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Shock transmission, global supply chains, and development: assessing responses to trade shocks

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Abstract

We analyse the impact of policy-driven (eg tariffs) and non-policy-driven (eg conflicts, natural disasters) trade shocks on intermediate versus final goods components of gross production for low, middle, and high-income country groups. Further, we examine the role of direct versus indirect, and foreign versus domestic, channels in transmitting these shocks. Results indicate that tariffs and conflicts impact the composition of gross production by changing its intermediate input component, and these changes are driven predominantly by indirect and foreign channels. Trade protectionism in high-income countries dampens low-income countries' global supply chain (GSC) network participation, but not that of middle-income countries. Further, it increases their domestic input contribution to output, at the expense of developing nations. On the other hand, trade liberalisation in low and low-middle-income countries increases their level of GSC involvement, with the adjustment taking place in high-income countries through an increase in their use of foreign intermediates.

Key words: Global supply chain networks, shock transmission, hidden exposure, resilience, counterfactual scenarios.

JEL classification: F13, F14, F15, F63.

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1 Introduction

The publication of inter-country input-output (ICIO) tables in the 2010s (e.g. the World Input-Output Database, WIOD, Timmer et al. 2015; OECD ICIO tables, OECD 2015; and EORA Database, Lenzen et al. 2013) accelerated the development of global ICIO analysis as a tool to understand the organization of international trade and production networks, including shock transmission. ICIO tables gained traction for such work because they allow to: decompose changes in gross production into intermediate versus final goods components in a consistent way; distinguish direct from indirect, and foreign from domestic channels in explaining changes on intermediate versus final goods components of production; and study shock exposure and dissipation depending on the type of trade friction.

Separately, the policy relevance of shock transmission through supply-chain networks has been front and center for three main reasons. First, global supply chains (GSCs) make up a disproportionate share of overall economic activity, with just under 70 percent of world output coming from the sale of intermediate inputs alone.[1] And, the share of global trade attributed to GSCs outweighs that attributed to final goods and services. By 2012, intermediate goods were already documented to account for up to two thirds of total international trade (Johnson and Noguera 2012), and this trend has continued to rise. Further, it has recently been shown that almost 50 percent of global trade today involves inputs which are embedded in supply-chain trade crossing borders at least twice (World Bank 2020). Because GSC trade can travel through direct and indirect channels, however, it is not always obvious how a shock in one nation would spill over into changes in economic outcomes in another.

Second, since the 2010s, the nature of shocks has largely shifted from idiosyncratic (i.e. isolated and limited in scope) to systemic.[2] Unlike idiosyncratic shocks, systemic shocks entail large-scale disturbances (some of which can be policy-driven) which affect numerous markets, regions, sectors, and suppliers, and can be longer-lasting than the shocks which arose before the 2010s. A few notable examples include the Global Financial Crisis, geopolitical implications of events like Brexit, US-China geoeconomic tensions, and worldwide pandemics such as the Covid-19 pandemic. Third, it is almost certain that the world is going to continue experiencing systemic shocks with some frequency, emanating from factors such as geopolitical tensions, climate change, and digital disruptions (Baldwin et al. 2023).

While ICIO tools and models which account for roundabout and indirect trade have aided the study and understanding of shock transmission, few studies have unpacked transmission channels for a wide set of countries of different development statuses. Indeed,

[1] Computations based on EORA data used in this paper and refer to year 2020. See panel A of Appendix figure A.1 for further details and splits by income group.

[2] See Goldberg and Reed (2023) and Baldwin et al. (2023) for a description and taxonomy of systemic versus idiosyncratic shocks.

due to paucity of publicly available input-output data covering extensive sets of emerging and developing economies, most studies either: (i) focus on high- and middle-income countries for which input-output data is more readily available, relegating lower-middle- and low-income countries to a "rest of the world" aggregate; or (ii) hone in on a particular type of shock—e.g natural disasters like the 2011 Tōhoku earthquake in Japan (Boehm et al. 2019; Carvalho et al. 2021), or the 2008 global financial crisis (Bricongne et al. 2012)—for a single economy.

Understanding the development angle of shock propagation through supply networks made up of countries with different development statuses is of paramount importance, however, in light of countries' recent calls to reshore production and deglobalize in the wake of some of the aforementioned major disruptive events. In other words, despite conventional wisdom that GSCs are an engine for development and poverty reduction,[3] they are increasingly being viewed in policy circles as a source of risk and exposure. However, even in light of deglobalizing policy prescriptions, it is unclear whether such strategies could be effective; the world trading system is highly interconnected with inputs sent both directly and indirectly between countries of different development statuses. This point is made empirically by Alfaro and Chor (2023), who show that the US is both highly dependent on China, and that US strategies to substitute away from Chinese imports by sourcing from "friendly" countries such as Vietnam and Mexico do little to reduce its exposure to Chinese production because Vietnamese and Mexican exports to the US depend on Chinese inputs as well. As such, given the tight-knit nature of supply chains across regions and nations of varying income levels, it is more important than ever to understand how shocks propagate among countries of different development statuses.

Our paper builds upon and contributes to three strands of the literature by shedding light on important questions related to shock transmission for a set of 175 developed and developing economies. First, alongside the development of ICIO tables, several papers have made important advancements in the modeling of shock propagation through input-output linkages and demonstrated their applications to understanding shock transmission (see Costinot and Rodríguez-Clare 2014; Johnson 2018; Bernard and Moxnes 2018; Carvalho and Tahbaz-Salehi 2019; and Antràs and Chor 2022 for extensive reviews). Second, a large and related strand of analysis unpacks the characteristics and consequences of GCSs at the country-sector level (Hummels et al. 1998; Fally 2012; Fally and Hillberry 2018; Antràs and Chor 2013, 2018; Johnson and Noguera 2017; Miller and Temurshoev 2017; Johnson 2018; Li et al. 2019; Borin et al. 2021; Fernandes et al. 2022; Borin and Mancini 2023).[4] Third, our work relates to an important and growing literature which models the formation of supply-chain networks (Bernard and Zi 2022; Dhyne et al. 2021; Arkolakis et al. 2023; Dhyne et al. 2023), as well as model-based studies of disruptions that implicitly

[3]See World Bank 2020 for a comprehensive review of this point

[4]Related studies have also been carried out at the firm-level, e.g Bernard et al. (2019); Baqaee and Farhi (2019, 2022, 2024); Carvalho et al. (2021); Bernard and Zi (2022); Dhyne et al. (2022); Pichler et al. (2023).

or explicitly account for elasticities of substitution among countries and intermediate inputs (see for example Acemoglu et al. 2012; Bonadio et al. 2021).

Our analysis complements this literature across two dimensions. First, we first explore how shocks change: (i) the relative importance of intermediate versus final goods channels for changes in production; (ii) the relative importance of direct and indirect channels for those changes; and (iii) the relative importance of domestic versus foreign channels for those changes. Second, we examine whether there are significant differences in the ways in which shocks propagate overall and through these channels depending on countries' development status. To do so, we split countries into three different income groups—high, middle, and low—and study whether the response to shocks differs depending on countries' development status. In addition, we explore whether country responses differ depending on whether the shock is statutory or non-statutory in nature. Examples of statutory shocks include standard policy-related trade costs (e.g. tariffs), while non-statutory shocks include frictions emanating from events like conflicts and natural disasters.

We perform our analysis in three steps. The first step is to formulate an exact-algebra decomposition of country-level sales into intermediate (including GSC-links) and final demand components. We further split these components into direct versus indirect, and foreign versus domestic channels. Each component reflects a combination of demand and supply factors, and this decomposition allows us to determine their changes and aggregate the components using exact-algebra. Second, we utilize the components as data to determine the contribution of statutory shocks (tariff changes) and non-statutory shocks (conflicts and natural disasters) on them. To do this, we regress the relevant trade cost vector on each component using a PPML gravity equation. Third, we use the gravity regression results to conduct counterfactual analysis for a set of "GSC-friendly" and "GSC-hostile" scenarios. This is done by setting the trade cost vector in each year to a value assigned by the counterfactual scenario at hand, and using the estimated parameters to answer the question: if the various risk/cost factors were at the artificially set level, what would the intermediate and final demand components have been in the present period (as well as the split between intermediates and final and domestic versus foreign channels)?

We explore two main types of counterfactual scenarios. Our first set of counterfactuals relate to trade policy, and reflect policies either geared at fostering integration into global supply chains (such as low-income countries eliminating tariffs on intermediate inputs) or factors which could dampen supply-chain participation (such as increasing tariffs). Our second set of counterfactuals relates to geopolitical tensions in the form of conflicts and natural disasters.

Overall, we draw three main conclusions from our analysis. First, we find that actions taken by governments under scenarios which are either GSC-friendly or GSC-hostile impact countries' participation in GSC networks by changing the composition of gross production between intermediate and final goods and services. In particular, countries targeted by a given trade policy experience the largest change in output composition, coming predominantly through (positive or negative) changes in the inputs component, depending on the scenario at hand. In terms of countries' income status, low-income countries tend to benefit from trade liberalizing scenarios through increased GSC network participation, while the reverse is true for trade protectionism scenarios. Trade protectionism in high-income countries, on the other hand, increases their domestic input contribution to GSC networks, largely at the expense of developing nations. On the other hand, trade shocks which occur randomly, such as natural disasters, reveal no clear trends in GSC outcomes and have much smaller magnitudes. These results reveal both that policy decisions (including those related to geopolitical tensions) play a powerful role in shaping the composition of GSC networks. They also reveal that countries are likely more resilient to shocks which are both transient in nature and occur unpredictably.

Second, we find that shifts in output composition are primarily driven by hidden-exposure, i.e. indirect, channels. This finding supports evidence based on a set of general equilibrium models in Costinot and Rodríguez-Clare (2014), where counterfactual responses tend to be considerably amplified by input-output linkages, relative to models where producers sell all their output directly to final consumers. Third, we find that changing tariffs and engaging in conflict tends to shift the contribution of input trade between domestic versus foreign partners in expected directions. This reveals that trade policies can be broadly effective in helping countries achieve GSC strategies, but also serves as a warning that protectionist trade policy and geoeconomic tensions which manifest in conflict have the ability to distort GSC networks and hinder development outcomes.

In what follows, section 2 presents the methodology used throughout the analysis. Section 3 describes the ICIO dataset used and other sources upon which we draw to consruct our trade cost vector. Section 4 presents both the gravity results from our analysis and findings from our counterfactual exercises, including robustness checks carried out. Finally, section 5 presents concluding remarks.

2 Methodology

In this section, we present the steps followed in our methodology. First, we introduce relevant notation and the fundamental input-output relationships needed to formulate an exact-algebra decomposition of a country's sales growth to a GSC-links and final demand component. Next, we describe how to further split these components into face-value (direct) versus hidden-exposure (indirect) GSC-links and domestic versus foreign channels. Finally, we describe how to determine the contribution of statutory and non-statutory shocks on each component using an empirical gravity model. Specifically, we propose a type of analysis which relies on counterfactual policy scenarios, and quantify the extent to which different types of shocks change the contributions of GSC-links and final-demand components to countries' sales growth relative to the measured components in the baseline scenario, i.e. observed changes in the data.

2.1 Notation and fundamental relationships

To fix ideas and introduce notation, we present well-known elements of input-output analysis.[5] In each period, the world economy can be described through an input-output model and categorized into maker/producer and user/customer countries.[6] We rely on the use-accounting identity which states that a country's gross production is distributed through sales of intermediates or sales to final demand. In our notation, subscripts indicate the maker/producer/origin nation ($i = 1, \ldots, C$), the user/customer/destination nation ($j = 1, \ldots, C$), and the time dimension ($t = 1, \ldots, T$).

In matrix notation, the use-accounting identity in each period t is:

$$\boldsymbol{X_t} = \boldsymbol{Z_t}\,\boldsymbol{\iota} + \boldsymbol{M_t}\,\boldsymbol{\iota} = \boldsymbol{N_t} + \boldsymbol{F_t}, \tag{1}$$

where $\boldsymbol{X_t} = (X_{i,t})$ is a $(C \times 1)$ vector of total sales with each element $X_{i,t}$ representing the value of country i's total (intermediate input and final) sales at home and abroad. $\boldsymbol{Z_t} = (Z_{ij,t})$ is a $(C \times C)$ matrix of bilateral intermediate input transactions, with each element $Z_{ij,t}$ representing the value of country i's intermediate input sales to country j (including itself, when $i = j$), and $\boldsymbol{\iota}$ is a $(C \times 1)$ column vector of ones used to aggregate the intermediate input sales matrix $\boldsymbol{Z_t}$ to a $(C \times 1)$ vector of total intermediate input sales $\boldsymbol{N_t} = (\sum_{j=1}^{C} Z_{ij,t})$ representing the value of country i's total intermediate input sales at home and abroad. $\boldsymbol{M_t} = (M_{ij,t})$ is a $(C \times C)$ matrix of bilateral final sales transactions, with each element $M_{ij,t}$ representing the value of country i's final sales to country j (including itself, when $i = j$), and as before $\boldsymbol{\iota}$ is used to aggregate the final sales matrix $\boldsymbol{Z_t}$ to a $(C \times 1)$ vector of total final sales $\boldsymbol{F_t} = (\sum_{j=1}^{C} M_{ij,t})$ representing the value of country i's total final sales at home and abroad.

Normalizing the input sales matrix ($\boldsymbol{Z_t}$), the use-accounting identity can be rewritten as:

$$\boldsymbol{X_t} = \boldsymbol{A_t}\boldsymbol{X_t} + \boldsymbol{F_t}, \tag{2}$$

where $\boldsymbol{A_t} = (a_{ij,t} = Z_{ij,t}/X_{j,t})$ is a $(C \times C)$ matrix, with each element $a_{ij,t}$, known as the input-output/technical coefficients, measuring fixed relationships between a country's

[5] Other related work following this structure includes: Miller and Blair (2009), Lenzen et al. (2013), OECD, WTO and World Bank Group (2014), Timmer et al. (2015), Borin and Mancini (2015, 2023), Antràs and Chor (2022), and Baldwin et al. (2022).

[6] We aggregate all sectors to the country level at this stage for computational reasons related to the need of annual gravity regressions discussed below and to reduce the data challenges involved in measuring bilateral trade costs at the sectoral level.

output and its inputs.[7] Solving (2) for $\boldsymbol{X_t}$ yields the classic Leontief relationship:

$$\boldsymbol{X_t} = \boldsymbol{L_t F_t}, \tag{3}$$

where $\boldsymbol{L_t} = (\boldsymbol{I} - \boldsymbol{A_t})^{-1}$, $\boldsymbol{I}$ is a $(C \times C)$ identity matrix and $\boldsymbol{L_t} = (\ell_{ij,t})$ is the Leontief inverse matrix, with each element $\ell_{ij,t}$, representing the gross production in every nation i needed to produce final output for every nation j (including itself, when $i = j$), taking account of all direct and indirect linkages in intermediate-inputs trade.

2.2 Exact-algebra decomposition of sales growth in GSCs

Equation (3) highlights two key factors behind total sales: GSC links ($\boldsymbol{L_t}$) and final demand sales ($\boldsymbol{F_t}$). We follow Arvis and Egger (2024) to provide an exact-algebra decomposition of these factors, here, for a one-sector world economy. Specifically, to establish changes in each factor between any year t and $t' < t$ we use the differencing operator (Δ) to form the decomposition:

$$\begin{aligned} \Delta \boldsymbol{X_t} &= \boldsymbol{L_t F_t} - \boldsymbol{L_{t'} F_{t'}} && (4) \\ &= \Delta \boldsymbol{L_t F_t} + \boldsymbol{L_{t'}} \Delta \boldsymbol{F_t} && (5) \end{aligned}$$

where $\Delta \boldsymbol{X_t} = \boldsymbol{X_t} - \boldsymbol{X_{t'}}$ is the sales growth between periods t and t' decomposed into a GSC-links component $\Delta \boldsymbol{L_t F_t}$ and a final demand component $\boldsymbol{L_{t'}} \Delta \boldsymbol{F_t}$.[8] Dividing each component with the elements of $\Delta \boldsymbol{X_t}$ and multiplying by 100 allows to express (5) as:

$$\boldsymbol{GSC_t} + \boldsymbol{FD_t} = 100\,\boldsymbol{\iota} \tag{6}$$

where $\boldsymbol{GSC_t} = (GSC_{i,t} = 100 * \sum_{j=1}^{C} \Delta\ell_{ij,t} F_{j,t} / \Delta X_{i,t})$ is a $(C \times 1)$ vector, with each element $GSC_{i,t}$ representing the contribution of changes in GSC-links to sales growth in period t relative to t'. $\boldsymbol{FD_t} = (FD_{i,t} = 100 * \sum_{j=1}^{C} \ell_{ij,t} \Delta F_{j,t} / \Delta X_{i,t})$ is a $(C \times 1)$ vector, with each element $FD_{i,t}$ representing the contribution of changes in final demand sales to sales growth in period t relative to t'. $100\boldsymbol{\iota}$ is a $(C \times 1)$ column vector of 100s, i.e. the sum of the two components.

It is interesting to highlight here that the component $\boldsymbol{FD_t}$ is similar in spirit to most traditional GVC/GSC indicators proposed in the literature which are designed to capture value chain participation (e.g. backward and forward linkages)[9] or supply-chain exposure (e.g. the more recent gross output-based indicators proposed by Baldwin et al. 2022).[10]

[7] Economies of scale in production are thus ignored; production in a Leontief system operates under constant returns to scale. Therefore, Leontief production functions require inputs in fixed proportions where a fixed amount of each input is needed to produce one unit of output.

[8] To get from equation (4) to (5) we add and subtract $\boldsymbol{L_{t'} F_t}$.

[9] For an extensive review of the literature on value chain indicators, see Johnson (2018); Antràs (2020); Antràs and Chor (2022).

[10] The most closely related indicators to $\boldsymbol{FD_t}$ are FPEX: Foreign Production Exposure on the Export

Specifically, for given GSC-links, i.e. a fixed intermediate-inputs network, we examine how changes in total final demand affect total sales (gross production) growth.[11]

On the other hand, the $\boldsymbol{GSC_t}$ component reflects, for given total final demand sales, how changes in GSC-links, i.e. adjustments in the intermediate-inputs network, affect total sales (gross production) growth.

Overall, $\boldsymbol{FD_t}$ reflects how shocks in final demand amplify through the GSC network of intermediate input transactions, while $\boldsymbol{GSC_t}$ reflects how changes in GSC-links, i.e. connectivity/GSC shocks, alter the responsiveness of producers' output needed to meet total final demand. While both components are highly relevant and reflect a combination of demand and supply factors, we find the latter of particular interest since it highlights the importance of changes in GSC-links which have become more policy-relevant given recent supply-chain disruptions.

2.2.1 Face-Value versus Hidden-Exposure channels

The matrix $\boldsymbol{A_t}$ captures the direct input-output links among countries, i.e., the tier-1 suppliers, that can be observed in inter-country input-output tables. $\boldsymbol{L_t}$ captures these direct links plus indirect purchases of inputs by all suppliers to all suppliers. As Miller and Blair (2009) and Antràs and Chor (2022) point out $\boldsymbol{L_t} = (\boldsymbol{I} - \boldsymbol{A_t})^{-1} = \boldsymbol{I} + \sum_{p=1}^{\infty} \boldsymbol{A_t^p}$.[12]

We use this relationship to decompose linkages into the face-value (direct) and hidden-exposure (indirect) links among countries, similar to Baldwin et al. (2022, 2023). Face-value (fv) links are given by $\boldsymbol{L_t^{fv}} = \boldsymbol{I} + \boldsymbol{A_t}$, where $\boldsymbol{I}$ reflects the production location of one unit value of final goods and $\boldsymbol{A_t}$ reflects the tier-1 intermediates necessary to make it. Hidden-exposure (he) links are given by the subsequent terms, $\boldsymbol{L_t^{he}} = \sum_{p=2}^{\infty} \boldsymbol{A_t^p}$, which capture the fact that inputs are used in inputs which are used in inputs, and so on without end. These links are 'hidden' in that they are not directly evident in the data; they must be calculated from input-output tables. The sum of face-value and hidden-exposure links equal the total links, i.e. $\boldsymbol{L_t} = \boldsymbol{L_t^{fv}} + \boldsymbol{L_t^{he}}$.

From this observation, we can express equation (3) as $\boldsymbol{X_t} = \boldsymbol{L_t^{fv}} \boldsymbol{F_t} + \boldsymbol{L_t^{he}} \boldsymbol{F_t}$, where the terms can be uniquely assigned to face-value versus hidden-exposure links. Equivalently, equation (5) can be decomposed into $\Delta \boldsymbol{X_t} = \Delta \boldsymbol{L_t^{fv}} \boldsymbol{F_t} + \Delta \boldsymbol{L_t^{he}} \boldsymbol{F_t} + \boldsymbol{L_{t'}^{fv}} \Delta \boldsymbol{F_t} + \boldsymbol{L_{t'}^{he}} \Delta \boldsymbol{F_t}$.[13] Dividing each component with the elements of $\Delta \boldsymbol{X_t}$ and multiplying by 100 allows to

side, derived by Baldwin et al. (2022), and the equivalent Higher Order Trade indicator introduced by Imbs and Pauwels (2020, 2022) to approximate the relationship between foreign shocks and domestic value added.

[11] We think of GSC links as being fixed (contractually or due to search costs) within a year but permit and consider changes in such links between years in our analysis.

[12] The notion that normalized input-output-link matrices adhere to the above Taylor-series expansion is actually much older. Moreover, it is used in the network–econometrics and -statistics literature to establish uniqueness and consistency of reduced-form estimates in models which feature such general links also beyond input-output analysis (see, e.g., Kelejian and Prucha 1999).

[13] This is equivalent to $\Delta \boldsymbol{X_t} = \Delta \boldsymbol{A_t} \boldsymbol{F_t} + \Delta \boldsymbol{L_t^{he}} \boldsymbol{F_t} + \boldsymbol{L_{t'}^{fv}} \Delta \boldsymbol{F_t} + \boldsymbol{L_{t'}^{he}} \Delta \boldsymbol{F_t}$ since $\Delta \boldsymbol{L_t^{fv}} = \Delta \boldsymbol{I} + \Delta \boldsymbol{A_t} = \Delta \boldsymbol{A_t}$, i.e. the production location of one unit value of final goods does not change.

further decompose equation (6) into:

$$\boldsymbol{GSC_t^{fv}} + \boldsymbol{GSC_t^{he}} + \boldsymbol{FD_t^{fv}} + \boldsymbol{FD_t^{he}} = 100\,\boldsymbol{\iota} \tag{7}$$

where $\boldsymbol{GSC_t^{fv}} = (GSC_{i,t}^{fv} = 100 * \sum_{j=1}^{C} \Delta a_{ij,t} F_{j,t} / \Delta X_{i,t})$ is a $(C \times 1)$ vector, with each element $GSC_{i,t}^{fv}$ representing the contribution of changes in tier-1 GSC-links to sales growth in period t relative to t'. $\boldsymbol{GSC_t^{he}} = (GSC_{i,t}^{he} = 100 * \sum_{j=1}^{C} \Delta(\ell_{ij,t} - a_{ij,t}) F_{j,t} / \Delta X_{i,t})$ is a $(C \times 1)$ vector, with each element $GSC_{i,t}^{he}$ representing the contribution of changes in tier-2 and above GSC-links to sales growth in period t relative to t'.

$\boldsymbol{FD_t^{fv}} = (FD_{i,t}^{fv} = 100 * \sum_{j=1}^{C} (\mathbb{1}[i=j] + a_{ij,t}) \Delta F_{j,t} / \Delta X_{i,t})$, where $\mathbb{1}[i=j]$ is the indicator function that equals one when $i = j$, is a $(C \times 1)$ vector, with each element $FD_{i,t}^{fv}$ representing the contribution of changes in final demand sales to sales growth in period t relative to t' coming through the direct GSC-links.[14] $\boldsymbol{FD_t^{he}} = (FD_{i,t}^{he} = 100 * \sum_{j=1}^{C} (\ell_{ij,t} - \mathbb{1}[i=j] - a_{ij,t}) \Delta F_{j,t} / \Delta X_{i,t})$ is a $(C \times 1)$ vector, with each element $FD_{i,t}^{he}$ representing the contribution of changes in final demand sales to sales growth in period t relative to t' coming through the indirect tier-2 and above GSC-links.

2.2.2 Domestic versus Foreign channels

The Leontief inverse matrix $\boldsymbol{L_t}$ is composed of a domestic $(\boldsymbol{L_t^d})$ diagonal matrix where $i = j$, and a foreign off-diagonal matrix $(\boldsymbol{L_t^f})$ where $i \neq j$, such that $\boldsymbol{L_t} = \boldsymbol{L_t^d} + \boldsymbol{L_t^f}$. Similarly, the final sales matrix $\boldsymbol{M_t}$ is composed of a domestic $(\boldsymbol{M_t^d})$ diagonal matrix where $i = j$, and a foreign off-diagonal matrix $(\boldsymbol{M_t^f})$ where $i \neq j$, such that $\boldsymbol{M_t} = \boldsymbol{M_t^d} + \boldsymbol{M_t^f}$. Therefore, we can decompose the total final sales vector into $\boldsymbol{F_t} = \boldsymbol{F_t^d} + \boldsymbol{F_t^f}$, where $\boldsymbol{F_t^d} = (F_{i,t}^d = \sum_{j=i} M_{ij,t})$ and $\boldsymbol{F_t^f} = (F_{i,t}^f = \sum_{j \neq i}^{C} M_{ij,t})$. Equivalently, equation (5) can be decomposed into $\Delta \boldsymbol{X_t} = \Delta \boldsymbol{L_t^d} \boldsymbol{F_t} + \Delta \boldsymbol{L_t^f} \boldsymbol{F_t} + \boldsymbol{L_{t'}} \Delta \boldsymbol{F_t^d} + \boldsymbol{L_{t'}} \Delta \boldsymbol{F_t^f}$. Dividing each component with the elements of $\Delta \boldsymbol{X_t}$ and multiplying by 100 allows to decompose equation (6) to:

$$\boldsymbol{GSC_t^{d}} + \boldsymbol{GSC_t^{f}} + \boldsymbol{FD_t^{d}} + \boldsymbol{FD_t^{f}} = 100\,\boldsymbol{\iota} \tag{8}$$

where $\boldsymbol{GSC_t^d} = (GSC_{i,t}^d = 100 * \sum_{j=i} \Delta \ell_{ij,t} F_{j,t} / \Delta X_{i,t})$ is a $(C \times 1)$ vector, with each element $GSC_{i,t}^d$ representing the contribution of domestic GSC-links to sales growth in period t relative to t'. Analagously, $\boldsymbol{GSC_t^f} = (GSC_{i,t}^f = 100 * \sum_{j \neq i}^{C} \Delta \ell_{ij,t} F_{j,t} / \Delta X_{i,t})$ is a $(C \times 1)$ vector, with each element $GSC_{i,t}^f$ representing the contribution of changes in foreign GSC-links to sales growth in period t relative to t'. $\boldsymbol{FD_t^d} = (FD_{i,t}^d = 100 * \sum_{j=1}^{C} \ell_{ij,t} \Delta F_{j,t}^d / \Delta X_{i,t})$ is a $(C \times 1)$ vector, with each element $FD_{i,t}^d$ representing the contribution of changes in domestic final demand sales to sales growth in period t relative to t'. And, $\boldsymbol{FD_t^f} = (FD_{i,t}^f = 100 * \sum_{j=1}^{C} \ell_{ij,t} \Delta F_{j,t}^f / \Delta X_{i,t})$ is a $(C \times 1)$ vector, with each element $FD_{i,t}^f$ representing the contribution of changes in foreign final demand sales to sales growth in period t relative to t'.

[14] This component can be further split to the effects from: final demand ($\boldsymbol{I}$); and tier-1 GSC-links ($\boldsymbol{A_t}$).

Overall, equation (8) allows to split the contributions of changes in GSCs and FD into domestic versus foreign sources. Note that the terms cannot be uniquely assigned to purely domestic versus foreign channels. For example, in $\boldsymbol{GSC_t^d}$ the domestic GSC-links could also capture domestic transactions that go through a foreign country. Similarly, in $\boldsymbol{FD_t^d}$ changes in domestic final demand could operate through the foreign GSC-links.[15]

2.3 Contributions of shocks on each component

The two fundamental elements underlying the relationships and components presented above are bilateral transactions between i and j of intermediate inputs ($\boldsymbol{Z_t} = (Z_{ij,t})$) and final goods ($\boldsymbol{M_t} = (M_{ij,t})$).

Various shocks are expected to change countries' intermediate-sales, final-sales, and total sales. The effects of such socks can arise through effective customer prices directly and transmit through direct/indirect, domestic/foreign, or combined channels. Specifically, trade policy and risks trigger supply and demand responses which affect sales across countries through each component. On the one hand, statutory sales frictions such as trade costs will make producers/customers, ceteris paribus, shift from relatively more to less friction-intensive inputs and final goods. On the other hand, non-statutory sales frictions emanating from supply and demand risk factors, such as conflicts and natural disasters, will also affect the pattern of trade.

Our goal is to measure how various policy-relevant shocks impact intermediate- and final-goods sales and, together, countries' total sales. To do so we create counterfactual scenarios based on various hypothetical statutory and non-statutory shocks. For each scenario, we rely on the structural gravity literature to compute counterfactual values for trade of intermediate inputs ($\boldsymbol{Z_t^*} = (Z_{ij,t}^*)$) and final goods ($\boldsymbol{M_t^*} = (M_{ij,t}^*)$). Following the same steps from sections 2.1 and 2.2, for any component $X \in \{GSC, FD, GSC^{fv}, GSC^{he}, FD^{fv}, FD^{he}, GSC^d, GSC^f, FD^d, FD^f\}$ derived in equations (6)-(8) we can now compute its counterfactual value X^* for each scenario.

As a final step, we report deviations of each counterfactual component $\boldsymbol{X_t^*}$ from the measured component $\boldsymbol{X_t}$ as $\boldsymbol{\widetilde{X}_t^*} = \boldsymbol{X_t^*} - \boldsymbol{X_t}$. Specifically, we consider the changes in the contributions of each component X accruing to the change in observed/targeted determinants under each counterfactual scenario. For example, this implies that equation (6) can be expressed in deviations:

$$\widetilde{\boldsymbol{GSC}}_{\boldsymbol{t}}^{*} + \widetilde{\boldsymbol{FD}}_{\boldsymbol{t}}^{*} = 0\,\boldsymbol{\iota}, \tag{9}$$

where each element $\widetilde{GSC}_{i,t}^{*}$ represents for producer country i the changes in the contribution of GSC links to sales growth in period t relative to t' accruing to the change in observed/targeted determinants under each counterfactual scenario of interest. By construction, the changes in $\widetilde{FD}_{i,t}^{*}$ are a negative/mirror image to those in $\widetilde{GSC}_{i,t}^{*}$.

[15]For a decomposition with purely domestic versus foreign channels see Arvis and Egger (2024).

Overall, these deviations form our measures of interest that we compute and report in the results sections. Below we describe how we construct the counterfactual values X^* capitalizing on the structural gravity literature and provide the list of counterfactual scenarios considered.

2.3.1 Counterfactual analysis

For the counterfactual analysis, we build on a generic gravity model of bilateral trade which can be expressed as follows:

$$V_{ij} \quad = \quad (t_{ij}^V)^{\eta^V} \Phi_i^V \Psi_j^V , \tag{10}$$

where bilateral sales $V \in \{Z, M\}$, measuring either the sales of intermediate inputs (Z) or of final goods (M) from country i to country j, are a function of sales-potential factors Φ^V and demand-potential factors Ψ^V as well as trade costs t^V and the so-called trade elasticity η^V. All measures on the right-hand side of (10) are specific to the type of flows, as is indexed by the superscript V. Moreover, as indicated in Anderson and van Wincoop (2003), the supply and demand factors Φ^V and Ψ^V, respectively, are proportional to the overall sales and purchases of the respective type of output and so-called multilateral-resistance (or scaled seller- and customer-price-index terms).[16]

A large class of models generates isomorphic gravity equations of this form (Arkolakis et al. 2012). And elegant quantitative general-equilibrium solutions can be derived for them (Yotov et al. 2016).[17]

In what follows, we rely on customary current approaches towards treating a model as in (10) in estimation. Specifically, the interest there is focused on obtaining reliable estimates of statutory and non-statutory trade costs (Baldwin and Taglioni 2006; Head and Mayer 2014; Yotov et al. 2016). Following the recommendations of Santos Silva and

[16] Outlining the model akin to Anderson and van Wincoop (2003), we might specify it as:

$$V_{ij} \quad = \quad Y^V \theta_i^V (\Pi_i^V)^{-\eta^V} \vartheta_j^V (P_j^V)^{-\eta^V} \, (t_{ij}^V)^{\eta^V} , \tag{11}$$

where Y^V are the world sales of type V, $\theta_i^V (\Pi_i^V)^{-\eta^V}$ measures what they called an exporter multilateral resistance term, and $\vartheta_j^V (P_j^V)^{-\eta^V}$ measures an importer multilateral resistance term. The terms θ and ϑ are sales and expenditure shares of one country in the world. This specification is obviously analogous to the one in (10), with $\Phi_i^V \propto \theta_i^V (\Pi_i^V)^{-\eta^V}$ and $\Psi_j^V \propto \vartheta_j^V (P_j^V)^{-\eta^V}$. One may define the expenditures of country j and V goods as $E_j^V = \sum_{i=1}^C V_{ij}$ and the sales of i as $Y_i^V = \sum_{j=1}^C V_{ij}$. Then, $Y^V = \sum_{i=1}^C \sum_{j=1}^C V_{ij}$ and $\theta_i^V = Y_i^V / Y^V$ and $\vartheta_j^V = E_j^V / Y^V$.

[17] Here we mention two differences between the treatment here and the customary literature. First, customary models which integrate intermediate-goods trade do not feature simultaneous final-goods trade (see Caliendo and Parro 2015). Obviously, this is not the case in input-output tables, where intermediate- as well as final-goods trade is recorded. However, models can straightforwardly be amended to permit intermediate as well as final-goods trade (see Bergstrand and Egger 2010). Second, accounting for the full general-equilibrium repercussions of shocks then depends on specific model specifications and sales and expenditure links are less general than in (Arkolakis et al. 2012) and (Yotov et al. 2016). This implies that a comparative static analysis may need more specific treatment, but the estimating equation is largely unaffected as long as country fixed effects are employed.

Tenreyro (2006, 2011) and Weidner and Zylkin (2021) we use the Poisson pseudo-maximum likelihood (PPML) estimator, which accounts for potential heteroskedasticity in trade data, to obtain our main estimates. Using $\phi_i^V + \psi_j^V \equiv \ln(\Phi_i^V \Psi_j^V)$, our estimating equation becomes:

$$V_{ij} = \exp[\eta^V ln(t_{ij}^V) + \phi_i^V + \psi_j^V]\varepsilon_{ij}^V, \quad (12)$$

where ϕ_i^V and ψ_j^V can be treated as seller- and customer-country fixed effects, which, inter alia, control for the ex-ante unobserved seller and customer multilateral resistance terms, and ε_{ij}^V is a stochastic error term that is assumed to not carry any systematic information about the trade costs.

Log bilateral trade costs $ln(t_{ij}^V)$ are typically specified as an additive-linear function of a series of observable statutory, non-statutory, geographic and other variables. Many of those have become standard covariates in empirical gravity specifications. Specifically, we specify scaled log trade costs as:

$$\begin{aligned} \eta^V ln(t_{ij}^V) = {} & \beta_1^V \tau_{ij} + \beta_2^V DTA_{ij} + \beta_3^V BIT_{ij} + \beta_4^V CONFL_{ij} \\ & + \beta_5^V DISAST_{ij} + \beta_6^V CNTG_{ij} + \beta_7^V CLANG_{ij} \\ & + \beta_8^V CLNY_{ij} + \beta_9^V ln(DIST_{ij}) + \beta_{10}^V INTRA_{ij} \end{aligned} \quad (13)$$

where the first three variables are statutory. $\tau_{ij} = ln(1 + tariff_{ij})$ where $tariff_{ij}$ is the ad-valorem equivalent tariff that country j imposes on purchases from country i and zero for domestic purchases V_{ii}. DTA_{ij} measures the depth of trade agreements as the share of legally enforceable policy areas covered by a trade agreement between countries i and j. It ranges between zero (no agreement) and one (maximum depth), which is also the value set for domestic sales V_{ii}. BIT_{ij} is a dummy variable that takes a value of one if there is a bilateral investment treaty between countries i and j or for domestic purchases V_{ii}.[18]

The subsequent two variables are non-statutory. $CONFL_{ij}$ is a dummy variable that takes a value of one if at least one country i or j experiences a domestic conflict or there is an international conflict between them. $DISAST_{ij}$ is a dummy variable that takes a value of one if at least one country i or j experiences a natural disaster.

Finally, the remaining variables cover geographic and other factors. $CNTG_{ij}$ is a dummy variable that captures the presence of contiguous borders between countries i and j. $CLANG_{ij}$ is a dummy variable that takes the value of one if there is a common official language between countries i and j. $CLNY_{ij}$ is a dummy variable that takes the value of one for the presence of colonial ties between countries i and j. $ln(DIST_{ij})$ is the logarithm of the bilateral simple distance in kilometers between the most populated cities

[18] Since tariffs are direct price shifters, the estimate of the coefficient on tariffs is $\beta_1^V = \eta^V$ and, hence, can be used to directly recover a value of the trade elasticity parameter η^V for each type of trade flow $V \in \{Z, M\}$ (e.g., see Egger and Larch 2012; Caliendo and Parro 2015; Heid and Larch 2016; Larch and Wanner 2017).

in country i and j (including domestic distance for V_{ii}). Finally, $INTRA_{ij}$ is a dummy variable that takes the value of one for domestic sales V_{ii} and zero for international trade V_{ij}.[19]

Note that in the data we have a time dimension. We estimate equation (12) for each period t separately to allow for heterogeneous responses of trade to trade-cost variables over time, while at the same time reducing computational burden. As such, all parameters β_k^V for $k = (1, \ldots, 10)$ carry a time index in (13).[20]

In sum, using the data from EORA covering 175 countries and years 1995-2020, we estimate the parameter vector β^V in specifications (12) and (13) for each type of trade flow $V \in \{Z, M\}$, i.e. intermediate inputs and final goods, and each period t separately to retrieve a reliable scaled trade-cost vector $\left(\widehat{\eta^V\, ln(t_{ij}^V)}\right)$ and thus predicted values of trade, $\widehat{V}_{ij}$, that we use to calculate the relevant components discussed in section 2.3 for the baseline scenario, i.e. the data.

To keep technical aspects as simple as possible, we rely on a conditional general equilibrium analysis, which can be seen as an intermediate step between a 'model-free' partial-equilibrium analysis and a full, 'model-dependent' endowment-based general-equilibrium analysis. Specifically, we abstain from producer-price repercussions in what follows. However, our approach allows for the effects of any counterfactual change in the trade cost vector between countries i and j to ripple through the rest of the world via the multilateral-resistance terms (see Yotov et al. 2016, for a comprehensive description).

Overall, the conditional general equilibrium effects capture both the direct partial equilibrium effects reflected in equation (12) and the corresponding indirect components through the multilateral resistances, for given producer sales and customer purchases levels.[21] From a practical perspective, the conditional general equilibrium variables can be recovered directly from PPML estimates of the fixed effects associated with the structural gravity model without the need to explicitly solve the structural gravity system of equations from a particular counterfactual model.[22]

To perform the conditional general equilibrium analysis we first define a counterfactual scenario $(*)$ by changing the relevant trade-cost variables to their proposed counterfactual values while holding their respective parameters β_k^V the same as their estimates in the

[19]The inclusion of this variable makes the specification of other variables for domestic sales above irrelevant.

[20]Thus, our trade-cost vector cannot include country-pair fixed effects as is recommended in gravity with panel data. It could at most include dyadic fixed effects that are the same for country pair ij and ji as in Egger and Nigai (2015), but this would come at a considerable loss of precision with the parameter estimation.

[21]In a full general-equilibrium analysis, one would also allow for general-equilibrium effects running through the endogenous factory-gate prices, by solving a larger structural gravity system of equations. However, this would unnecessarily distract from a focus on the data and the decomposition we wish to highlight here.

[22]This relies on an additive property of the PPML estimator, shown by Arvis and Shepherd (2013) and Fally (2015), which leads to a perfect match between the structural gravity terms and the corresponding importer and exporter fixed effects (ϕ_i and ψ_j). For a complete discussion see Yotov et al. (2016).

observed data ($\hat{\beta}_k^V$). With this at hand, we next solve for the conditional counterfactual gravity terms as follows.

Denote estimates of the parameter vector β^V at some counterfactual scenario $*$ by $\hat{\beta}^{V*}$. Let us, for K regressors among the observable trade costs, specify the vector TC_{ij} on which β^V is estimated. Note that TC_{ij} is not indexed by V. Then, we could say that our parameterization implies that $\eta^V \ln t_{ij}^V = TC_{ij}\beta^V$. As discussed above, for our counterfactuals we will hold (some elements in) TC_{ijt} fixed at TC_{ij}^* and do the same with β^{V*}. Then, the counterfactual estimate of $\widehat{\eta}^V \ln t_{ij}^{V*} = TC_{ij}^*\beta^{V*}$. We then postulate

$$V_{ij}^* \quad = \quad \exp[TC_{ij}^* \, \widehat{\beta}^{V*} + \phi_i^{V*} + \psi_j^{V*}], \tag{14}$$

where ψ_j^{V*} and ψ_j^{V*} carry an index $*$ because they will be adjusted depending on which type of counterfactual $*$ is considered. Hence, the country fixed effects are now not held fixed but conditionally adjusted as suggested in Yotov et al. (2016). The counterfactual values of the bilateral trade costs and the estimated multilateral resistances suffice to construct predicted trade values $\widehat{V}_{ij}^*$ for each counterfactual scenario. Using predicted values of trade for the baseline model $\widehat{V}_{ij}$ which are based on observed trade costs, we can calculate the relevant components discussed in section 2.3 for both the baseline $\widehat{V}_{ij}$ and the counterfactual $\widehat{V}_{ij}^*$. Finally, note that as in equation (12) we estimate (14) for each period t separately, meaning that all of its elements also carry a time index.

2.3.2 Counterfactual scenarios

This framework offers the flexibility to adjust all counterfactual trade cost variables in the vector TC_{ij}^* as needed to reflect the desired changes in each counterfactual scenario. Specifically, the counterfactual trade cost vector is: $TC_{ij}^* \, \widehat{\beta}^{V*} = f^V(TC_{ij}) \, \widehat{\beta}^V$, where TC_{ij}^* is a transformation ($f^V(\cdot)$) of the observed vector of trade cost variables (TC_{ij}) to the desired counterfactual levels.

We define two broad groups of counterfactual exercises with scenarios on statutory shocks related to trade policy and non-statutory shocks related to conflicts and natural disasters as follows.

Scenario 1—Trade liberalization: Low and low-middle-income countries eliminate import tariffs on intermediate inputs. We set $\tau_{ij}^* = 0$ only if $V = M$ and importing country j is classified as low or low-middle income in the base-sample year 1995 and it is not importing from itself, i.e. $j \neq i$.

Scenario 2—Trade protectionism: High-income countries and China[23] increase tariffs on intermediate and final goods by 25 percentage points. We set $\tau_{ij}^* = ln(1 + \mathit{tariff}_{ij} + 25)$ if importing country j is China, Hong Kong, Macao or classified as high income in the base-sample year 1995 and it is not importing from itself, i.e. $j \neq i$.

[23]In scenarios 2 and 3, reference to China includes Hong Kong and Macao.

Scenario 3—Trade protectionism - China: All countries increase tariffs on intermediate and final goods from China by 50 percentage points. China increases tariffs on intermediate and final goods by 50 percentage points. Any existing DTAs and BITs between China and other countries are eliminated. Thus, we set $\tau^*_{ij} = ln(1 + tariff_{ij} + 50)$, $DTA^*_{ij} = 0$ and $BIT^*_{ij} = 0$ if exporting country i or importing country j is China, Hong Kong or Macao and it is not importing from itself, i.e. $j \neq i$.
Scenario 4—Conflicts: If a conflict arose at any point since 1946, we assume that it never ended. Thus, we update the conflict variable with $CONFL^*_{ij}$ by carrying forward in time since 1946 the unit values in the $CONFL_{ij}$ variable.
Scenario 5—Natural disasters: If a natural disaster occurred at any point since 1940 we assume that it never ended. Accordingly, we update the natural disasters variable with $DISAST^*_{ij}$ by carrying forward in time since 1940 the unit values in the $DISAST_{ij}$ variable.

3 Data description and sources

Our analysis draws upon several different data sources to comprehensively compute face value (direct) and hidden-exposure (indirect) trade components of gross production, as well as relevant variables that enter into our trade cost vector.

Decomposition of gross production: The primary ICIO data source used in our analysis is the United Nations' EORA dataset (Lenzen et al. 2013), which is available for years 1990-2020.[24] As standard across all ICIO datasets, the EORA ICIO tables provide information on the flow of intermediate and final goods and services, as well as value added, to paint a comprehensive picture of global production.

The EORA dataset provides this information for 26 unique goods and services sectors (which we aggregate to the country level) for 189 countries and a Rest of World aggregate. Compared to other ICIO data sources, the primary strength of the EORA dataset lies in its extensive coverage of emerging and developing economies, particularly in regions like Africa, Latin America, and Central and South Asia. After cleaning the data and matching it with relevant information which features in our trade cost vector, our final ICIO dataset comprises information on 175 countries. Using the World Bank's yearly income classification (which is based on the Gross National Income per capita of the preceding year) yields the following breakdown of countries by income status: 38 high-income; 23 upper-middle income; 55 low-middle income; and 59 low-income. The countries used in our analysis (including their income status), as well as additional details related to cleaning the EORA data, are listed in appendix C.2.

Trade cost vector: We draw upon six different data sources to construct our trade cost vector. These sources provide information related to: (i) trade policy variables,

[24] For our analysis, we use data for years 1995-2020 due to data inconsistencies on the import side for prior years.

informative for scenarios related to statutory trade shocks; (ii) conflicts and natural disasters, informative for scenarios related to non-statutory shocks; and (iii) standard, time-invariant, bilateral trade costs (such as bilateral distance) which we include as controls in our cross-sectional gravity regressions.

The trade policy component of our trade cost vector comprises information on bilateral applied ad-valorem equivalent (AVE) tariffs, deep trade agreements (DTAs), and bilateral investment treaties (BITs). Data on applied AVE tariffs are from the United Nations Conference on Trade and Development (UNCTAD) Trade Analysis Information System (TRAINS), downloaded through the World Bank World Integrated Trade Solutions (WITS) platform. Data are available at the Harmonized System (HS) 6-digit level for over 200 countries and cover all years available in the EORA dataset. In processing the data, we construct our tariff series by selecting the effectively applied tariff, defined here as the lowest available applied AVE tariff for a given country-pair-product-year combination.[25] We then aggregate the HS 6-digit tariff data to the country level by taking the simple average across products for each country-pair-year observation.[26]

Data on DTAs comes from the World Bank Content of Deep Trade Agreements database (herein WB DTA database), described in Hofmann et al. (2017). This database records information on the full set of 400 trade agreements notified to the WTO between 1958 and 2023. The WB DTA database also provides information on 52 provision categories which can factor into DTAs, each coded as a binary bilateral variable equal to one if a given provision is present in an agreement. These provisions are classified as either WTO+, signaling that they fall within the current WTO mandate, or WTO-X, indicating that the extend beyond the WTO mandate. Following Hofmann et al. (2017), we focus on the set of 18 "core" provisions which the literature has shown to be most relevant in terms of easing market access (see Baldwin 2008; Damuri 2012). Given that our trade cost vector already comprises information on bilateral tariffs, we exclude the two provisions related to tariff liberalization in the set of core provisions,[27] leaving 16 DTA provisions of interest. These include all WTO+ provisions and four WTO-X areas.[28] Then, following Mattoo et al. (2022), we construct our DTA coverage ratio for each year using the count of provisions (a) embedded in a given DTA: $DTA_{ij} = \sum_{a=1}^{16} provision_{a,ij}$. In line with the literature using this data (e.g. Mulabdic et al. 2017; Laget et al. 2020; Mattoo et al. 2022),

[25]This procedure follows the WITS concept. Specifically, if an applied AVE preferential tariff exists, it will be used as the effectively applied tariff. Otherwise, the AVE MFN applied tariff will be used.

[26]In the event of missing observations, we carry forward the information from the most recent year. For example, if a country-pair has data for 2017 and 2020 but missing information for years 2018-2019, we assume that the bilateral tariff rate in 2017 applies.

[27]These are provisions for "FTA agriculture" and "FTA industrial," which represent whether a given DTA includes tariff liberalization agricultural and industrial goods, respectively.

[28]WTO+ areas include clauses on: anti-dumping; customs; countervailing measures; export taxes; general agreement on trade in services (GATS) provisions; public procurement; sanitary and phytosanitary (SPS) measures; state aid; state trading enterprises measures; technical barriers to trade measures; trade-related intellectual property rights (TRIPS) measures; trade-related investment (TRIMS) measures. WTO-X areas include clauses on: competition policy; investment; intellectual property rights; and movement of capital.

we only consider provisions which are classified as legally enforceable in the computation of our coverage ratio.

Lastly, data on Bilateral Investment Treaties (BITs) is sourced from UNCTAD's Work Program on International Investment Agreements. This dataset offers comprehensive information on the full set of 2,222 BITs in force.[29] We use this to construct a binary variable equal to unity if a BIT was in force between country pairs in a given time period.

The non-statutory component of our trade cost vector comprises information on conflicts and natural disasters. Data concerning armed conflict and organized violence is obtained from the Uppsala Conflict Data Program (UCDP), the world's main provider of data on organized domestic and international violence. This data source records various types of international and domestic conflicts which took place over years 1946-2022. We rely on three conflict types. First, foreign conflicts, which the UCDP classifies as interstate, are defined as a conflict between two or more governments. Second, domestic conflicts can be either intrastate (i.e. a conflict between a government and a non-governmental party, such as a rebel group, with no support from international countries) or internationalized intrastate (i.e. an armed conflict between a government and a non-governmental party where troop support from international parties is received).[30] We code our conflict variable as a binary variable equal to one if any conflict took place in a given year. Note that, while the conflict variable is binary, it could refer to multiple conflict events.[31]

Information regarding climate hazards and natural disasters is sourced from the Emergency Events Database (EM-DAT), maintained by the Center for Research on the Epidemiology of Disasters. This dataset contains records of over 26,000 mass natural disasters which occurred worldwide from 1900 onwards,[32] including earthquakes, tsunamis, hurricanes, floods, droughts, and other such events. In order for such an event to qualify as a natural disaster, one or more of the following criteria must be met: 10 fatalities; 100 affected people; a declaration of state of emergency; or a call for international assistance.

Finally, data on standard bilateral trade costs are sourced from the CEPII GeoDist database (Mayer and Zignago 2011). The GeoDist database provides useful information on inter- and intranational bilateral distance, as well as a set of other time-invariant trade cost variables for a set of 225 countries (thus covering all countries included in the EORA dataset). In addition to the CEPII variable on bilateral distance—measured as the Geodesic distance between most populated cities (in kilometers)—the variables that we use for our analysis include information on whether bilateral partners: share a border (i.e. are contiguous); share a common official or primary language; and had a common colonizer post-1945.

[29] Our data covers the period 1959-2018 and we carry forward BIT data until year 2020.

[30] We do not use information on extrasystemic conflicts, as these are defined as being between a state and a non-state group outside its own territory.

[31] For example, the Russia-Ukrane war is coded as one conflict, but the underlying data contains many related events.

[32] Our data series starts in 1940 to ensure consistent data quality over the full sample.

4 Empirical results

In this section we bring the methodology to the data and present results of our main gravity specification and subsequent counterfactual exercises.

4.1 Gravity results

Before turning to insights gained from our counterfactual exercises, we first present the results from the gravity specification 12, run separately for intermediate and final goods for each sample year. In addition to our main variables of interest (which are used when modifying the trade cost vector in the counterfactual exercises below) our trade cost vector also includes standard controls for: contiguity; common official or primary language; common colonizer post 1945; and bilateral distance across country pairs.[33]

We obtain expected coefficients and magnitudes on all standard gravity controls. In line with resutls in Conconi et al. (2020) and Miroudot et al. (2009), we find that intermediate inputs are more sensitive to distance, albeit to a small extent and with the exception of the last five sample years, signalling that geographic proximity and the timely delivery of inputs is an important factor for GSC trade. Two potential explanations for the slight differences with our results are the inclusion of trade in services data in our regressions as well as the level of disaggregation of our analysis, which could mask some underlying heterogeneity at the product level.[34]

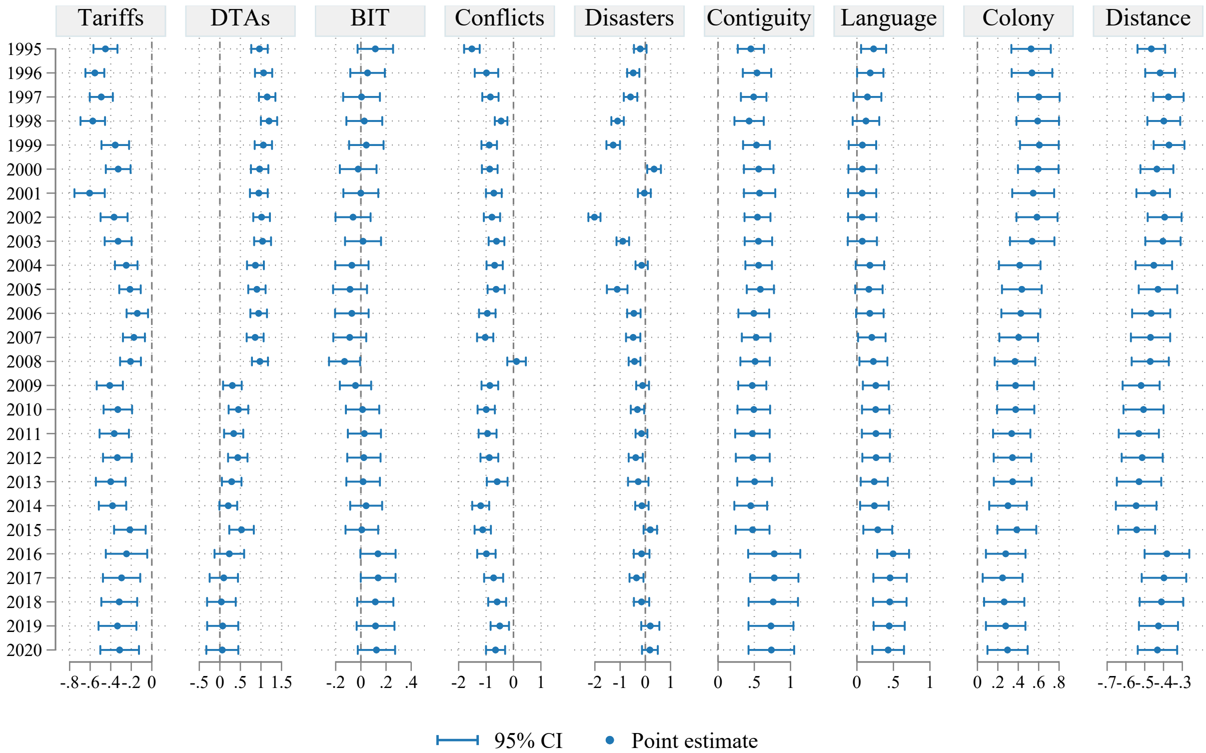
As expected, we also find negative and statistically significant coefficients for tariffs and conflicts. The point estimates for DTAs are positive and statistically significant for most sample years, but become statistically insignificant in later sample years. This observation is consistent with results of Nagengast and Yotov (2023), who find no significant effects of trade agreements on bilateral trade after year 2000. While somewhat counterintuitive, this result is explained in part by the fact that: (i) the most natural trade agreements were signed in the 1980s and 1990s, leaving less potential for new agreements in later years; and (ii) agreements signed in later periods coincide with lower MFN tariffs than those signed in earlier periods, thus leaving limited scope for trade-enhancing tariff reductions included alongside deeper DTA provisions. In this vein, point estimates for BITs are also largely statistically insignificant.

Finally, we note that the point estimates on natural disasters are primarily negative both for intermediate and final goods, albeit with wide-ranging magnitudes depending on the year in question. Figure 1 below presents our gravity results for intermediate input trade and appendix Figure B.1 presents analogous estimates for final goods.

[33]We use the CEPII variable dist, which refers to the geodesic distance between most populated cities (in kilometers). However, our results are robust to all distance measures available in the CEPII dataset.

[34]Indeed, the results in Conconi et al. (2020) relate to disaggregate trade for over 5,000 products at the 6-digit level.

Figure 1: Gravity estimates (columns) per year (rows) for intermediate input trade



Notes: This figure presents the estimation results and 95% confidence intervals for specification 12 for intermediate inputs, run annually for years 1995-2020.

4.2 Counterfactual scenarios and results

In what follows we present the main results of our counterfactual exercises whereby, in each case, we follow the steps explained in sections 2.3.1 and 2.3.2. We explore two types of scenarios. Our first set of counterfactuals relate to trade policy, or, statutory trade shocks. Here, we run three counterfactual scenarios related to policies either geared at fostering integration into global supply chains (such as low-income countries eliminating tariffs on intermediate inputs) or factors which could dampen supply chain participation (such as increasing tariffs). From a policy standpoint, the trade liberalization versus protectionism scenarios are particularly important. On the one hand, trade is typically more liberalized ex-ante amongst high-income countries compared to low-income countries, and hence a scenario which explores a leveling out of input tariffs amongst income groups sheds light on how the global supply network might react. On the other, trade protectionism scenarios speak directly to current events, and in particular the calls to reshore production in the wake of largescale international disasters such as the Covid-19 pandemic, or countries' ability to impose trade policy punitively to isolate a given trade partner.

Our second set of counterfactuals relates to geopolitical tensions in the form of conflicts and natural disasters. Both of these are non-statutory in nature. Compared to the trade policy scenarios, this set of exercises entails a different pattern of treatment heterogeneity. Specifically, countries engage in conflicts for very different reasons than altering tariffs, however, there could still be spillover effects to domestic and international trade patterns. And, with regards to natural disasters, these tend to occur randomly and be rather unpredictable in nature, in contrast to tariff changes which are announced in advance.

We examine the impact of these counterfactual shocks for three different groups of countries: high-income; middle-income; and low-income.[35] For each counterfactual exercise, we also examine three distinct outcomes for each income group. First, we explore how much the intermediate input component of gross output has contributed to changes in total gross output relative to 1995, i.e. the base year of analysis. Second, we examine whether those changes are driven predominantly by face value (direct) versus hidden-exposure (indirect) channels. Finally, we explore whether the changes are driven mainly by domestic versus foreign trade channels.

Broadly speaking, we find that actions taken by governments under scenarios geared at fostering or hindering GSC participation impact countries' participation in GSC networks by changing the composition of gross production. With few exceptions, the countries targeted by a given trade policy experience the largest change in output composition, irrespective of their development status. In terms of conflicts, we find that geopolitical tensions which manifest in domestic and/or international clashes reduce the contribution of intermediate inputs to gross output across the board. This indicates that policy decisions and geopolitical tensions play a very real and powerful role in shaping the composition of GSC networks. On the other hand, trade shocks which occur randomly, such as natural disasters in the form of extreme weather events or otherwise, reveal no clear trends in GSC outcomes and have much smaller magnitudes compared to counterfactual exercises which involve direct policy decisions. These results indicate that countries are likely more resilient to shocks which are both transient in nature and occur unpredictably.

Across the board, our results also point to the fact that shifts in output composition are primarily driven by hidden-exposure channels. This reinforces evidence based on a set of general equilibrium models in Costinot and Rodríguez-Clare (2014), where counterfactual responses tend to be augmented considerably through input-output linkages relative to models where producers sell all their output directly to final consumers. Further, we find that changing tariffs and engaging in conflict tends to shift the contribution of input trade between domestic versus foreign partners in expected directions.

In what follows, we describe the different scenarios and related results in detail. While all counterfactual exercises were run for each year relative to the baseline year 1995, we present counterfactual results for the first and last year of analysis (1996 and 2020) both for conciseness and to draw comparisons across two very different periods where the state

[35]We follow the World Bank's yearly income classification based on countries' Gross National Income per capita of the preceding year, and classify countries' income status based on values for year 1995. Appendix C.2 lists all countries included in the analysis as well as their income classification. For our purposes, middle-income countries include both upper-middle and lower-middle-income groups. For counterfactual exercises related to non-statutory trade costs, we forego the income split and instead look at countries which receive the specific shock.

of the world (and hence trade-cost vector) was different.[36]

For clarity, we present results in graphical form for each scenario. Each figure contains six panels. Panels A and B (top row) present results for changes in the contribution of intermediate inputs (GSC-links) to changes in gross production relative to the raw data, following equation 9. Panels C and D (middle row) show the split of those changes in contributions between hidden-exposure and face value trade channels. Finally, panels E and F (bottom row) show the split of those changes in contributions between domestic and foreign trade channels. We use different colors to differentiate high- (blue), middle- (green), and low-income (orange) country groups, as well as countries which are subject to old (blue) and new (orange) conflicts and natural disasters.[37]

4.2.1 Statutory trade shocks related to trade policy

Our first three counterfactual exercises relate to trade policy in the form of tariff changes. This can come in two forms: increases in trade liberalization geared towards fostering GSC participation, on the one hand; and protectionism which might disrupt GSC participation, on the other. The first two counterfactual exercises are inspired by Brenton et al. (2022), and represent policy scenarios which they term as “friendly” and “hostile” to GSCs, respectively.

Scenario 1—Trade liberalization: Low- and low-middle-income countries eliminate import tariffs on intermediate inputs.

In this GSC-friendly scenario, low- and low-middle-income countries fully eliminate import tariffs on intermediate inputs. This scenario is friendly to supply-chain participation for two reasons. First, it is well known that low- and low-middle income countries charge higher tariffs than countries in higher income groups; on average, developed countries impose tariffs which are roughly 4.5 times higher than those in place by industrial countries (IMF, and World Bank 2001). This fact is also supported by the data we use here, which show that, across years, low- and low-middle-income countries impose import tariffs which are significantly higher than middle- and high-income countries. While the tariff gap has narrowed over time, average tariffs in low-income countries were 6.5 percentage points higher than average tariffs in high-income countries in 2020, and average tariffs in low-middle-income countries were 3.6 percentage points higher (appendix Figure A.1, panel B). Hence, low- and low-middle-income countries eliminating tariffs on inputs would act to level out applied tariff rates globally. Second, targeting intermediate inputs specifically via tariff reductions is expected to boost input trade both within and across country groups, and thus enhance integration into supply networks where parts and components are critical.

Under this scenario, we find that the contribution of intermediate inputs to gross output increases for low- and low-middle-income countries, i.e. those which enact the

[36] Additional results for all years are available upon request.

[37] For clarity of presentation, we do not present extreme outlier values.

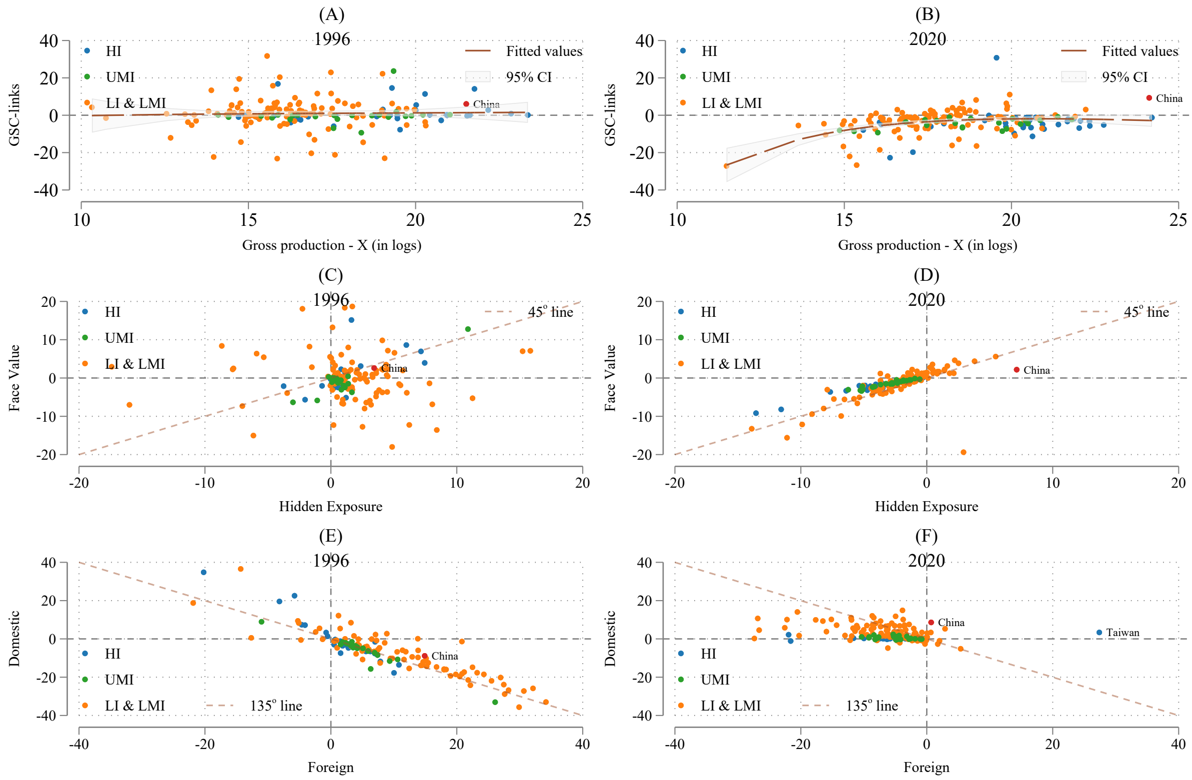
liberalization policy. On the other hand, high-income countries experience reductions in the contribution of intermediates to gross output sales, signaling that they shift more towards sales in final goods and services. This is shown in panels A and B of Figure 2 and it is particularly stark for the year 2020. Specifically, in panel B we see the low- and low-middle-income countries[38] tend to cluster above the line of best fit, and predominantly above zero, while high-income countries take almost exclusively negative values. Compared to 1996, increases in the input component of production is particularly noticeable for China; for year 2020 (Panel B) and under this scenario the contributions of input trade to Chinese output growth would increase by roughly 10 percent. The green dots for upper-middle-income countries tend to hover around zero, signaling that they are minimally affected by this policy scenario.

For the first counterfactual year, there is no clear indication as to whether face-value or hidden-exposure links contribute more to changes in the contribution of intermediates to gross output (Panel C). This picture crystallizes by 2020. Indeed, under this scenario China is the main country that experiences an increase in input trade through indirect channels in 2020, as shown by its placement below the 45-degree line in the upper right quadrant of Panel D. Hidden exposure channels are also primarily responsible for the decline in the contribution of intermediates to gross output experienced by high- and upper-middle-income countries, as well as a large portion of lower-middle-income countries, as shown by their clustering primarily above the 45-degree line in the bottom left quadrant.

We also observe that when low- and low-middle-income countries eliminate intermediate-input tariffs, domestic input transactions tend to overtake foreign input transactions in 2020 (Panel F), irrespective of countries' development status. This is shown by the majority of the respective symbols clustering just below the diagonal line in the upper left quadrant. Clearly, these are effects emanating from the deflection of trade flows in the multilaterally connected system. Two notable exceptions are China, for which there seems to be little net change in the domestic versus foreign split, and Taiwan, for which foreign transactions lead the change in output composition.

[38] For this counterfactual scenario, low-middle-income countries are shown with orange dots alongside low-income countries. Upper-middle-income countries are shown with green dots. For all other scenarios the middle income category includes low-middle- and upper-middle-income countries.

Figure 2: Counterfactual results from Scenario 1—trade liberalization



Notes: This figure presents results from the counterfactual exercise where low and low-middle income countries eliminate tariffs on intermediate inputs. Panels A and B plot changes in the intermediates component of gross production relative to total gross production values for years 1996 and 2020. Panels C and D decompose these changes into face value and hidden exposure channels. Panels E and F decompose these changes into domestic and foreign channels. LI, LMI, UMI, and HI refers to low-income, lower-middle-income, upper-middle-income, and high-income countries, respectively.

Scenario 2—Trade protectionism: High-income countries and China[39] increase tariffs on intermediate and final goods by 25 percentage points.

In the wake of recent geopolitical tensions and major global shocks, such as the Covid-19 pandemic, there were many calls by governments worldwide for companies to reshore production. For instance, at the onset of the pandemic and as supply-chain disruptions were making headlines, the European Parliament publicly stated its support for the reintegration of supply chains inside the EU (European Parliament 2020) and Japan provided over $2.2bn in funding for Japanese firms to leave China and set up shop within the ASEAN region (Reynolds and Urabe 2020). As such, it is not unreasonable to imagine a world whereby various countries would enact policies to encourage reshoring of production. This scenario, inspired by what Brenton et al. (2022) term their "reshoring leading economies scenario," has high-income countries and China (including Hong Kong and Macao) increase import tariffs on both intermediate and final goods by 25 percentage points.

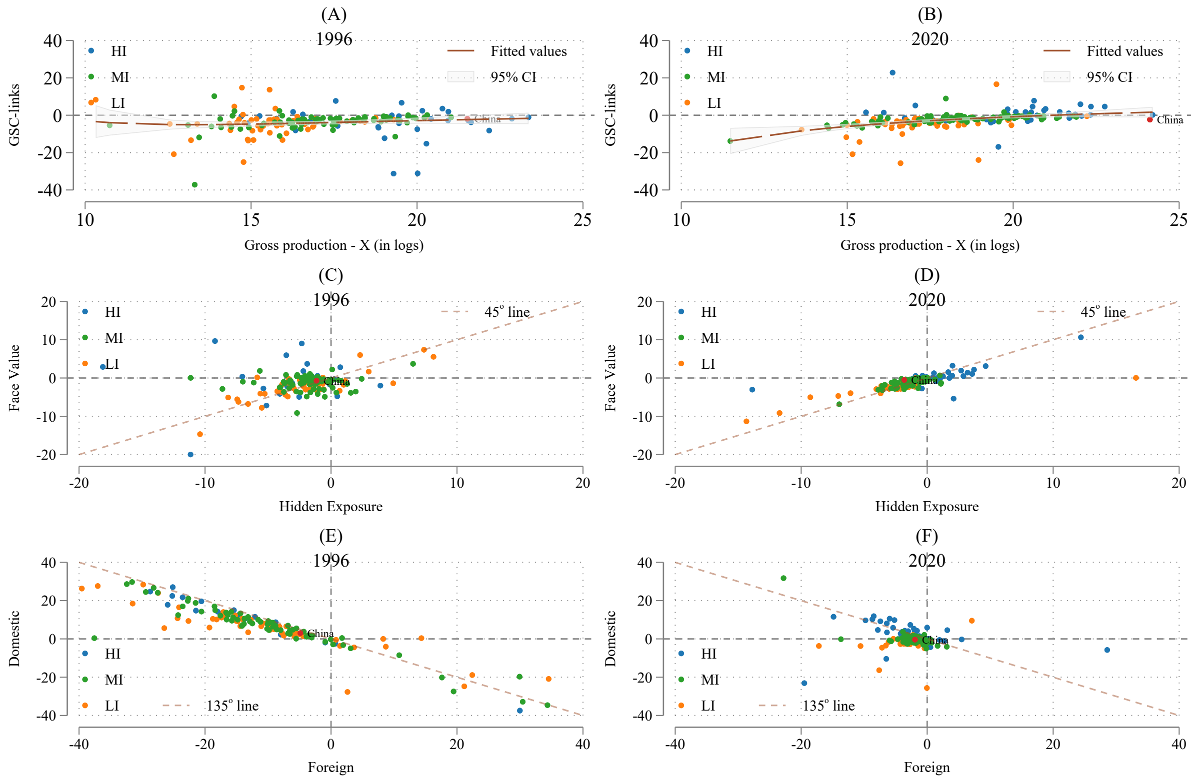
Under this scenario, most high-income countries see increases in the contribution

[39] In scenarios 2 and 3, reference to China includes Hong Kong and Macao.

of intermediate-inputs production to gross output, and this is most stark in the last counterfactual year as seen by the placement of the blue dots above zero (Figure 3, Panel B). These changes are predominantly driven by changes in hidden-exposure, as seen clearly by the fact that the majority of the blue dots in Panel D are clustered just below the 45-degree line in the top right quadrant. Moreover, for the high-income countries which imposed increased import tariffs, in 2020 the increase in the contribution of intermediates to output growth is driven mostly by domestic intermediates production, suggesting that increasing import tariffs as a reshoring policy is effective. This is seen from the blue dots which are mostly clustered above the diagonal line in the upper left quadrant of Panel F. Interestingly, this effect is much starker in 2020 (panel F) compared to 1996 (panel E). A possible explanation for this could be that tariffs became progressively lower over this period, and hence a 25 percentage point increase in later years is relatively larger than in earlier years, creating a larger trade response.

Low-income countries, on the other hand, see a decrease in the contribution of intermediate inputs to gross output, as seen by the fact that the orange dots are below zero for years 1996 and 2020, while middle income countries (green dots) experience little to no change (Figure 3 panels A and B). The negative change in the contribution of intermediate inputs to gross output for low-income countries appears to be driven by hidden-exposure channels, as seen by the fact that negative changes are clustered just above the 45-degree line in the bottom left quadrant of Panel D. And, the split between foreign and domestic channels (panels E and F) is much less apparent than for the case of high-income countries.

Figure 3: Counterfactual results from Scenario 2—trade protectionism



Notes: This figure presents results from the counterfactual exercise where high-income countries and China (including Hong Kong and Macao) increase tariffs on intermediate and final goods by 25 percentage points. Panels A and B plot changes in the intermediates component of gross production relative to total gross production values for years 1996 and 2020. Panels C and D decompose these changes into face-value and hidden-exposure channels. Panels E and F decompose these changes into domestic and foreign channels. LI, MI, and HI refers to low-income, middle-income, and high-income countries, respectively.

Scenario 3—Trade protectionism - China: All countries increase tariffs on intermediate and final goods from China by 50 percentage points. China increases tariffs on intermediate and final goods by 50 percentage points. Any existing DTAs and BITs between China and other countries are eliminated.

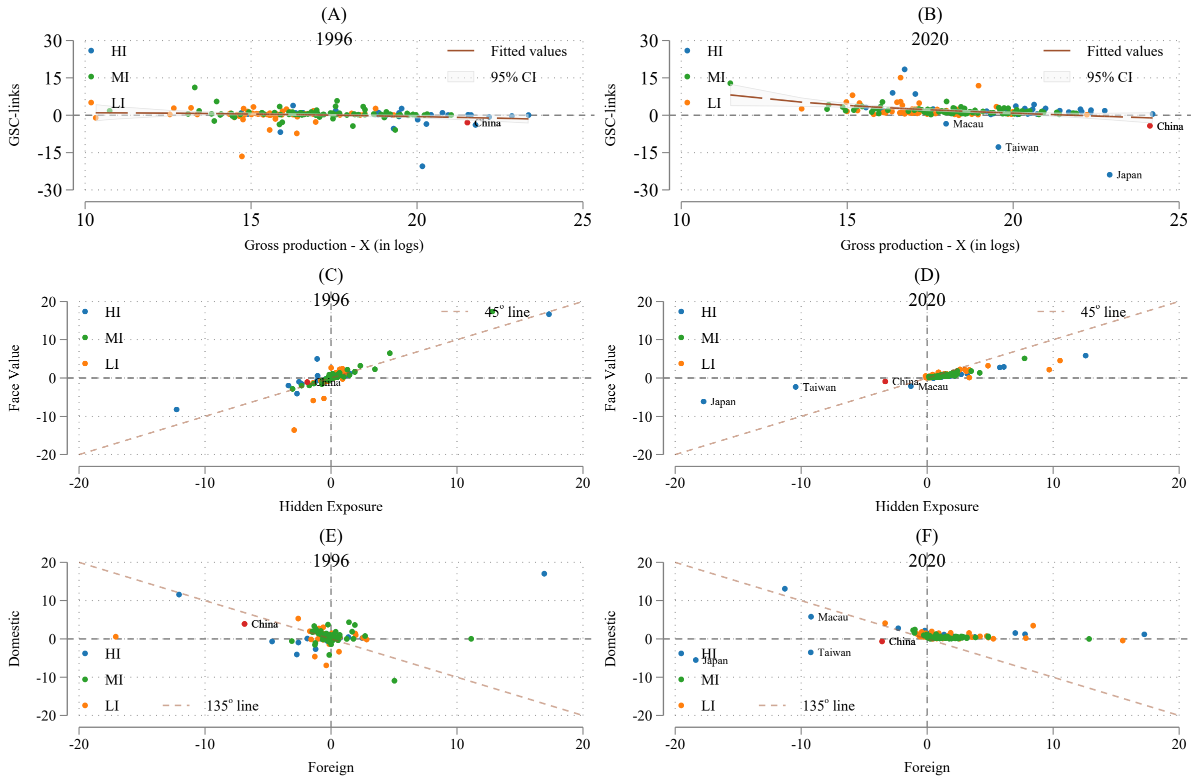
Geopolitical tensions aimed at disrupting GSC activity can manifest in many forms, and in recent years the world has witnessed the outbreak of tariff spikes imposed by various administrations on specific trade partners, as well as retaliatory tariffs which follow suit (Bown 2017, 2021). In this spirit, our next counterfactual scenario posits that all countries increase tariffs on intermediate and final goods from China by 50 percentage points, and that China imposes reciprocal tariff increases on its trade partners. Further, any DTAs and BITs between China and the world are eliminated, signalling full dis-integration of the world with these countries. In the same spirit as scenario 2, this is also a GSC-hostile scenario insofar as China has become the dominant producer of manufacturing inputs worldwide, surpassing all developed and developing countries combined (Baldwin et al. 2023), as well as the dominant supplier of manufacturing inputs to all major manufacturing countries worldwide (Baldwin et al. 2022).

As shown in Panels A and B of Figure 4, under this scenario China, Taiwan, Macau and Japan become more isolated from GSC networks, and experience declines in the contribution of input trade in the order of 5 percent (China and Macau), 14 percent (Taiwan) and 20 percent (Japan). On the other hand, all other countries experience an increase in the contribution of inputs to gross output. For all countries, these shifts work through hidden-exposure channels, in particular in the last counterfactual year (Panel D). This can be seen clearly by the fact that the dots for Japan, Taiwan, China (and to a lesser extent Macao) lie above the 45-degree line in the bottom left quadrant of Panel D, while all other countries lie below the 45-degree line in the upper right quadrant.

Further, as shown in panel F, in 2020 the declines in the contribution of input trade to gross output for China, Hong Kong, Macao and Japan are driven mostly by foreign input trade channels. This is intuitive, insofar as trade policies intended to isolate nations would push their production more towards the domestic market. The increases in input trade's gross output contribution for all other countries are also driven mostly by foreign channels, signaling that these countries gain in terms of cross-border trade integration.

One particularly interesting outcome from this scenario is the large declines in the input component seen for Japan, which is not targeted by the policy scenario. One potential explanation for this could be that within Asia, China and Japan are particularly tightly knit—with over 4 percent of Japan's total inputs (both domestic and foreign) being sourced both directly and indirectly from Chinese manufacturing sectors alone (Baldwin et al. 2022). Further, given the proximity of these trading partners to one another—as opposed to, say, Mexico, which is also highly dependent on Chinese manufacturing inputs—the hit to the input component of Japanese production could be felt particularly strongly.

Figure 4: Counterfactual results from Scenario 3—trade protectionism - China



This figure presents results from the counterfactual exercise where all countries increase tariffs on intermediate and final goods from China (including Hong Kong and Macao) by 50 percentage points and China (including Hong Kong and Macao) increases tariffs on intermediate and final goods by 50 percentage points. Any existing DTAs and BITs between China (including Hong Kong and Macao) and other countries are eliminated. Panels A and B plot changes in the intermediates component of gross production relative to total gross production values for years 1996 and 2020. Panels C and D decompose these changes into face-value and hidden-exposure channels. Panels E and F decompose these changes into domestic and foreign channels. LI, MI, and HI refers to low-income, middle-income, and high-income countries, respectively.

4.2.2 Non-statutory trade shocks related to conflicts and natural disasters

Having explored both GSC-friendly and GSC-hostile policy scenarios in section 4.2.1 above, we now turn to two counterfactual exercises related to non-statutory trade shocks, namely increases in international and domestic conflicts and increases in natural disasters. Our prior is that both of these scenarios would hamper supply networks, but for different reasons. Conflicts—in which countries actively engage—could decrease GSC participation (and gross production generally speaking) by making it harder to produce goods for internal consumption, e.g. due to disruptions to infrastructure, or to export goods, e.g. due to damage to road networks linking factories to ports. Depending on the conflict, geopolitical tensions which manifest in conflicts could also cause drops in international demand through boycotts, and decreases in supply caused by punitive actions imposed by foreign trade partners, such as sanctions and embargoes.

Natural disasters, on the other hand, are more random in the sense that their timing and specific nature is somewhat unpredictable. Further, natural disasters are not directly related to any specific policy decision or action. Nonetheless, natural disasters such as hurricanes, volcano eruptions, earthquakes, etc. are highly disruptive and have been known to knock production facilities, ports, and electric power plants offline, disrupting production overall (Baldwin et al. 2023).

Interestingly, as shown through scenarios 4 and 5 below, we find that while increased conflicts have a negative impact on the GSC component to output, natural disasters do not reveal any strong effect. This likely hints that countries are resilient to shocks like natural disasters, which tend to be more transient in nature and unrelated to geopolitical tensions and direct policy actions. In what follows, we describe the results of these two counterfactual exercises in detail.

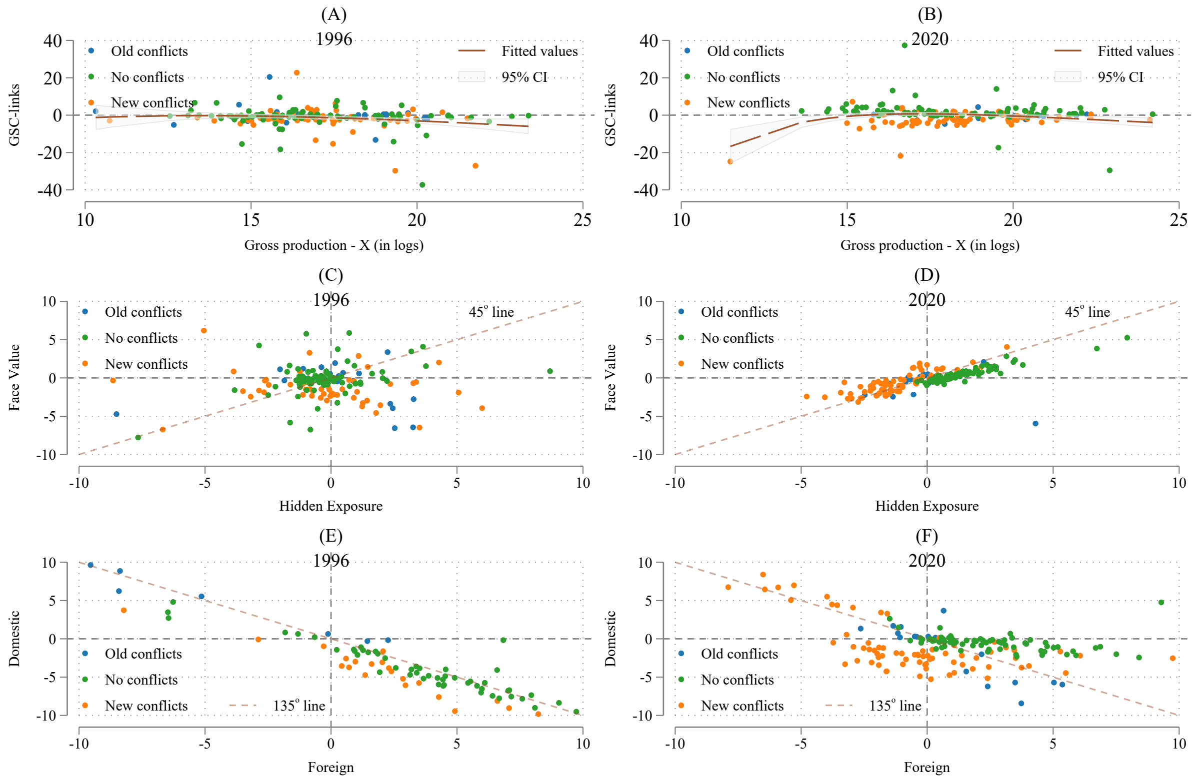
Scenario 4—Conflicts: If a conflict arose at any point since 1946, we assume that it never ended.

As explained in section 3, the data from the Uppsala Conflict Data Program provides rich information on international and domestic conflicts and organized violence from 1946 onwards. In this scenario, we examine the impact of conflicts on three unique sets of countries. First, those with old conflicts represent countries for which a conflict was underway in the counterfactual year. Second, those with new conflicts represent countries for which we artificially "switch on" a conflict, under the assumption that an old conflict never ended. For instance, if a country experienced a conflict in 2000, this country would be subject to a new conflict for years 2001 onwards. Finally, those with no conflicts represent countries for which a conflict never took place.

Under this counterfactual exercise a very clear message emerges. Countries which have old and new conflicts experience a stark downward shift in the contribution of intermediate inputs to overall production, and this is particularly apparent in year 2020. In contrast, countries which have no conflicts see marginally positive changes in the contribution of intermediate inputs to production (Figure 5, panels A and B). This result supports the notion that engaging in conflicts hinders GSC participation by suppressing the contributions of input trade to gross output.

Unpacking this result into face-value versus hidden-exposure channels on the one hand, and foreign versus domestic channels on the other, also reveals interesting patterns. While in 1996 the picture is quite scattered in terms of whether face value versus hidden exposure channels are driving the declines (Panel C), in 2020 a clear picture emerges (Panel D). Specifically, we observe that the decrease in the contribution of inputs for countries which experience old and new conflicts is driven almost exclusively by face-value channels, as shown by the clustering of the orange and blue dots just above the 45-degree line in the bottom left quadrant of Panel D. Furthermore, countries which have old and new conflicts see the decrease in input contributions coming mostly through foreign trade connections (Panel F). In line with our priors, this result points to the fact that conflicts, be them domestic or international, negatively and disproportionately hinder countries' ability to exploit international supply-chain networks. On the other hand, countries which never experienced a conflict see the small positive changes in the contribution of inputs to production coming through foreign trade channels, indicating that political stability fosters the proliferation of GSC networks.

Figure 5: Counterfactual results from Scenario 4—increased conflicts



This figure presents results from the counterfactual exercise where we assume that if a conflict arose at any point since 1959 it never ended. Panels A and B plot changes in the intermediates component of gross production relative to total gross production values for years 1996 and 2020. Panels C and D decompose these changes into face value and hidden exposure channels. Panels E and F decompose these changes into domestic and foreign channels.

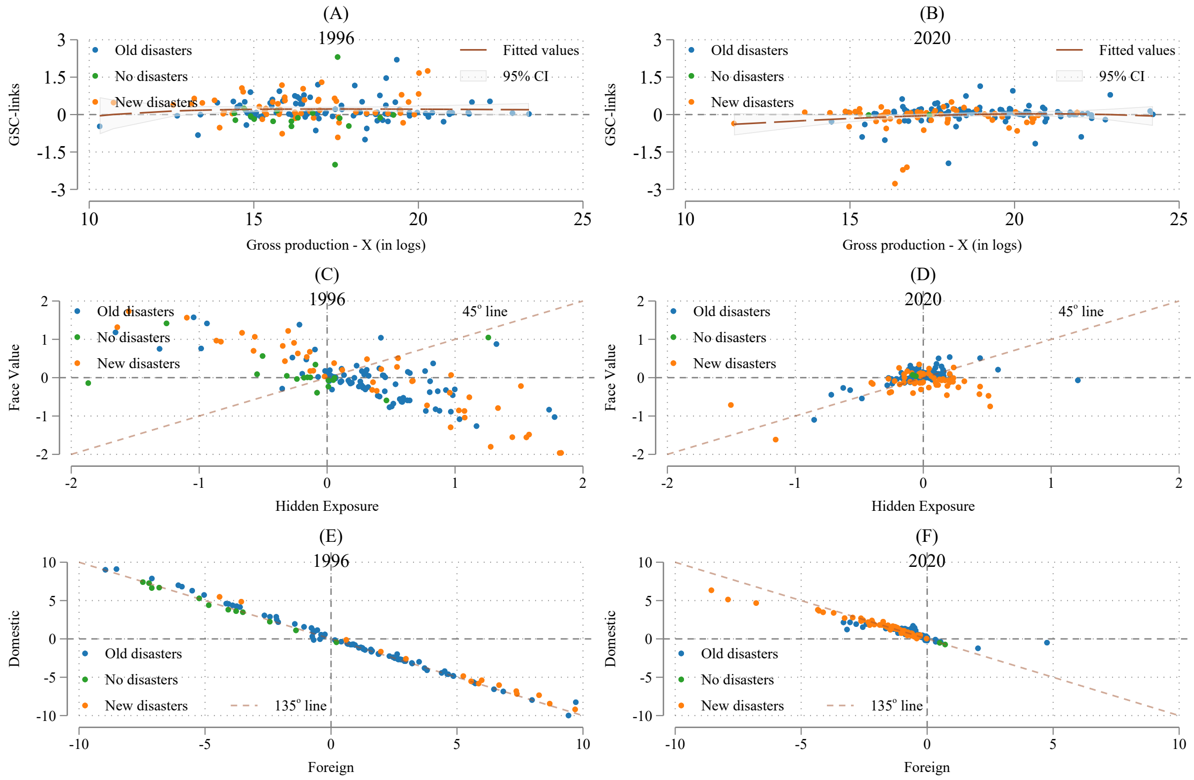
Scenario 5—Natural disasters: If a natural disaster occurred at any point since 1940 we assume that it never ended.

Our final counterfactual exercise exploits the detailed information on climate hazards and disasters from the EM-DAT International Disaster database, which houses information on the occurrence of over 26,000 mass climate disasters (see section 3). In the same spirit as the previous counterfactual scenario, we define three sets of countries: those with old disasters, meaning that a disaster actually occurred in the year of the counterfactual; those with new disasters, meaning that we have artificially carried forward a disaster to the current time period; and those which never experienced a disaster.

Compared to the other four scenarios explored thus far, this scenario differs in that natural disasters are not related to government actions or decisions per se. Rather, their timing and nature, although potentially very disruptive to GSC trade and global connectivity more generally, is rather unpredictable.

Unlike the other scenarios, there are no clear trends in how natural disasters (old or new) impact the contribution of the intermediate input component of gross output. This is seen in panels A and B of Figure 6, where the blue and orange dots are more or less symmetrically scattered above and below the line of best fit, which itself hovers around zero. Similarly, there is no clear pattern with regards to whether face-value or hidden-exposure channels dominate (panels C and D). And, consistent with this story, foreign versus domestic channels tend to cancel each other out, as shown in panels E and F which have almost all dots perfectly along the diagonal line. Together, these results speak to the resiliency of GSC networks under transient shocks which are free from geopolitical motives.

Figure 6: Counterfactual results from Scenario 5—increased natural disasters



This figure presents results from the counterfactual exercise where we assume that if a natural disaster arose at any point since 1940 it never ended. Panels A and B plot changes in the intermediates component of gross production relative to total gross production values for years 1996 and 2020. Panels C and D decompose these changes into face value and hidden exposure channels. Panels E and F decompose these changes into domestic and foreign channels.

4.3 Robustness checks

In order to test the robustness of our analysis, we replicate all main results presented above using the 2023 release of the OECD ICIO Tables (OECD 2023). Like the EORA data, these tables also provide data for years 1995-2020 and hence the time period of analysis is consistent.

Comparing results against those found when using the OECD ICIO tables serves as a meaningful exercise for two reasons. First, the comparison provides external validity of our analysis due to differences in the construction of the ICIO data itself. More specifically, the OECD data comprises information on a fewer number of countries, 76 in total, compared to EORA for which we have data on 175 countries. This manifests in a vast under-representation countries across all income categories, and in particular low-middle- and low-income countries in the OECD dataset compared to the EORA ICIO tables (Appendix C.2).[40] However, given potential issues with data quality which are known to arise particularly in the compilation of national accounts, supply use tables and trade statistics for developing countries—including but not limited to a lack of annual data—this also implies that there are many more imputations and assumptions underlying the EORA data than the OECD data. This point holds for both developed and developing nations, given that worldwide trade and production needs to balance across all countries. As such, using the OECD data as a benchmark against the EORA data provides a "sense check" of our main results. Second, the comparison sheds light on differences in counterfactual scenario outcomes when using a data source (EORA) which allows us to take into account the full network of supply chain connections across countries of varying income levels.

Table 1 presents results of this robustness check. Columns (1) and (2) contain pairwise correlation coefficients for observed intermediate input ($Z_{ij,t}$) and final goods and services ($M_{ij,t}$) domestic and international trade for the common set of 76 countries across datasets. As can be seen, these variables are essentially perfectly correlated in all years. Importantly, this correlation tells us that, if we were to run our counterfactual exercises on the restricted set of 76 countries using the EORA data, results would be virtually identical to results of the counterfactual scenarios when using the OECD data. In line with this observation, the gravity estimates when using the OECD ICIO dataset (appendix Figures B.2 and B.3) track those found when using the EORA data, presented in Figure 1 and appendix Figure B.1.

Columns (3)-(7) of Table 1 contain pairwise correlation coefficients of the GSC-links component ($\widetilde{GSC}^{*}_{i,t}$) of our five counterfactual scenarios for a select set of years. We observe that the correlation varies quite a bit across scenarios, is quite low in early years, and increases to some extent post-2016. Given the very high correlation coefficients from columns (1) and (2), however, this result showcases the importance of including the most detailed country information possible in the study of trade shock transmission, as adding low-middle- and low-income countries to the mix appears to have a non-negligible impact on how general equilibrium effects ripple through GSC-links across counterfactual outcomes. Therefore, when comparing the figures 2-6 from our baseline results to the analogous figures using the OECD ICIO data (B.4-B.8) it is not surprising that patterns

[40] Specifically, following the same income classification used for the EORA data, the OECD ICIO tables (versus EORA tables) contain information on 29 (versus 38) high-income countries, 13 (versus 23) upper-middle income countries, 22 (versus 55) lower-middle income countries, and 12 (versus 59) low-income countries.

in the data differ for the cases for which the correlation from Table 1 is low.

Table 1: Correlation of key variables between EORA and OECD data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Trade		Component $\widetilde{GSC}^*_{i,t}$ for scenario:				
Year	$Z_{ij,t}$	$M_{ij,t}$	1	2	3	4	5
1996	0.9975	0.9997	0.118	0.024	0.026	0.122	0.084
2000	0.9977	0.9994	-0.000	-0.234	-0.084	0.111	0.021
2005	0.9957	0.9991	0.002	0.630	0.382	0.057	0.544
2010	0.9960	0.9991	0.051	0.260	0.083	0.288	0.468
2015	0.9852	0.9929	-0.025	-0.136	0.084	0.151	0.424
2016	0.9932	0.9996	0.415	0.597	0.333	0.478	0.339
2017	0.9948	0.9995	0.173	0.413	-0.022	0.100	-0.204
2018	0.9943	0.9993	0.802	0.865	0.439	0.801	0.203
2019	0.9934	0.9994	0.712	0.553	0.445	0.674	0.151
2020	0.9901	0.9991	0.667	0.527	0.376	0.654	0.185

Notes: Columns (1) and (2) of this table present pairwise correlation coefficients for observed intermediate input ($Z_{ij,t}$) and final goods and services ($M_{ij,t}$) domestic and international trade, for the common set of 76 countries across EORA and OECD datasets. Columns (3)-(7) contain pairwise correlation coefficients of the GSC-links component ($\widetilde{GSC}^*_{i,t}$) of our five counterfactual scenarios, described in section 4.

5 Conclusion

This paper sheds light on important questions related to shock transmission through global supply-chain (GSC) networks, and differentiates outcomes by countries' development status. In doing so, for low-, middle-, and high-income country groups, we examine the relative impact of shocks on changes in intermediate versus final goods components of gross production, as well as the relative importance of direct and indirect as well as foreign versus domestic channels for those changes. In addition, we explore whether country responses to shocks differ depending on whether the shock is statutory and policy-driven (e.g. tariffs) or non-statutory (e.g. conflicts and natural disasters) in nature.

Using rich input-output data for 175 countries across years 1995-2020 allows us to provide new insights not only on the channels of shock transmission across GSC networks, but also across different types of countries. This is particularly important in today's policy climate due to conflicting viewpoints that GSC networks are an important engine for growth and poverty reduction, on the one hand, and a source of risk and exposure, on the other.

In performing our analysis, we run five counterfactual scenarios which can be categorized as related to: (i) trade policy, or, statutory trade shocks; and (ii) non-statutory shocks including conflicts and natural disasters. In terms of trade policy scenarios, the hypothetical states of the world we explore impose policies geared either at liberalizing trade (and which are GSC-friendly) or which are protectionist in nature (and which are GSC-hostile). The GSC-friendly scenario, which has low and low-middle income countries eliminating tariffs on input trade, speaks directly to common policy prescriptions for developing nations—which typically impose much higher tariffs than high-income nations—to liberalize trade. The GSC-hostile scenarios, which involve tariff increases imposed predominantly by high-income countries, speak to recent calls by policymakers to reshore production and increase trade barriers as a means to reduce GSC risk and exposure. Finally, the scenarios related to conflicts and natural disasters speak to both the potential spillover effects of geopolitical tensions which play out across the international and domestic scene, as well as the possibility of experiencing large-scale shocks which can arise unexpectedly.

Three main conclusions emerge from our analysis. First, results point to the fact that actions taken by governments impact countries' participation in GSC networks by changing the composition of gross production towards intermediate inputs. Countries which are targeted by a given trade policy experience the largest change in output composition. In terms of countries' development status, we find that low-income countries benefit from trade liberalizing scenarios through increased GSC network participation, while the reverse is true for trade protectionism scenarios. On the other hand, trade protectionism in high-income countries acts to increase their domestic input contribution to GSC networks at the expense of developing nations. These findings support both that liberalization is an effective means through which to boost GSC participation, and also that protectionism can be used to exclude country groups from supply networks. Similar patterns are also observed in the case of conflicts, where countries which experience old or new conflicts are less integrated into supply networks overall. On the other hand, trade shocks which occur randomly, such as natural disasters, reveal no clear trends in GSC outcomes, indicating that countries are likely more resilient to shocks which are both transient in nature and occur unpredictably.

Second, we find that shifts in output composition are primarily driven by hidden exposure, i.e. indirect, channels. This speaks to the important nature of the complexity of trade networks overall, and the indirect routes that inputs travel before reaching their final destination. Third, we find that changing tariffs and engaging in conflict tends to shift the contribution of input trade between domestic versus foreign partners in expected directions. This is both reassuring and cautionary. Specifically, this result reveals that trade policies can be broadly effective in helping countries achieve GSC strategies, but also indicates that protectionist trade policy and conflicts have the ability to distort GSC networks and hinder development outcomes.

While contributing to the literature by shedding light on important questions related to shock transition and the interplay with countries' development status, our analysis leaves the door open to future research to further unpack results, for example through an exploration of sector-level heterogeneity. This would be particularly interesting, especially given the fact that certain sectors (such as manufacturing) and sub-sectors (such as automotives, electrical equipment, etc.) are both heavily GSC-intensive and rely on the deep interconnection of input trade across developing and developed nations.

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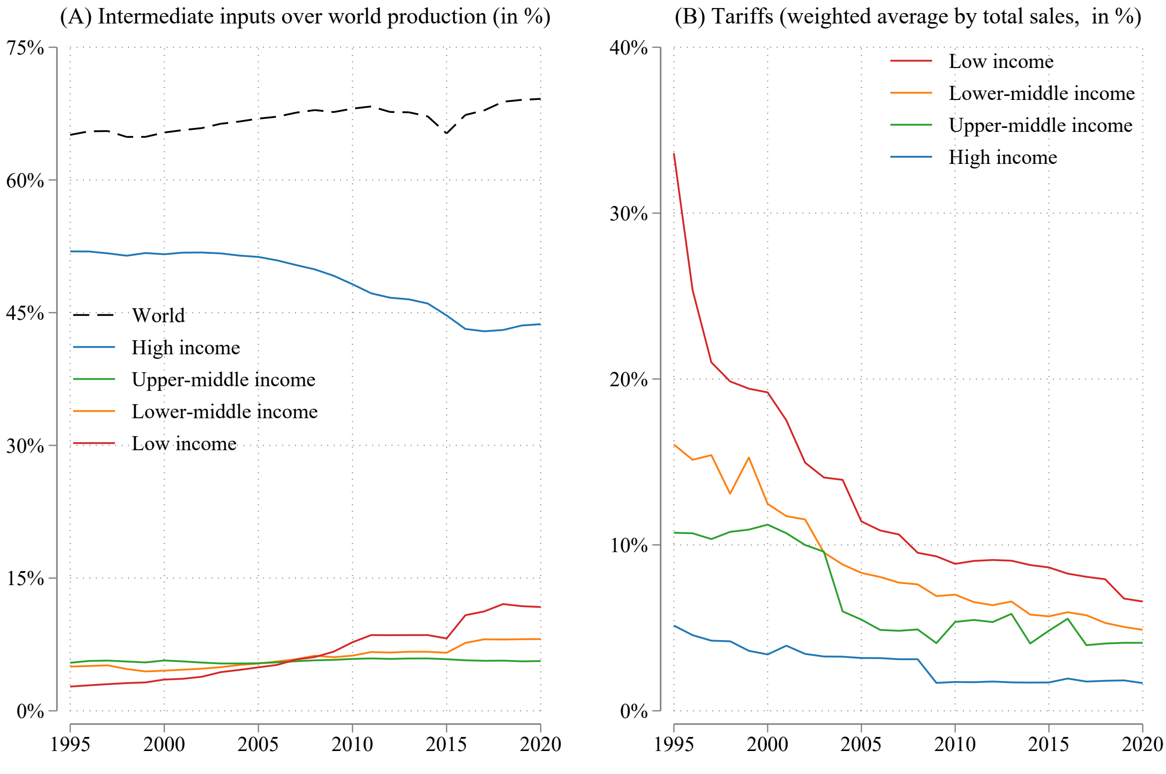
Appendix

A Additional descriptive statistics

This Appendix presents additional descriptive statistics on the share of intermediate inputs in gross output and tariffs, both referred to in the main text.

The left panel of Figure A.1 shows the share of intermediate inputs in world gross production for years 1995-2020. Overall, in year 2020, intermediate inputs make up just under 70 percent of total gross output. There is large heterogeneity by income group, however, with high-, upper-middle-, low-middle-, and low-income income countries accounting for 44 percent, 6 percent, 8 percent, and 12 percent, respectively. Over time, we observe that the share attributed to high-income countries has fallen from 52 percent in 1995 to 44 percent in 2020, while the shares for low-middle-income and low-income countries has risen. The most notable share rise is for low-income countries, from just 2.7 percent in 1995 to 12 percent in 2020. This jump is primarily driven by China, however, which is classed as a low-income country in 1995.

Figure A.1: World input share and average tariffs, by input group, 1995-2020



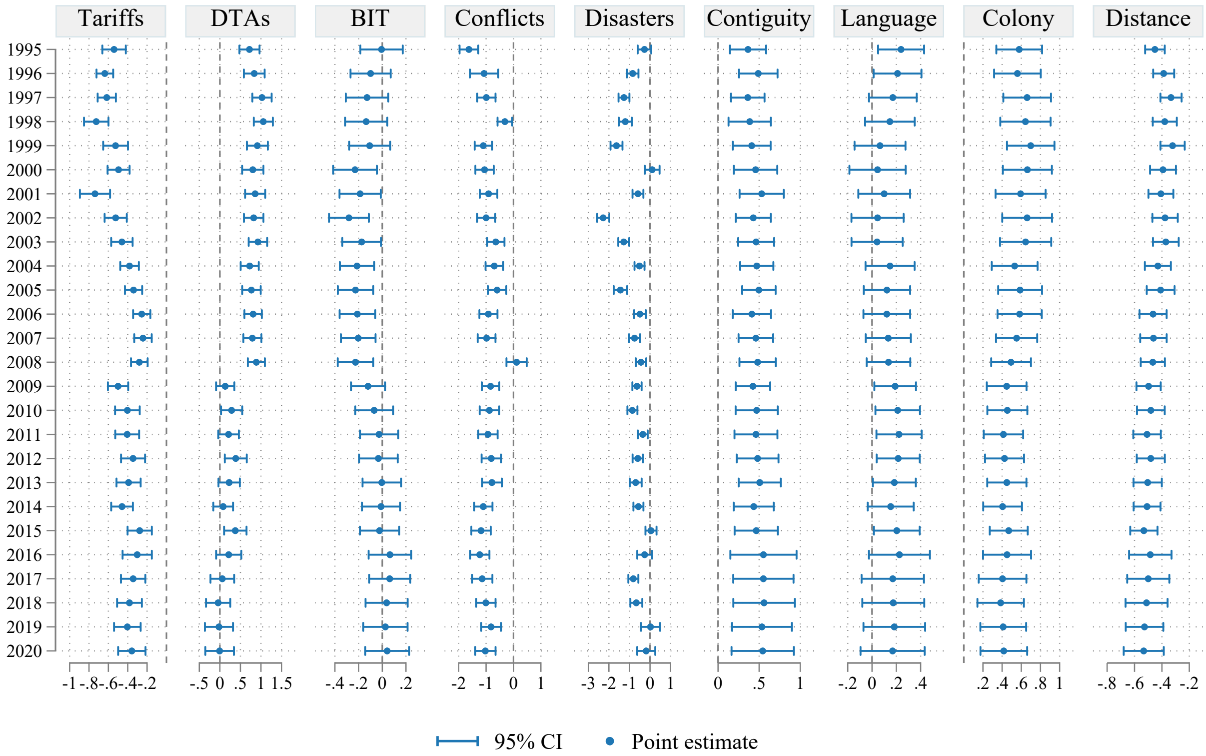
Source: Authors' calculations based on EORA database (Panel A) and WITS database (Panel B).
Notes: Panel A presents the share of intermediate inputs in total gross production, by income group. Panel B presents average tariffs by income group, weighted by total sales. Following the main methodology in the paper, countries' income group refers to year 1995.

The right panel of Figure A.1 shows the average applied tariff imposed by each income group over years 1995-2020, weighted by total sales. Average tariffs are highest for low-income countries, followed by low-middle- upper-middle- and high-income country groups. This is consistent with the notion of least developed countries imposing higher import tariffs than more developed countries. Nonetheless, low-income countries have also decreased tariffs by far more than other country groups over the sample period.

B Additional results and robustness

B.1 Additional results

Figure B.1: Gravity estimates (columns) per year (rows) for final goods and services trade

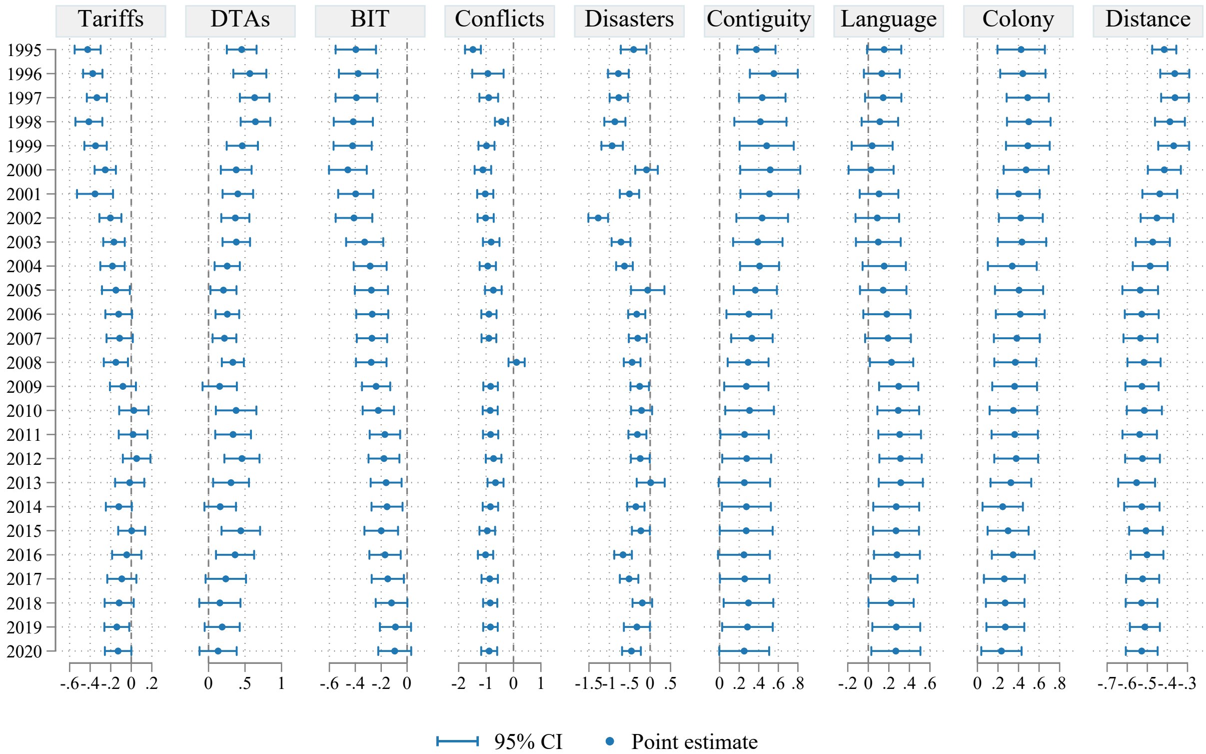


Notes: This figure presents the estimation results and 95% confidence intervals for specification 12 for final goods and services, run annually for years 1995-2020.

B.2 Robustness exercises

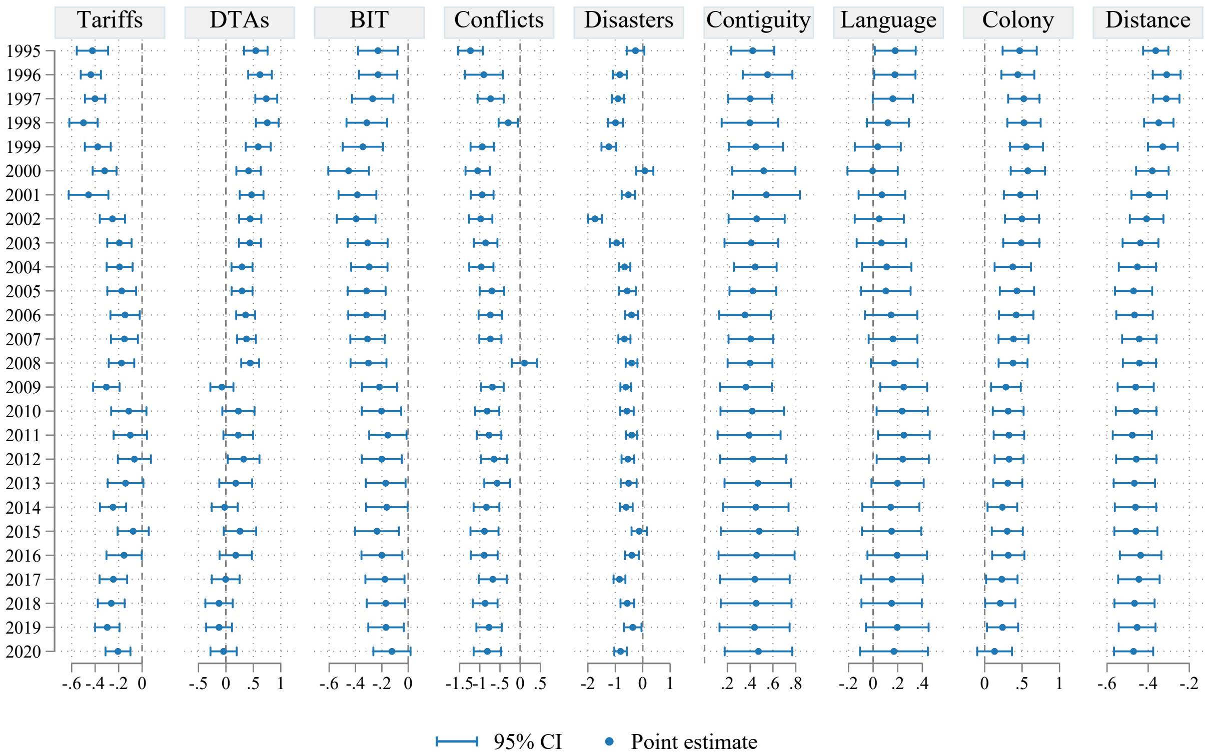
This appendix contains results of robustness exercises described in section 4.3 of the main text.

Figure B.2: OECD ICIO: Gravity estimates (columns) per year (rows) for intermediate input trade



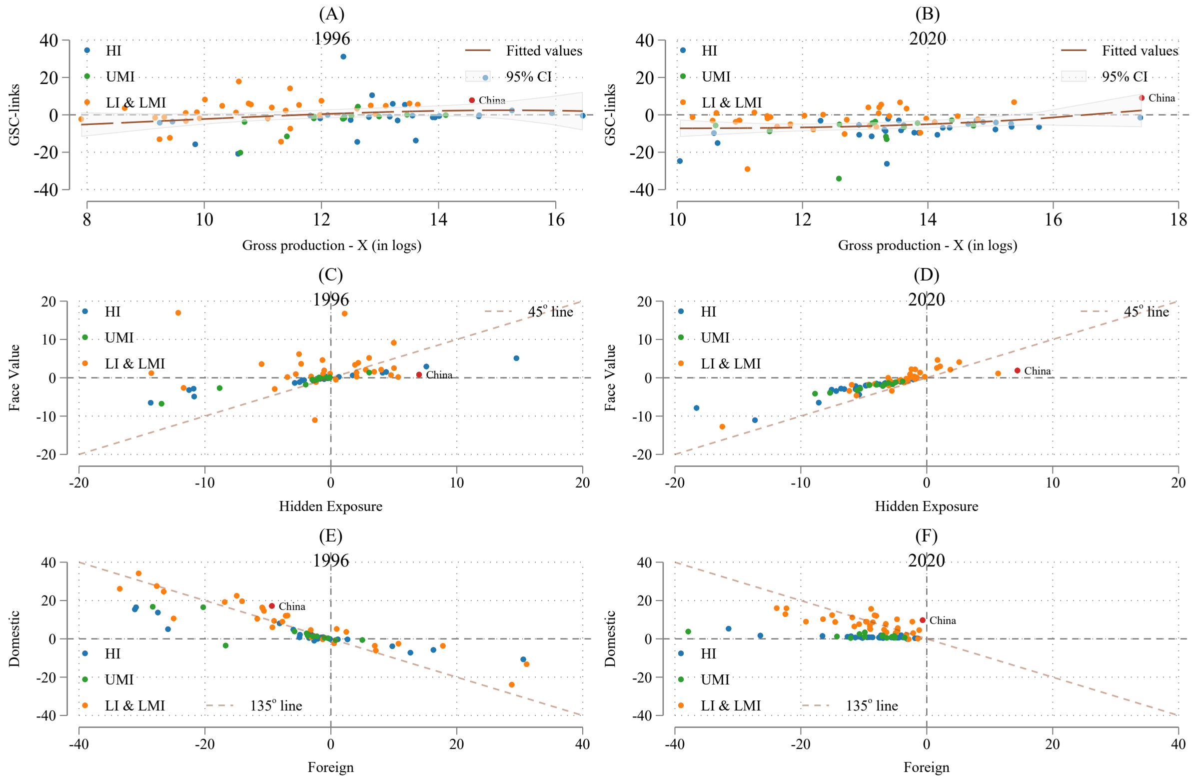
Notes: This figure presents the estimation results and 95% confidence intervals for specification (12) for intermediate input trade, run annually for years 1995-2020 using the OECD ICIO tables (OECD 2023).

Figure B.3: OECD ICIO: Gravity estimates (columns) per year (rows) for final goods and services trade



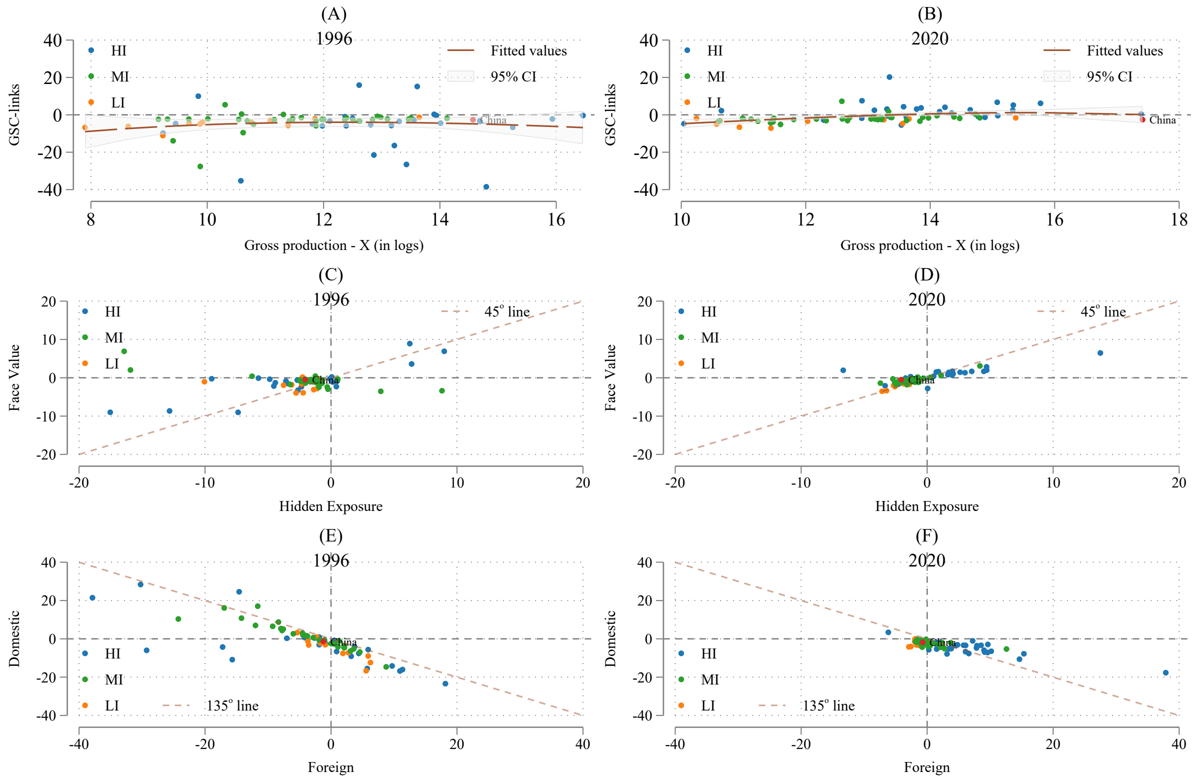
Notes: This figure presents the estimation results and 95% confidence intervals for specification (12) for final goods and services, run annually for years 1995-2020 using the OECD ICIO tables (OECD 2023).

Figure B.4: Counterfactual results from Scenario 1 using OECD ICIO data—trade liberalization



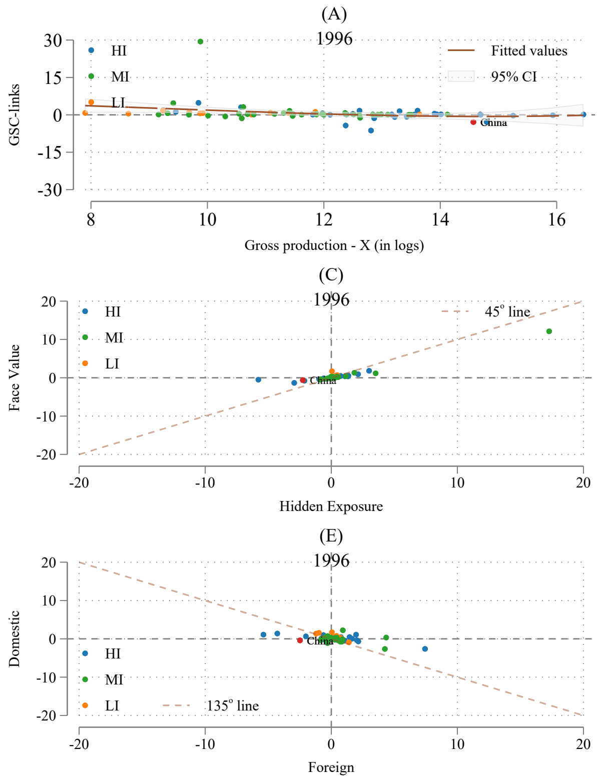
Notes: This figure presents results from the counterfactual exercise where low and low-middle income countries eliminate tariffs on intermediate inputs, when using OECD ICIO tables (OECD 2023). Panels A and B plot changes in the intermediates component of gross production relative to total gross production values for years 1996 and 2020. Panels C and D decompose these changes into face value and hidden exposure channels. Panels E and F decompose these changes into domestic and foreign channels. LI, LMI, UMI, and HI refers to low-income, lower-middle-income, upper-middle-income, and high-income countries, respectively.

Figure B.5: Counterfactual results from Scenario 2 using OECD ICIO data—trade protectionism



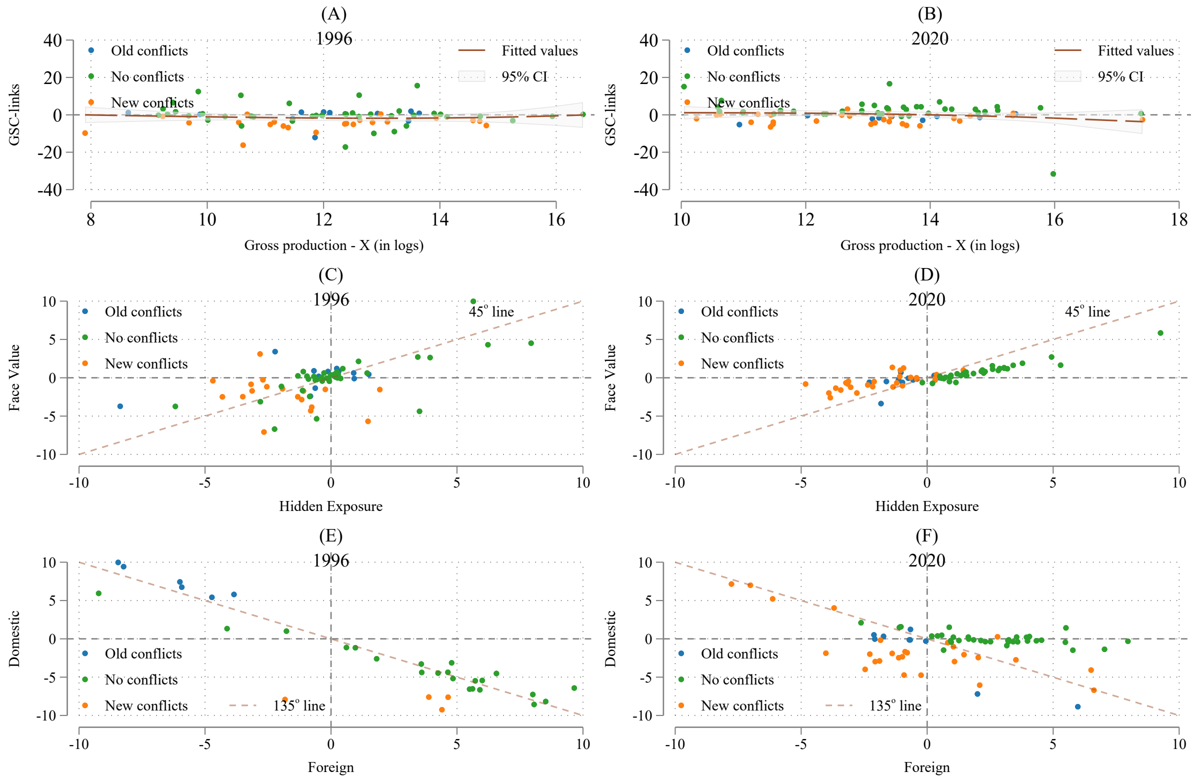
Notes: This figure presents results from the counterfactual exercise where high-income countries and China (including Hong Kong and Macao) increase tariffs on intermediate and final goods by 25 percentage points, when using OECD ICIO tables (OECD 2023). Panels A and B plot changes in the intermediates component of gross production relative to total gross production values for years 1996 and 2020. Panels C and D decompose these changes into face-value and hidden-exposure channels. Panels E and F decompose these changes into domestic and foreign channels. LI, MI, and HI refers to low-income, middle-income, and high-income countries, respectively.

Figure B.6: Counterfactual results from Scenario 3 using OECD ICIO data—trade protectionism - China



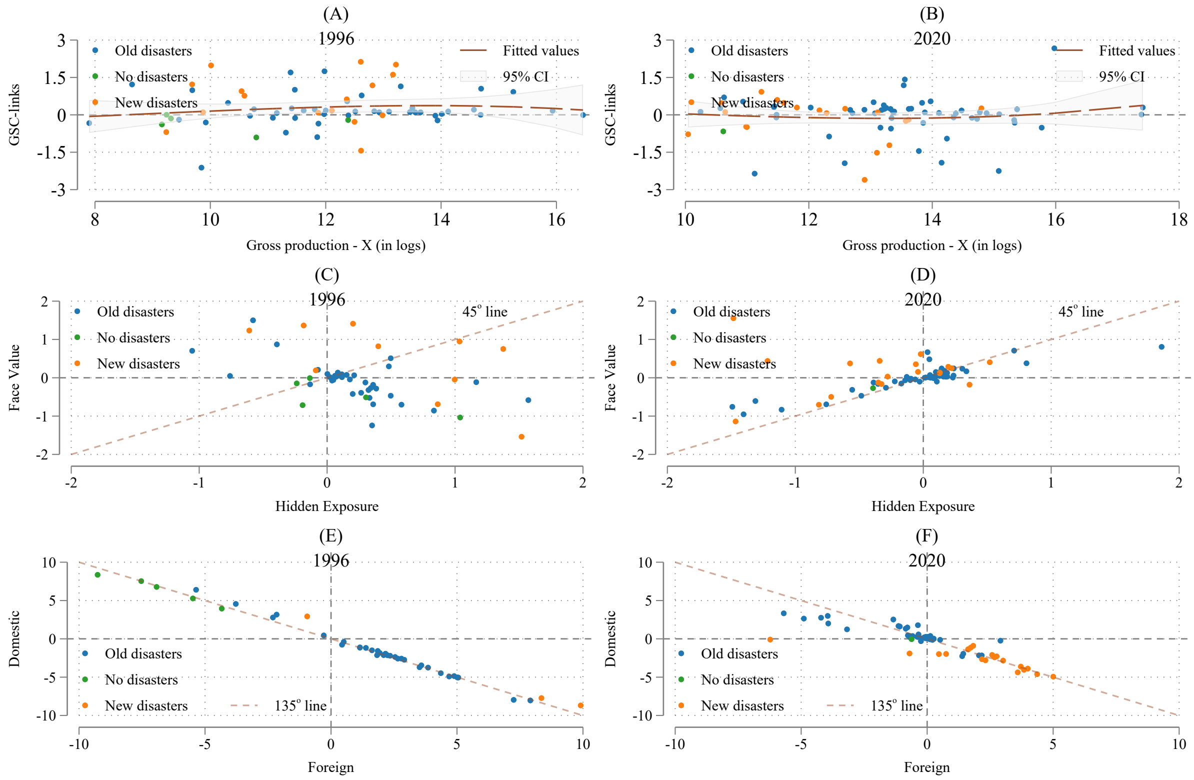
This figure presents results from the counterfactual exercise where all countries increase tariffs on intermediate and final goods from China (including Hong Kong and Macao) by 50 percentage points and China (including Hong Kong and Macao) increases tariffs on intermediate and final goods by 50 percentage points. Any existing DTAs and BITs between China (including Hong Kong and Macao) and other countries are eliminated, when using OECD ICIO tables (OECD 2023). Panels A and B plot changes in the intermediates component of gross production relative to total gross production values for years 1996 and 2020. Panels C and D decompose these changes into face-value and hidden-exposure channels. Panels E and F decompose these changes into domestic and foreign channels. LI, MI, and HI refers to low-income, middle-income, and high-income countries, respectively.

Figure B.7: Counterfactual results from Scenario 4 using OECD ICIO data—increased conflicts



This figure presents results from the counterfactual exercise where we assume that if a conflict arose at any point since 1959 it never ended, when using OECD ICIO tables (OECD 2023). Panels A and B plot changes in the intermediates component of gross production relative to total gross production values for years 1996 and 2020. Panels C and D decompose these changes into face value and hidden exposure channels. Panels E and F decompose these changes into domestic and foreign channels.

Figure B.8: Counterfactual results from Scenario 5 using OECD ICIO data—increased natural disasters



This figure presents results from the counterfactual exercise where we assume that if a natural disaster arose at any point since 1940 it never ended, when using OECD ICIO tables (OECD 2023). Panels A and B plot changes in the intermediates component of gross production relative to total gross production values for years 1996 and 2020. Panels C and D decompose these changes into face value and hidden exposure channels. Panels E and F decompose these changes into domestic and foreign channels.

C Data appendix

This appendix presents additional details on data cleaning steps of the EORA data, as well as presents a list of countries used in our analysis and their associated income groups.

C.1 Additional EORA cleaning steps

When cleaning the EORA data, we follow the steps outlined in Borin et al. (2021) to ensure that the data are balanced. First, we drop the Rest of World aggregate, as this cannot be matched with other data in our trade cost vector.[41] Given that the EORA data contains information on virtually all countries worldwide, however, this is not of large concern. Second, we compute values for total gross output at the country-sector level by summing across the rows (for sales of intermediate inputs and final demand) and columns (for purchases of intermediate inputs and value added), respectively. In the EORA input-output data, it can be the case that gross output values differ depending on whether one is summing across the rows or down the columns. For the vast majority of cases, these differences are trivial. Third, in order to reconcile potential discrepancies, we select the higher of the two values of total gross output and, depending on which gross output value was selected, we redistribute the balance to either the final demand or value added vector. Finally, we collapse the sectoral dimension of the data to the country-year level.

C.2 EORA country list

As mentioned in the main text, the EORA database contains input-output data for 190 countries (including the Rest of the World, which we exclude when cleaning the data) over the period 1990-2020. We drop information on 14 countries when matching the EORA data with other datasets used to construct our trade cost vector, due to data availability. Overall, these countries make up a trivial share of total gross output (ranging from 0.1 to 0.3 percent of total gross output depending on the year).[42]

Specifically, we drop information on 13 countries due to lack of tariff data. Cases where there was no tariff data available at all include: Palestine and the British Virgin Islands. Cases where we have no information on tariffs imposed by a given country include: Andorra; Antigua and Barbuda; Greenland; Iraq; Monaco; New Caledonia; North Korea; South Sudan; San Marino; and Somalia.

Further, we drop Liechtenstein from the data as there is missing information for this country in the CEPII Geodist database. Finally, we exclude the USSR from the EORA data, as the USSR is classified as Russa from 1991 onwards. Due to data anomolies, however, the EORA data does contain a few records for the USSR post 1991. In all cases,

[41] Of note, the Rest of World aggregate in EORA also does not include information on the sectoral breakdown for the intermediate inputs matrix.

[42] The dropped countries account for 0.07 to 0.45 percent of total world exports.

values for intermediates and final demand are very small and can be rounded off to zero in almost every case, and values for total trade are less than a few thousand dollars.

The below list presents all countries used in our analysis, classified by income status. In order to classify countries' income status, we follow the World Bank's yearly income classification based on countries' Gross National Income per capita of the preceding year. Our country classification is based on values for year 1995, which is the baseline year in our main analysis. Countries with an asterisk (*) denote countries also available in the OECD ICIO Tables (OECD 2023).

High-income countries

1. Aruba
2. Australia*
3. Austria*
4. Bahamas
5. Belgium*
6. Bermuda
7. Brunei
8. Canada*
9. Cayman Islands
10. Cyprus*
11. Denmark*
12. Finland*
13. France*
14. French Polynesia
15. Germany*
16. Hong Kong*
17. Iceland*
18. Ireland*
19. Israel*
20. Italy*
21. Japan*
22. Kuwait
23. Luxembourg*
24. Macao
25. Netherlands*
26. New Zealand*
27. Norway*
28. Portugal*
29. Qatar
30. Singapore*
31. South Korea
32. Spain*
33. Sweden*
34. Switzerland*
35. Taiwan*
36. United Arab Emirates
37. United Kingdom*
38. USA*

Upper-middle-income countries

1. Antigua
2. Argentina*
3. Bahrain
4. Barbados
5. Brazil*
6. Chile*
7. Croatia*
8. Czech Republic*
9. Gabon
10. Greece*
11. Hungary*
12. Libya
13. Malaysia*
14. Malta*
15. Mauritius
16. Mexico*
17. Oman
18. Saudi Arabia*
19. Seychelles
20. Slovenia*
21. South Africa*
22. Trinidad and Tobago
23. Uruguay

Lower-middle-income countries

1. Algeria
2. Belarus*
3. Belize
4. Bolivia
5. Botswana
6. Bulgaria*
7. Cape Verde
8. Colombia*
9. Costa Rica*
10. Cuba
11. Djibouti
12. Dominican Republic
13. Ecuador
14. Egypt*
15. El Salvador
16. Estonia*
17. Fiji
18. Guatemala
19. Indonesia*
20. Iran
21. Jamaica
22. Jordan*
23. Kazakhstan*
24. Latvia*
25. Lebanon
26. Lesotho
27. Lithuania*
28. Maldives
29. Moldova
30. Montenegro
31. Morocco*
32. Namibia
33. North Macedonia
34. Panama
35. Papua New Guinea
36. Paraguay
37. Peru*
38. Philippines*
39. Poland*
40. Romania*
41. Russia*
42. Samoa
43. Serbia
44. Slovakia*
45. Suriname
46. Swaziland
47. Syria
48. Thailand*
49. Tunisia
50. Turkey*
51. Turkmenistan
52. Ukraine*
53. Uzbekistan
54. Vanuatu
55. Venezuela

Low-income countries

1. Afghanistan
2. Albania
3. Angola
4. Armenia
5. Azerbaijan
6. Bangladesh*
7. Benin
8. Bhutan
9. Bosnia & Herzegovina
10. Burkina Faso
11. Burundi
12. Cambodia*
13. Cameroon*
14. Central African Rep.
15. Chad
16. China*
17. Congo
18. Côte d'Ivoire*
19. Dem. Rep. of Congo
20. Eritrea
21. Ethiopia
22. Gambia
23. Georgia
24. Ghana
25. Guinea
26. Guyana
27. Haiti
28. Honduras
29. India*
30. Kenya
31. Kyrgyzstan
32. Laos*
33. Liberia
34. Madagascar
35. Malawi
36. Mali
37. Mauritania
38. Mongolia
39. Mozambique
40. Myanmar*
41. Nepal
42. Nicaragua
43. Niger
44. Nigeria*
45. Pakistan*
46. Rwanda
47. Sao Tome and Principe
48. Senegal*
49. Sierra Leone
50. Sri Lanka
51. Sudan
52. Tajikistan
53. Tanzania
54. Togo
55. Uganda
56. Vietnam*
57. Yemen
58. Zambia
59. Zimbabwe