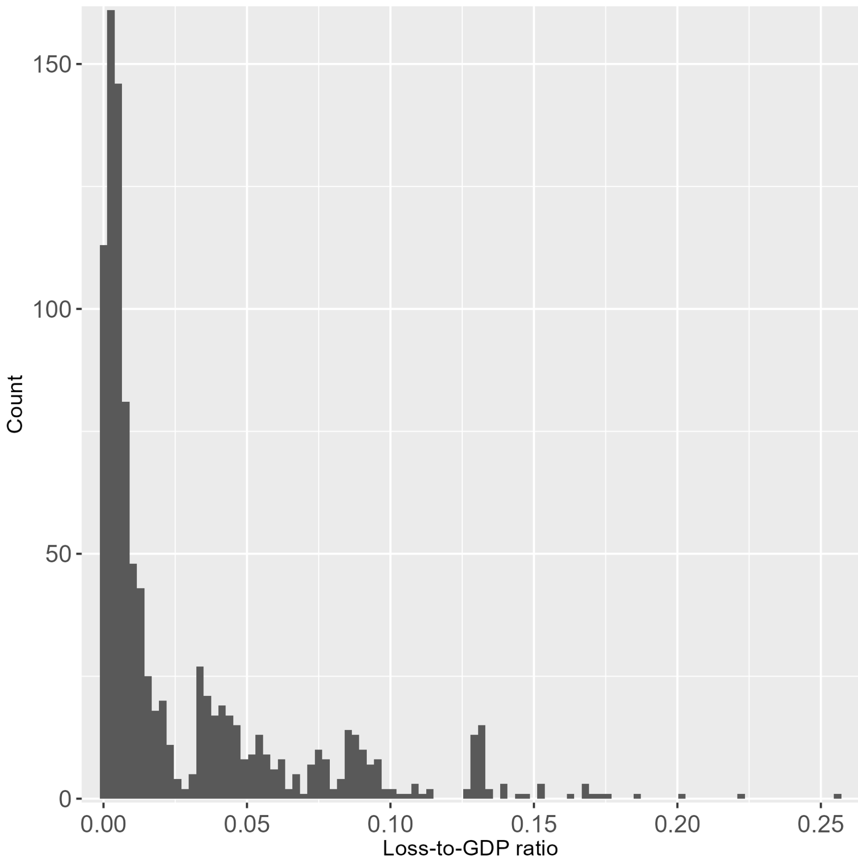


Figure 1: Distribution of the simulated values of the loss-to-GDP ratio from the baseline scenario of no import reduction policy.

cating that the distribution of the loss-to-GDP ratio is heavily right-skewed. In this distribution, the mean value is 0.028 while the +2SD value is $0.105 = 0.028 + 0.0385 \times 2$, where 0.0385 is a value of one standard deviation.

4.2 Results

The results from the Monte Carlo simulations are presented in Figure 2. The y-axis presents the loss-to-GDP ratio, while the x-axis displays the η values. For legibility, only a subset of the η values used is plotted, where the crossover points are observed. The first row presents the results using the mean of the simulated loss-to-GDP ratio values, while the second row displays those using the +2SD value. In each panel, the flat red line denotes the loss under the baseline scenario of no import reduction policy ($\pi = 0$ and, therefore, a value of η is irrelevant); each of the remaining lines indicates the loss under each scenario of import reduction policies ($\pi = \{0.025, 0.05, 0.075, 0.1\}$).

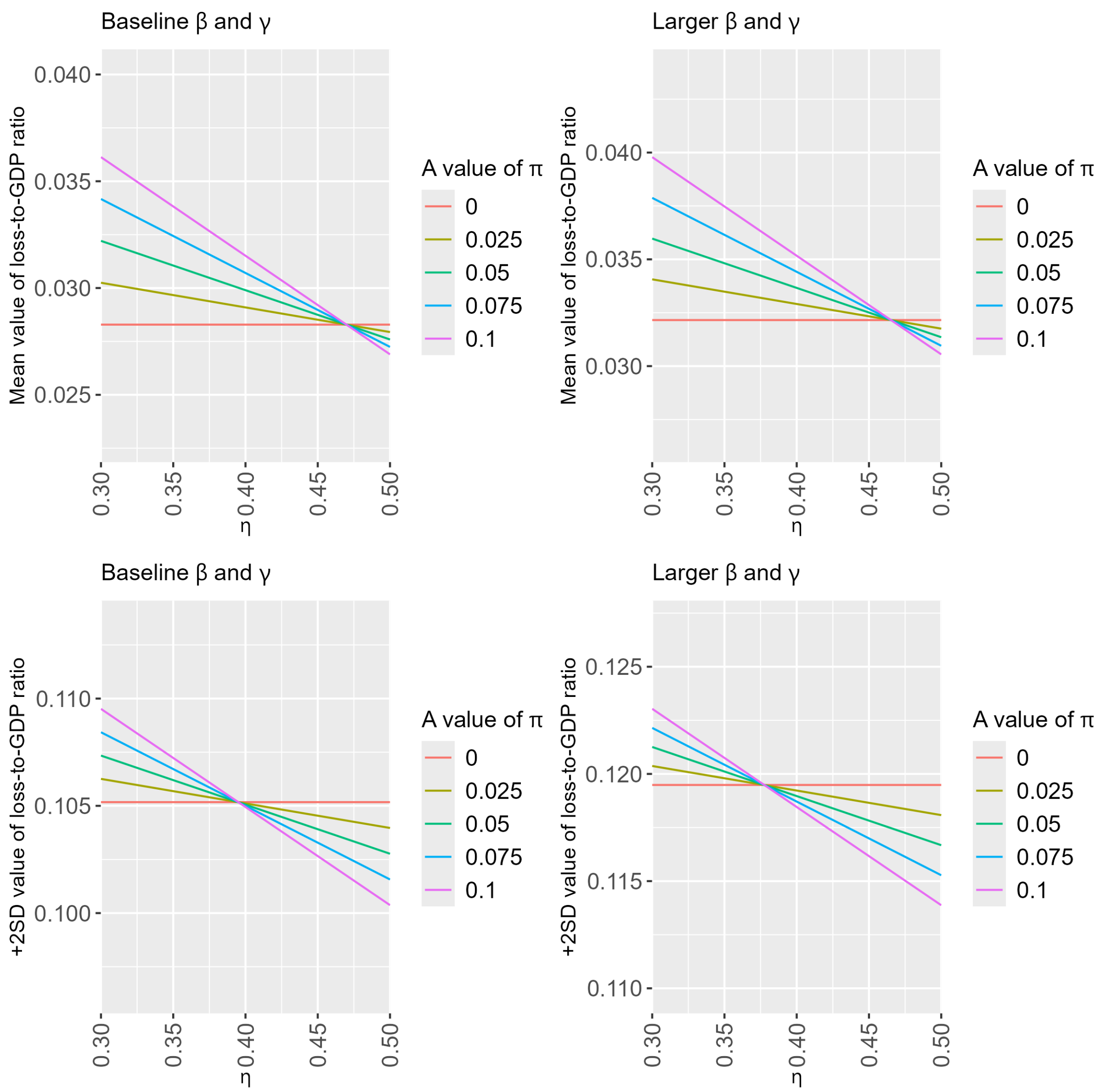


Figure 2: Loss-to-GDP ratio under the baseline and import reduction policy scenarios.

There are three points to highlight. First, compare the two graphs in each of the two rows, where the baseline and larger values of β and γ are used respectively. Focusing on a specific quantity of loss-to-GDP ratio (the mean or +2SD value), if the sizes of β and γ are larger, the crossover point between the baseline (in red) and the remaining scenario lines shifts towards left. This means that greater inefficiency in domestically compensating for the former imports after an import reduction policy (i.e., a smaller η value) is allowed for, when foreign extreme events (modelled to take place after an import reduction policy) have larger effect sizes.

Second, the slope of each line is steeper, when the policy size of import reduction (π)

is greater. This means that a greater policy size of import reduction causes the effect of the (in)efficiency in domestically compensating for the former imports (η) to be more pronounced. Additionally, the crossover point between an import reduction policy scenario and the baseline policy scenario is the same across all import reduction scenario values. This implies that the η value of the crossover point generates the same loss-to-GDP ratio regardless of a π value. It substantively means that at a certain (in)efficiency level of domestically compensating for the former imports after an import reduction policy, there is such an equilibrium between the loss caused by home extreme events and that caused by foreign extreme events, to make the loss-to-GDP ratio the same regardless of how much the imports are reduced in advance.

Finally, compare the results in terms of the mean value of loss-to-GDP ratio with those in terms of its +2SD value. Under the same β and γ value specification, the crossover point shifts towards the left. In other words, there are cases, under the same parameter specification, where an import reduction policy results in a greater loss than the status quo under the mean value, while the opposite is true under the +2SD value. This means the possibility that reducing the imports generates a greater loss *in expectation*, but at the same time results in a smaller loss under an *extreme case* of extreme events, than keeping the status quo. In short, the comparison between the mean and +2SD values of loss-to-GDP ratio suggests a dilemma in policymaking – whether to minimize the expected loss or a rare but extreme loss.

5 Conclusion

This paper has examined whether trade-open economies are more vulnerable or less so to extreme events. It has developed a new, parsimonious model, i.e., the trade and extreme event model, showing that the relationship between trade openness and the vulnerability to extreme events is nonlinear. The Monte Carlo analysis, using the small open economy of Ireland as an example, has substantiated the trade and extreme event model, and has presented further insights into the complex relationship between trade openness and the vulnerability to extreme events.

The key findings are as follows. First, given the parameter combinations employed, there is a greater possibility that a trade reduction policy (modelled to be implemented prior to extreme events) can decrease the loss to the home country compared to no reduction policy, as the net cost of lost comparative advantage opportunities becomes smaller or the effect sizes of foreign extreme events become larger. Second, the comparison between the mean and +2SD values across 1,000 iterations implies that reducing trade can cause a greater loss in expectation, but at the same time result in a smaller loss under an extreme case of extreme events, than keeping the status quo.

The policy implication is that, to evaluate an economy's vulnerability to extreme events, a detailed analysis is necessary on a case-by-case basis. Such an analysis needs to be done in terms of (1) how much trade will be reduced as a policy (the parameters π_i and ϕ_i) and how efficiently the former traded goods and services can be compensated for by the domestic economy after a trade reduction policy (the parameters η_i and θ_i); (2) how vulnerable the home country's economy is to extreme events (the parameters α and p); and (3) how vulnerable its trade partner countries are to extreme events (the parameters β_i, γ_i, and q_i). The proposed model helps such an analysis.

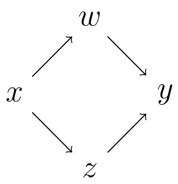
Appendix A: Modelling Causal Mechanisms

Assume the following data generating process:

$$\begin{aligned} w_i &= \alpha_0 + \alpha_1 x_i + u_i^w, \\ z_i &= \gamma_0 + \gamma_1 x_i + u_i^z, \\ y_i &= \beta_0 + \beta_1 w_i + \beta_2 z_i + u_i^y, \end{aligned} \tag{4}$$

where x, w, z, y are variables; each of u denotes the stochastic error term with respect to the outcome variable signified by its superscript; α_0, γ_0, and β_0 are the intercepts;

and α_1, γ_1, β_1, and β_2 signify the causal effects.[17] The above data generating process can be expressed as the Directed Acyclic Graph (Pearl 2009):



where the stochastic error terms are omitted for simplicity.

Assume the following situation. One develops a theoretical model that captures the causal mechanisms, $x \rightarrow w \rightarrow y$ and $z \rightarrow y$, i.e., having only the first and third lines of equation block 4 above, perhaps because of the limitation of knowledge. They obtain the unbiased estimates of the causal effect parameters α_1, β_1, and β_2 from the two (correctly specified) regressions, $w_i = \alpha_0 + \alpha_1 x_i + u_i^w$ and $y_i = \beta_0 + \beta_1 w_i + \beta_2 z_i + u_i^y$. They then simulate a change in y by manipulating a value of x.

Under the presumed model, the effect of x on y is $\alpha_1\beta_1$.[18] However, the *total* effect of x on y in the true data generating process is $\alpha_1\beta_1 + \gamma_1\beta_2$, as the effect of x is channelled to y through both w and z. In other words, if one fails to model the causal mechanism $x \rightarrow z \rightarrow y$, manipulating x does not simulate the total effect of x on y.

If one develops a theoretical model that focuses on the causal effect of x on y rather than the mechanisms between them, it means that the model needs only a single causal effect parameter to simulate the total effect of x on y (i.e., it is unnecessary to know all causal mechanisms). The total effect can be estimated from data by the regression of y on x, $y_i = \theta_0 + \theta_1 x_i + v_i$, where θ_1 is an unbiased estimate of the total effect (while θ_0 is the intercept and v_i is the stochastic error term). The same specification as the above regression can be used to simulate the total effect of x on y, given a manipulation of a value of x.

[17] The letters used for the parameters and variables here are not related to those in the main text.

[18] β_2 is irrelevant: It is not part of the causal effect of x on y here, as the presumed model does not treat z as a function of x.

Appendix B: Export Reduction Policy

Figure 3 presents the results from the Monte Carlo analysis swapping the parameter values used in the Monte Carlo analysis in the main text between π and ϕ and between η and θ, to simulate export rather than import reduction policy scenarios. The three points highlighted in section 4.2 remain valid.

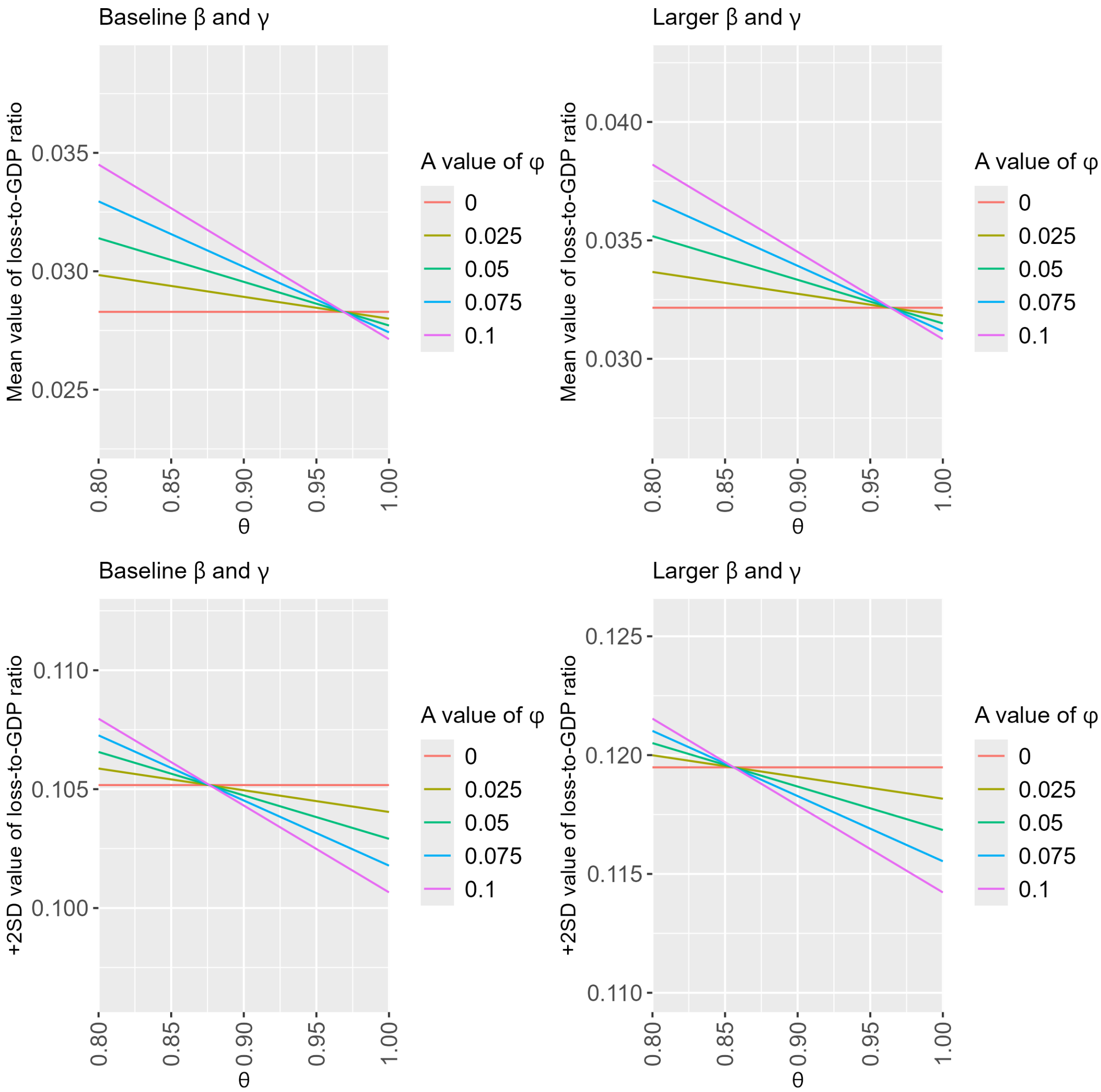


Figure 3: Loss-to-GDP ratio under the baseline and export reduction policy scenarios.

References

Aiyar, Shekhar, Anna Ilyina, et al. 2023. *Geoeconomic Fragmentation and the Future of Multilateralism.* Staff Discussion Note SDN/2023/001. International Monetary Fund, Washington, DC. January. https://www.imf.org/en/Publications/Staff-Discussion-Notes/Issues/2023/01/11/Geo-Economic-Fragmentation-and-the-Future-of-Multilateralism-527266.

Bai, Xiwen, Jesús Fernández-Villaverde, Yiliang Li, and Francesco Zanetti. 2024. *The Causal Effects of Global Supply Chain Disruptions on Macroeconomic Outcomes: Evidence and Theory.* CESifo Working Paper No. 10930, January. https://ssrn.com/abstract=4723723.

Baldwin, Richard, and Rebecca Freeman. 2022. "Risks and Global Supply Chains: What We Know and What We Need to Know." *Annual Review of Economics* 14:153–180.

Baqaee, David, Julian Hinz, Benjamin Moll, Moritz Schularick, Feodora A. Teti, Joschka Wanner, and Sihwan Yang. 2024. "What If? The Effects of a Hard Decoupling from China on the German Economy." In *Paris Report 2: Europe's Economic Security,* edited by Jean Pisani-Ferry, Beatrice Weder di Mauro, and Jeromin Zettelmeyer, 101–133. Paris and London: CEPR Press, May 6, 2024.

Brunsden, Jim, and Michael Peel. 2020. "Covid-19 Exposes EU's Reliance on Drug Imports." *The Financial Times* (April 20, 2020). Accessed October 24, 2022. https://www.ft.com/content/c30eb13a-f49e-4d42-b2a8-1c6f70bb4d55.

Carvalho, Vasco M., Makoto Nirei, Yukiko U. Saito, and Alireza Tahbaz-Salehi. 2021. "Supply Chain Disruptions: Evidence from the Great East Japan Earthquake." *Quarterly Journal of Economics* 136 (2): 1255–1321.

Caselli, Francesco, Miklós Koren, Milan Lisicky, and Silvana Tenreyro. 2020. "Diversification Through Trade." *Quarterly Journal of Economics* 135 (1): 449–502.

Central Bank of Ireland. 2008. *Quarterly Bulletin – Q1 2008 – Economic Commentary,* February 1, 2008. https://www.centralbank.ie/docs/default-source/publications/quarterly-bulletins/qb-archive/2008/2008-no--1-economic-commentary.pdf?sfvrsn=1b35a01d_6.

Central Statistics Office. 2022. "Gross Domestic Product: How It Is Measured," July 15, 2022. https://www.cso.ie/en/interactivezone/statisticsexplained/nationalaccountsexplained/grossdomesticproducthowitismeasured/.

———. 2023a. "NA005: Gross Value Added at Basic Prices by Sector of Origin and Gross and Net National Income at Current Market Prices," July 14, 2023. https://data.cso.ie/table/NA005.

———. 2023b. "NA007: Expenditure on Gross and Net National Income at Current Market Prices," July 14, 2023. https://data.cso.ie/table/NA007.

———. 2023c. "NA008: Expenditure on Gross and Net National Income at Constant Market Prices," July 14, 2023. https://data.cso.ie/table/NA008.

———. 2024a. "CPM15: EU Harmonised Index of Consumer Prices," January 16, 2024. https://data.cso.ie/table/CPM15.

———. 2024b. "NAQ04: Expenditure on Gross National Product," March 1, 2024. https://data.cso.ie/table/NAQ04.

Clancy, Daragh, Vilém Valenta, and Donal Smith. 2023. *The Macroeconomic Effects of Global Supply Chain Reorientation.* Central Bank of Ireland Research Technical Paper, Vol. 2023, No. 5. https://www.centralbank.ie/docs/default-source/publications/research-technical-papers/the-macroeconomic-effects.pdf.

di Giovanni, Julian, and Andrei A. Levchenko. 2009. "Trade Openness and Volatility." *Review of Economics and Statistics* 91 (3): 558–585.

———. 2012. "Country Size, International Trade, and Aggregate Fluctuations in Granular Economies." *Journal of Political Economy* 120 (6): 1083–1132.

di Giovanni, Julian, Andrei A. Levchenko, and Isabelle Mejean. 2024. "Foreign Shocks as Granular Fluctuations." *Journal of Political Economy* 132 (2): 391–433.

Eurostat. 2024. "EU trade since 1999 by SITC," March 18, 2024. https://ec.europa.eu/eurostat/databrowser/view/ds-018995/default/table?lang=en.

Goes, Carlos, and Eddy Bekkers. 2023. "The Impact of Geopolitical Conflicts on Trade, Growth, and Innovation." Paper presented at the IMF Conference on Geoeconomic Fragmentation, May 25. https://www.imf.org/en/News/Seminars/Conferences/2023/05/25/imf-workshop-on-geoeconomic-fragmentation.

Grossman, Gene M., Elhanan Helpman, and Hugo Lhuillier. 2021. *Supply Chain Resilience: Should Policy Promote Diversification or Reshoring?* NBER Working Paper Series 29330. http://www.nber.org/papers/w29330.

Hakobyan, Shushanik, Sergii Meleshchuk, and Robert Zymek. 2023. *Divided We Fall: Differential Exposure to Geopolitical Fragmentation in Trade.* IMF Working Paper WP/22/270, December. https://www.imf.org/en/Publications/WP/Issues/2023/12/22/Divided-We-Fall-Differential-Exposure-to-Geopolitical-Fragmentation-in-Trade-542842.

Hernandez, Leonardo F., and Rodrigo O. Valdes. 2001. "What Drives Contagion: Trade, Neighborhood, or Financial Links?" *International Review of Financial Analysis* 10 (3): 203–218.

Javorcik, Beata S., Lucas Kitzmüller, Helena Schweiger, and Muhammed A. Yıldırım. 2023. *Economic Costs of Friend-Shoring.* CESifo Working Paper No. 10869, December. https://ssrn.com/abstract=4696010.

Kim, Bong-Han, Hyeongwoo Kim, and Bong-Soo Lee. 2015. "Spillover Effects of the U.S. Financial Crisis on Financial Markets in Emerging Asian Countries." *International Review of Economics and Finance* 39:192–210.

Kose, M. Ayhan, Eswar S. Prasad, and Marco E. Terrones. 2003. "Financial Integration and Macroeconomic Volatility." *IMF Economic Review* 50 (Suppl 1): 119–142.

Kren, Janez, and Martina Lawless. 2024. "How Has Brexit Changed EU–UK Trade Flows?" *European Economic Review* 161 (January): 1–27.

Mensi, Walid, Shawkat Hammoudeh, Duc Khuong Nguyen, and Sang Hoon Kang. 2016. "Global Financial Crisis and Spillover Effects among the U.S. and BRICS Stock Markets." *International Review of Economics and Finance* 42:257–276.

Nishimizu, Mieko, and Sherman Robinson. 1984. "Trade Policies and Productivity Change in Semi-Industrialized Countries." *Journal of Development Economics* 16 (1-2): 177–206.

OECD. 2020. *Shocks, Risks and Global Value Chains: Insights from the OECD METRO Model,* June. https://read.oecd-ilibrary.org/view/?ref=1060_1060135-p3hlf0m1v9&title=Shocks-risks-and-global-value-chains-insights-from-the-OECD-METRO-model.

Pearl, Judea. 2009. *Causality: Models, Reasoning, and Inference.* 2nd ed. Cambridge: Cambridge University Press.

Pisani-Ferry, Jean, Beatrice Weder di Mauro, and Jeromin Zettelmeyer, eds. 2024. *Paris Report 2: Europe's Economic Security.* Paris and London: CEPR Press, May 6, 2024. https://cepr.org/publications/books-and-reports/paris-report-2-europes-economic-security.

R Core Team. 2024. *R: A Language and Environment for Statistical Computing.* Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org.

Rasmussen, Carl, and Zoubin Ghahramani. 2000. "Occam's Razor." In *Advances in Neural Information Processing Systems,* edited by T. Leen, T. Dietterich, and V. Tresp, vol. 13. MIT Press. https://proceedings.neurips.cc/paper_files/paper/2000/file/0950ca92a4dcf426067cfd2246bb5ff3-Paper.pdf.

Taleb, Nassim Nicholas. 2007. *The Black Swan: The Impact of the Highly Improbable.* New York, NY: Random House.

Wickham, Hadley. 2016. *ggplot2: Elegant Graphics for Data Analysis.* 2nd ed. Cham: Springer International Publishing.

World Bank. 2020. *World Development Report 2020: Trading for Development in the Age of Global Value Chains.* Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1457-0.

———. 2023. "World Development Indicators," December 18, 2023. https://databank.worldbank.org/source/world-development-indicators.