Pandemic-induced increases in container freight rates: Assessing their domestic effects in a globalised world*

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Abstract

The Covid-19 pandemic severely disrupted the sea transportation industry, leading container freight rates to reach record highs from late 2020 and into 2021. This study examines the welfare effects of this disruption on a specific country, Colombia. For this, I use a quantitative model of international trade with out-of-steady-state transitional dynamics and a rich structure for the organization of production, plus an instrumental variable approach to estimate a trade elasticity to freight. I quantify both the direct effects of freight increases on goods transported to and from Colombia, as well as the indirect impact of heightened rates on routes across the rest of the world. The resulting welfare loss of 1.4% is solely attributable to the direct effects, as the indirect impact simultaneously improves Colombia's relative trade openness, thereby compensating for the effects of the increased shipping costs worldwide.

Keywords: Container freight, transportation costs, international trade, Covid-19.
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1 Introduction

One of the most well-established results in the international trade literature is the close connection between welfare and trade costs. Alongside natural and regulatory trade barriers, a substantial proportion of these costs arises from international transportation, which was profoundly disrupted by the Covid-19 pandemic. Notably, the sea transport industry, responsible for approximately 80% of total international trade (Heiland and Ulltveit-Moe, 2020*a*; UNCTAD, 2021*b*), encountered a confluence of intricate logistical and operational challenges, resulting in a historic surge in freight rates that began in late 2020 and persisted until mid-2022. Thus, while the Covid-19 pandemic diminished welfare for various reasons, one of the channels through which welfare was affected was the impact on international trade and the global production networks resulting from the disruption in the maritime transport industry. Despite its importance, efforts to comprehensively quantify the significance of this channel have been relatively scarce.

In this study, I estimate the size of this welfare reduction for a specific country, Colombia. Given the increasing importance of global trade networks, I not only assess the effects of increased freight rates on the goods imported and exported by Colombia but also analyze the indirect impacts resulting from the rises in freight rates on all other international routes. For this, I use a quantitative model of international trade that encompasses multiple countries and sectors and uses an input-output structure similar to Caliendo and Parro (2015) to account for the global production network. In addition, given the dynamic nature of the shock, the model incoporates out-of-steady-state transitional dynamics and reallocation costs for workers, as in Caliendo, Dvorkin and Parro (2019) (hereafter CDP). Building on CDP, I model bilateral trade costs as a function of sector-specific duties and overall transportation costs. These transportation costs, in turn, depend on the observed freight rates (along with unobservable factors) and an elasticity of transportation costs with respect to freight.

The latter elasticity of transportation costs to freight, which is a key input for the quantification exercise, is estimated in a model-consistent way. Particularly, the gravity equation of the model suggests that this elasticity can be derived by combining two trade elasticities that are feasible to estimate: one related to freight and the other related to tariffs. Since bilateral freight rates are arguably endogenous to bilateral trade flows, I employ an instrumental variable (IV) approach to estimate the first elasticity. The instrument takes advantage of both the heterogeneous timing of lockdowns during the pandemic and the pre-existing conditions in port infrastructure. This empirical strategy yields a statistically significant trade elasticity to freight close to -1, falling within the range estimated in the relevant literature. By combining this elasticity with estimates of sectoral trade elasticities to tariffs obtained from recent studies, I obtain the elasticities of transportation costs to container freight. These elasticities, along with series of observed freight rates, enable me to quantify the time-series of shocks to transportation costs resulting from the pandemic.

With the obtained series of transportation cost shocks, I use the quantitative model of trade to evaluate the effects of these shocks in the domestic economy. For this, I start by constructing a quarterly baseline economy that begins in a pre-pandemic year with full availability of data (2018), and that, after that, evolves towards its steady state under the assumption that freight and other exogenous state variables (e.g., sectoral productivity levels, mobility costs across sectors, other bilateral international trade costs, etc.) remain constant. Subsequently, I analyze the implications for the allocation of labour, real wages, and welfare across various counterfactual scenarios, wherein I solely modify the transportation costs using my series of shocks. Those quantitative exercises are performed using the dynamic extension of the "exact-hat algebra" approach of Dekle, Eaton and Kortum (2008), recently proposed by CDP.

The results of the counterfactual exercises suggest that the observed increases in worldwide freight rates generated sizable effects on Colombian real wages that impacted the path of real consumption and hence the model-consistent measure of welfare, which displays a loss of 1.4%. Regarding employment, the rise in worldwide freight led to 0.12% of the workers (28.6K) moving towards non-employment, and, within employment, a reallocation of workers towards non-tradable sectors, particularly construction, which ended with an increase of 0.07% in their employment share (13.4K workers). Although sizable in absolute terms, these effects in the labour market are moderate compared to the paths of labour reallocation that exhibit the baseline economy without shocks.

As stated above, to understand the importance of global trade networks and the role of the country's degree of openness in shaping the latter results, I divide the full set of shocks into a subset that includes increases in freight rates only in routes that involve Colombia directly (i.e. freight rates for its imports and exports), and a subset with the increases in freight rates in all remaining routes. By doing so, the results of the corresponding counterfactuals show that the effects on employment reallocations work in opposite directions. This is because employment reallocations respond to changes in relative wages; and each subset of shocks triggers opposite impacts on the wages of tradable sectors relative to non-tradable sectors. While in the case of increasing freight only in routes that involve Colombia the country becomes relatively more closed with respect to the rest of the world, inducing a decrease on relative wages in tradable sectors, in the case in which freight increases only in routes that do not involve Colombia the country becomes relatively more open, and hence the opposite effect on relative wages occurs. Therefore, the moderate employment reallocation effects obtained in the main counterfactual with the full set of shocks on, are the result of the sum of opposite forces on labour reallocation that partially offset each other.

Regarding welfare, my findings indicate that the total loss in welfare resulting from the disruption in the maritime transport industry can be solely attributed to the higher freight rates on goods imported and exported by Colombia. Interestingly, the increase in freight rates in other routes that do not involve Colombia, while causing a cost-push effect that impacts Colombia's productive structure, also enhances the country's relative trade openness with respect to the rest of the world. This, in turn, enables the tradable sector to expand, generating gains from trade that effectively offsets the effects of the increased shipping costs worldwide.

Related literature

This study belongs to a burgeoning literature in trade that uses quantitative Ricardian models to study transitional dynamics after a set of shocks hits an economy. The core structure of those models, built on the multi-sector version of the Eaton and Kortum's (2002) model of trade and its extension to consider I-O linkages of Caliendo and Parro (2015), is a workhorse framework in the trade literature, that, as opposed to older computable general equilibrium models, provides micro-theoretical foundations and a tight connection between theory and data. This type of models has been used extensively for quantitative analysis during the last decade –see Costinot and Rodríguez-Clare (2014) and Caliendo and Parro (2022) for a review, but mainly for the purpose of performing comparative static exercises (e.g., assessing the impact of trade policies or technology shocks, or the consequences of liberalization episodes). Instead, their use to study out-of-steady-state transitional dynamics is relatively recent.

Up to my knowledge, the only papers that incorporate those type of dynamics into a multi-sector, multi-factor model of trade with I-O linkages are CDP, Rodríguez-Clare, Ulate and Vásquez (2020), Dix-Carneiro et al. (2020), Caliendo et al. (2021), and Ulate, Vasquez and Zarate (2023)[1]. In the first three cases, their models also incorporate spatial frictions between regions (a dimension that I abstract from) to study the implications of the "China" trade shock in the the US (CDP and Rodríguez-Clare, Ulate and Vásquez, 2020), and the implications of the 2004 European Union enlargement (Caliendo et al., 2021). In the fourth case, their model instead adds consumption-saving decisions and labour market frictions within sectors, to study the response of labour markets in six countries to technology, trade and preference shocks. Finally, in the concurrent study by Ulate, Vasquez and Zarate (2023), which is the most closely related to this research, the model developed by Rodríguez-Clare, Ulate and Vásquez (2020) is used to examine the effects of temporary increases in iceberg trade costs on the U.S. labour market, aiming to simulate the global supply chain disruptions during the pandemic. One of the main differences between the their study and mine lies in my additional effort to link the observed evolution of container freight rates across different shipping routes and the model-specific transportation cost shocks, through the estimation of the relevant trade elasticities.

My research is also related to the literature that estimates trade elasticities to transportation costs, particularly the papers of Limão and Venables (2001), Martínez-Zarzoso and Suárez-Burguet (2005), Jacks and Pendakur (2010), Shapiro (2016) and Fraser (2018). Usu-

[1] Kleinman, Liu and Redding (2023) also uses a model of trade with out-of-steady-state transitional dynamics and choices of migration, that include forward-looking investment decisions, but, in their baseline specification, with a single sector.

ally, transportation costs are measured either in a direct way using available freight rates for particular routes (as in Limão and Venables, 2001; Martínez-Zarzoso and Suárez-Burguet, 2005; Jacks and Pendakur, 2010; or in my case) or in an indirect way based on CIF/FoB ratios[2] that are collected from the same reporter, given the issues raised by Hummels and Lugovskyy (2006) of comparing data from different reporters.[3] The empirical strategies are usually based on the estimation of a gravity-type of equation, and, in similar way as here, some of those use IV approaches to address the problem of endogeneity between freight rates and trade flows (Martínez-Zarzoso and Suárez-Burguet, 2005; Jacks and Pendakur, 2010; Shapiro, 2016). Except for Jacks and Pendakur (2010), all the cited studies estimate trade elasticities to transportation costs that are significant and of the expected negative sign. The estimated elasticities range from -0.42 in the case of Fraser (2018) and -7.91 in the case of Shapiro (2016), so my estimated elasticity of -1.04 in my preferred specification lies inside that range.

This study also belongs to a vast literature that explores implications of the Covid-19 pandemic in different dimensions. Particularly, it is related to those papers analyzing the evolution of the global maritime transportation industry during the pandemic (Heiland and Ulltveit-Moe, 2020*a*,*b*; UNCTAD, 2021*b*) and the impacts of the pandemic on the Colombian economy; more specifically on real consumption (Acevedo et al., 2022; Bonilla-Mejía et al., 2022*a*) and the allocation of sectoral employment (Alfaro, Becerra and Eslava, 2020; Morales et al., 2022*a*,*b*; Bonilla-Mejía et al., 2022*b*).

Finally, considering my results regarding the increase in freight rates in routes not involving Colombia, that indicate that Colombia's relative position improves as other countries fare worse, there is a potential link between this study and the existing literature on unilateral trade protection. For example, relevant papers in this strand include Brander and Spencer (1981), Venables (1987), Ossa (2011), and Tobal (2017), among others.

The organization of this paper is as follows. Section 2 presents my empirical motivation, by examining the evolution of the container freight rates during the Covid-19 pandemic. Section 3 introduces the dynamic model of trade with observable freight rates. Section 4 discusses the procedure that allows me to infer the magnitude of the transportation cost shocks in the model, particularly by estimating the trade elasticity to freight rates. Section 5 performs the results of the counterfactual exercises of adding the inferred transportation costs shocks to the baseline economy. I also perform some robustness checks to the baseline results. Finally, Section 6 concludes.

[2]CIF: Cost, Insurance and Freight; FoB: Free on Board. Since CIF is the sum of FOB and transport costs, CIF/FOB equals one plus the ad valorem freight and insurance rate.

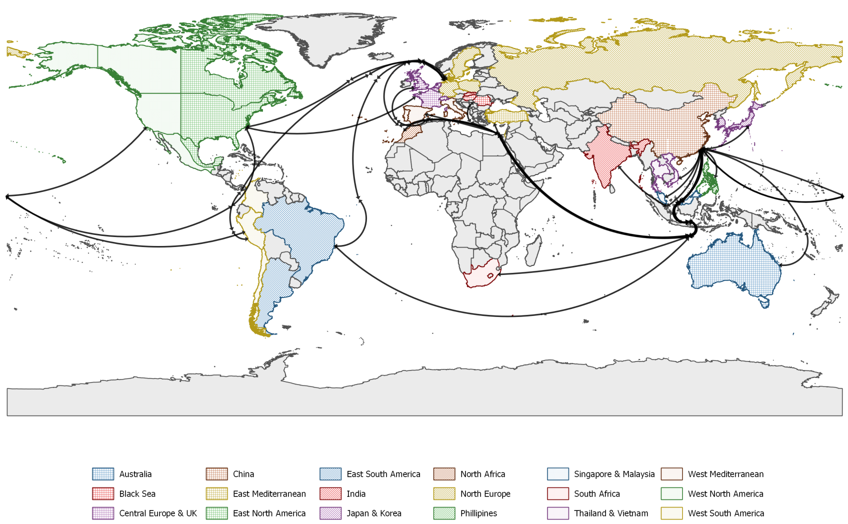
[3]Because of this, the advantage of the use of direct freight rates is that they are often considered to be of better quality (Gaulier et al., 2008)

2 Container freight rates during the Covid-19 pandemic

As the world economy emerged from the severe and abrupt decline in economic activity caused by the Covid-19 pandemic in early 2020, a combination of various factors triggered a significant increase in container freight rates worldwide, beginning in late 2020. These factors included congestion and delays at ports resulting from lockdowns and other sanitary measures, bottlenecks faced by many manufacturing sectors due to supply chain disruptions, logistical challenges in meeting the rapid recovery in demand compared to anticipated levels, and even some exogenous shocks such as the obstruction of the Suez Canal (e.g., the obstruction of the Suez Canal) (see Brooks, Fortun and Pingle 2020*a*,*b*; Reserve, 2021; UNCTAD, 2021*a*). Although initially perceived as transitory, most of these factors persisted longer than expected, leading to historically high delivery times and freight rates in 2021 and 2022. Only in 2023, following the aftermath of the pandemic and the complete recovery of the global economy, the industry gradually returned to normalcy.

To study the evolution of container freight rates during the pandemic, I collect available time series for different routes all around the world from three different data providers: Drewry, Freightos/Baltic Exchange and Ningbo. Each of those sources collect real-time information of spot carry rates from different freight forwarders, and aggregate them to construct representative rates for individual shipping routes.[4] Table C.1 in the Appendix shows the 36 routes with available information from any of the three data providers. Those routes involve trade between 18 different worldwide regions, displayed in Figure 1, that are either shipping destinations, shipping origins or both.

Figure 1 – Routes and Regions with Available Information of Container Freight

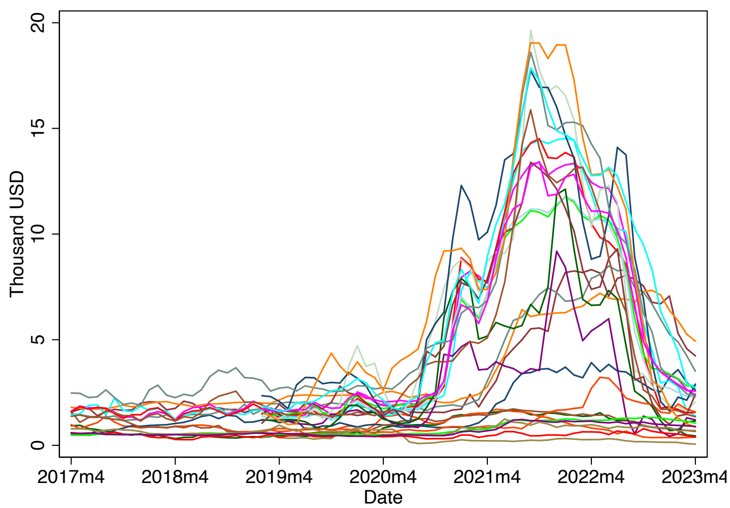


Note: The sources for each route are indicated in Table C.1, and the countries that belong to each of the displayed regions are listed in Table C.2.

[4]All rates are reported in USD per forty foot container, so the resulting measures are comparable.

Figure 2 jointly depicts the monthly evolution of all available container freight rates since 2017. Most of the series display a noticeable increase, starting by late 2020. In 2021, worldwide freight rates increased on average to four times their 2019 levels (306%). However, the increases were largely heterogeneous. By splitting the routes between origins and destinations that depart or arrive from Asia (East) or otherwise (West), Figure 3 shows that the increases were more striking in the routes departing from locations in the East (first row). This asymmetry is even present when observing freight rates between the same pair of regions. For instance, the 2021 average container freight for shipping from China to East North America increased 323% relative to their 2019 average level, whereas shipping the other way round was only 34% more expensive in 2021 compared to 2019.

Figure 2 – Container Freight Rates During the Covid-19 Pandemic



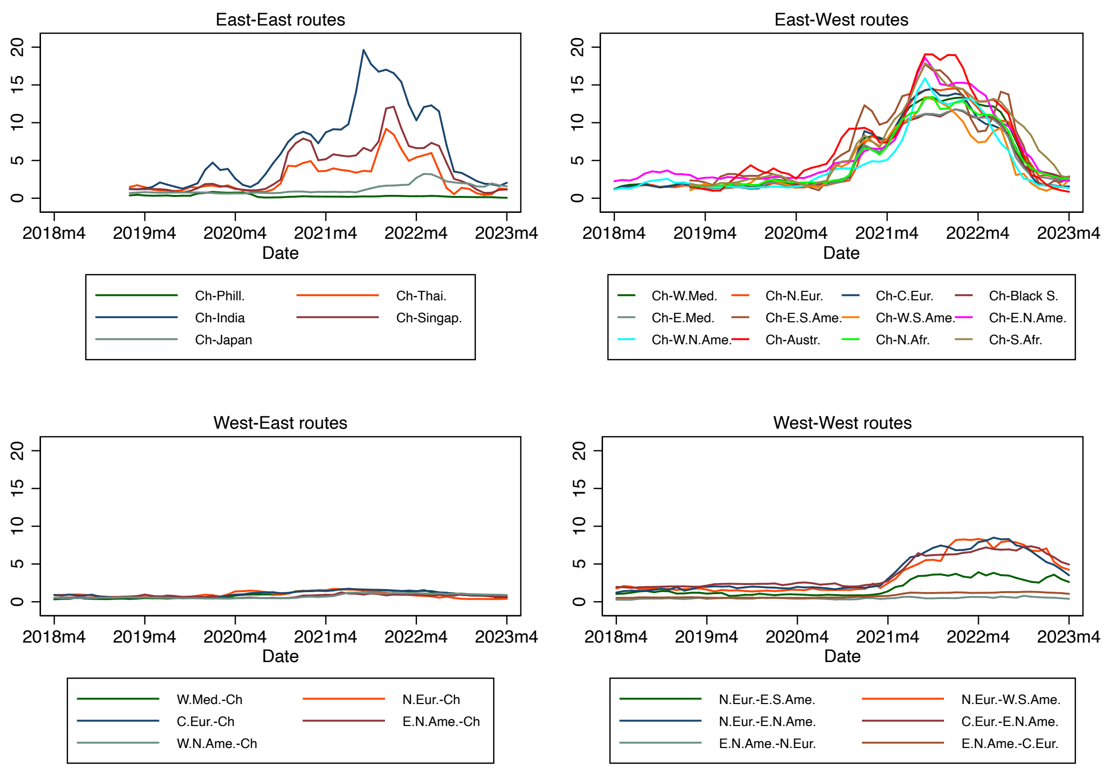
Note: All rates are reported in thousand USD per forty foot container. Sources: Drewry, Freightos and Ningbo container indexes.

The latter set of facts poses a challenge to the standard approach in which transportation costs are introduced in quantitative trade models. Commonly, under the assumption of a full pass-through of tariffs to consumers, the consumer price of a good from sector j in country n originated in country i at time t, is modeled as a function of the before-duty and transport-cost price at country i's border (FOB price) $p_t^{i,j}$ as:

$$p_t^{ni,j} = \left(1 + \tau_t^{ni,j}\right) \psi^{ni,j} p_t^{i,j} \tag{1}$$

where $\psi^{ni,j} > 1$ is the (iceberg) transportation cost component, that includes freight and insurance, and $\tau_t^{ni,j}$ is the ad-valorem tariff on the CIF price ($\psi^{ni,j} p_t^{i,j}$). Usually $\psi^{ni,j}$ is unobservable and is modeled simply as a function of distance between the pair of countries, (e.g. Hummels, 2007; Fontagné, Guimbard and Orefice, 2022); or as function of distance and other time-invariant country-pair characteristics representing both natural barriers (adjacency, land border) and cultural barriers (common language, colonial background); or simply as a time-invariant importer-exporter fixed effect. In any of the latter cases, the approach is at odds with the behavior of freight in the aftermath of the Covid-19 pandemic. First, freight were clearly time-variant as Figure 2 shows. And second, even in a cross-section, the distance effect was asymmetric between West and East inbound and outbound routes (Figure 3). To address these issues, in the next section I introduce in an otherwise standard model of international trade a more general representation of transportation costs. Particularly, I make $\psi^{ni,j}$ time-variant and use observable container freight rates from country i to n (F_t^{ni} hereafter) to inform the model about its temporal evolution.

Figure 3 – Container Freight Rates by West/East Direction of the Route



*All rates are reported in thousand USD per forty foot container. Sources: Drewry, Freightos and Ningbo container indexes.

3 A quantitative dynamic trade model with freight rates

In what follows I present a standard quantitative Ricardian model of international trade with multiple sectors and an input-output structure as in Caliendo and Parro (2015), extended to consider transitional dynamics in multiple periods as in CDP. The model closely resembles an economy that is similar to the one depicted by CDP's model, but abstracting from spatial (regional) dynamics within the studied country for simplicity. The main difference is that international trade costs are divided into sector-specific duties and international transportation costs, which in turn are a function of observed freight rates. The key elasticity of trade costs to freight rates, that is estimated below, links the observed increases in freight rates to transportation costs shocks in the model. In the following I denote time periods by $t = 1, 2, ...$ sectors by $j, k = 1, 2, ..., J$ and countries by $i, n = 1, 2, ..., N$.

3.1 Consumers

Consumers in each country are forward looking and have perfect foresight and a discount rate $\beta \geq 0$. They can be either employed or non-employed, in the latter case consumption is obtained from the country-specific exogenous home production $b^n > 0$. In our country of interest, call it n, the labour market is segmented, with barriers to mobility across sectors,[5] represented by a time-invariant sector-pair specific labour relocation cost $\zeta^{n,jk}$ measured in terms of utility.[6] Thus, workers in sector j supply a unit of labour inelastically and receive a sector-specific competitive market wage $w_t^{n,j}$. The total consumption of those individuals is represented by $C_t^{n,j}$, which is a Cobb–Douglas aggregator of the final goods purchased from each other sector, i.e. $C_t^{n,j} = \prod_{k=1}^{J} (c_t^{n,jk})^{\alpha^{n,k}}$ where $\alpha^{n,k}$ are the expenditure shares that add up to one. The aggregate price index is $P_t^n = \prod_{k=1}^{J} (P_t^{n,k}/\alpha^{n,k})^{\alpha^{n,k}}$ where $P_t^{n,k}$ is the price index of final goods purchased from sector k, defined below.

The consumers' problem is to decide in each period in which sector supply their labour in order to maximize their lifetime utility, subject to idiosyncratic shocks for each choice, denoted by ϵ_t^k (with zero mean), and the barriers to mobility across sectors ζ^{jk}. Denoting sector 0 as non-employment, the formal problem of a worker is:

$$\mathrm{v}_t^{n,j} = \ln C_t^{n,j} + \max_{\{k\}_{k=0}^{J}} \left\{ \beta E \left[\mathrm{v}_{t+1}^{n,k} \right] - \zeta^{n,jk} + \nu \epsilon_t^k \right\}$$

$$\text{s.t. } C_t^{n,j} \equiv \begin{cases} b^n & \text{if } j = 0 \\ w_t^{n,j}/P_t^n & \text{otherwise} \end{cases}$$

where $\mathrm{v}_t^{n,j}$ is the lifetime utility, and ν quantifies the variance of the idiosyncratic shocks. Once a distributional assumption on the shocks ϵ_t^k is imposed (Type-I extreme value), it is possible to obtain closed-form solutions for both the expected lifetime utility for working in a given sector j and the transitions of labour across sectors.[7] Particularly, denoting the expected

[5]The existence of barriers of mobility across sectors even for workers that do not migrate from their initial locations has been well documented in the literature. See for instance Alvarez-Cuadrado, Amodio and Poschke (2020) or Pulido and Święcki (2020) for the case of barriers between agriculture and non-agriculture.

[6]For simplicity and to avoid larger data requirements, for the remaining countries a non-segmented labour market is assumed; i.e. with free labour mobility and the same wage across sectors.

[7]These solutions are standard in discrete choice models, see CDP for the full derivations.

lifetime utilities by $V^{n,j} \equiv E\left[\mathrm{v}_{t+1}^{n,j}\right]$, these are given by:

$$V^{n,j} = \ln C_t^{n,j} + \nu \ln \left[\sum_{h=0}^{J} \exp\left(\beta V_{t+1}^{n,h} - \zeta^{n,jh}\right)^{1/\nu} \right] \tag{2}$$

so the expected lifetime utilities depend on both the current utility derived from working in the current sector and the option value to move to any other sector. Finally, the share of workers in the studied country n that relocate from sector j to k in time t, can be written as:

$$\mu_t^{n,jk} = \frac{\exp\left(\beta V_{t+1}^{n,k} - \zeta^{n,jk}\right)^{1/\nu}}{\sum_{h=0}^{J} \exp\left(\beta V_{t+1}^{n,h} - \zeta^{n,jh}\right)^{1/\nu}} \tag{3}$$

Notice that in (2) and (3), $1/\nu$, the inverse of the standard deviation of the idiosyncratic shocks, plays the role of a inter-sectoral relocation elasticity. Further, equation (3) helps to characterize the evolution over time of sectoral employment in country n, since employment in sector j in time $t+1$ can be expressed simply as:

$$L_{t+1}^{n,j} = \sum_{k=0}^{J} \mu_t^{n,kj} L_t^{n,k}. \tag{4}$$

3.2 Firms

A continuum of firms of country n in each sector j produce varieties of intermediate goods. Firms use as inputs labour ($l_t^{n,j}$) and structures ($h_t^{n,j}$) as primary factors and a bundle of materials from all the sectors of the economy, $\prod_{k=1}^{J} (M_t^{n,jk})^{\gamma^{n,jk}}$, where $\gamma^{n,jk}$ is the share of materials from sector k in the production of sector j. Their total factor productivity depends on a common sectoral component ($A^{n,j}$) and a firm-specific component ($z^{n,j}$). As usual, I assume that the latter component is the realization of a Fréchet distribution with a shape parameter that varies by sector, θ^j.[8] Finally, firms' technology displays constant returns to scale, and takes the form:

$$q_t^{n,j} = z^{n,j} (A_t^{n,j} (h_t^{n,j})^{\xi^n} (l_t^{n,j})^{1-\xi^n})^{\gamma^{n,j}} \prod_{k=1}^{J} (M_t^{n,jk})^{\gamma^{n,jk}}$$

where $\gamma^{n,j} \geq 0$ is the share of value added in output,[9] ξ^n the share of structures in value added and $q_t^{n,j}$ the units of the variety produced. Cost minimization in perfect competition

[8] Here the location parameter is normalized to 1, but this parameter is isomorphic to the sectoral component of firm-productivity, $\left(A_t^{n,j}\right)^{\gamma^{n,j}}$.

[9] Constant returns to scale implies that $\gamma^{n,j} + \sum_{k=1}^{J} \gamma^{n,jk} = 1$

implies that firms price at their unit cost, $x_t^{n,j}/z^{n,j}(A_t^{n,j})^{\gamma^{n,j}}$, where $x_t^{n,j}$ is the standard Cobb-Douglass unit price of an input bundle, given by:

$$x_t^{n,j} = B^{n,j}((r_t^{n,j})^{\xi^n}(w_t^{n,j})^{1-\xi^n})^{\gamma^{n,j}} \prod_{k=1}^{J}(P_t^{n,k})^{\gamma^{n,jk}} \tag{5}$$

where $r_t^{n,j}$ is the rental price of structures in sector j of country n and $B^{n,j}$ is a constant. In this way, the price of any variety depends on the aggregate price of all intermediate goods, implying that a shock in any single sector (as a transportation cost shock) will affect all the sectors in the economy, via the cost of the bundle of materials.

In each sector there are producers of composite intermediate goods that are used either as materials for the production of intermediate varieties or for final consumption. They supply in total $Q_t^{n,j}$ units of the good by purchasing intermediate varieties from the lowest cost suppliers across countries.[10] Varieties purchased from other countries are subject to international trade costs $\kappa_t^{in,j}$. These costs are composed of transport costs and sector-specific ad-valorem tariffs $\zeta_t^{in,j}$. Transport costs are of the "iceberg" type, such that to obtain in country n an unit of the variety shipped from country i requires producing $\psi_t^{ni,j} \geq 1$ units in country i. I assume that observable container freight rates F_t^{ni} between the origin country i and the destination country n are informative about the evolution of $\psi_t^{ni,j}$. Particularly, $\psi_t^{ni,j}$ and F_t^{ni} are related through:

$$\psi_t^{ni,j} = \Upsilon^{ni,j} \left(F_t^{ni}\right)^{\rho_F^j} \varepsilon_t^{ni,j}$$

where $\Upsilon^{ni,j}$ represents any time-invariant determinant of transportation costs between n and i for sector j (e.g. transactions costs due to language, etc. or the distance effect that is not accounted by freight), that I call non-freight barriers; $\varepsilon_t^{ni,j}$ collapses other time-variant determinants of transportation costs apart from container freight and orthogonal to them, plus mean-zero measurement errors; and ρ_F^j is the key elasticity of transportation costs to observable freight rates. In this way, the wedge between the before-duty and transport-cost price at country i's border and the final price that is paid by producers of the composite good in country n is given by:

$$\kappa_t^{ni,j} = \left(1+\tau_t^{ni,j}\right)\psi_t^{ni,j} = \left(1+\tau_t^{ni,j}\right)\Upsilon^{ni,j}\left(F_t^{ni}\right)^{\rho_F}\varepsilon_t^{ni,j} \tag{6}$$

with $\psi_t^{ni,j} = \kappa_t^{ni,j} = \infty$ for non-tradable sectors j and $\kappa_t^{ni,j} = 1 \ \wedge \ \tau_t^{ni,j} = 0$ for $n = i$. Thus, the price paid by producers of the sectoral aggregate good for a particular variety is given by the minimum unit cost across all countries, taking into account trade costs:

$$p_t^{n,j} = \min_{\{i\}_{i=i}^N} \left\{ \frac{\kappa_t^{ni,j} x_t^{i,j}}{z^{i,j}(A_t^{i,j})^{\gamma^{i,j}}} \right\}$$

[10] In particular, $Q_t^{n,j}$ is a CES aggregator of the different quantities demanded of intermediate goods of a given variety.

with $\kappa_t^{ni,j}$ as in (6). By solving for $p_t^{n,j}$, standard properties of the Fréchet distribution over $z^{i,j}$ imply that the price of the sectoral aggregate good has a closed form solution, equal to:

$$P_t^{n,j} = \Gamma^{n,j} \left[\sum_{i=1}^{N} \left(x_t^{i,j} \kappa_t^{ni,j} \right)^{-\theta^j} \left(A_t^{i,j} \right)^{\theta^j \gamma^{i,j}} \right]^{-1/\theta^j} \tag{7}$$

and that the share of total expenditure in country n on goods j from market i is equal to:

$$\pi_t^{ni,j} = \frac{(x_t^{i,j} \kappa_t^{ni,j})^{-\theta^j} (A_t^{i,j})^{\theta^j \gamma^{i,j}}}{\sum_{m=1}^{N} (x_t^{m,j} \kappa_t^{nm,j})^{-\theta^j} (A_t^{m,j})^{\theta^j \gamma^{m,j}}} = \frac{(x_t^{i,j} \kappa_t^{ni,j})^{-\theta^j} (A_t^{i,j})^{\theta^j \gamma^{i,j}}}{\Psi_t^{n,j}} \tag{8}$$

with $\pi_t^{ni,j} \equiv \frac{X_t^{ni,j}}{X_t^{n,j}}$. Equation (8) is the gravity equation of the model, and it guides my estimation of ρ_F.

3.3 Markets clearing

The model is closed with standard goods and factors market-clearing conditions. By one side, goods market-clearing requires that the total expenditure on a good of a given sector in a country be equal to the value of the total demand for the good used as materials in all sectors in the economy, plus the value of its final demand. The final demand is a constant share ($\alpha^{n,j}$) of the total income of workers and rentiers of structures. To deal with trade imbalances, following CDP, it is assumed that rentiers of structures send all their local rents to a global portfolio, which in return receive a constant share ι^n from it (here ι^n is disciplined by observed trade imbalances in the initial period).[11] By the other side, the labour and structures market-clearing conditions requires that the total expenditure of both workers and rentiers of structures to be equal to their respective incomes. Since these conditions are essentially the same as in CDP, their equations (B.1-B.3) are relegated to Appendix B.1.

3.4 Equilibrium

The equilibrium of the model is a sequential competitive equilibrium that can be formulated as follows. Given an initial distribution of workers $\{L_0^{n,j}\}_{n=1,j=1}^{N,J}$, constant exogenous state variables $\left\{\zeta^{n,jk}, b^n, \Upsilon^{ni,j}, H^{n,j}\right\}_{n=1,i=1j=1,k=1}^{N,N,J,J}$, time-varying exogenous state variables $\{A_t^{n,j}, \tau_t^{ni,j}, \varepsilon_t^{ni,j}\}_{n=1,i=1,j=1,t=0}^{N,N,J,\infty}$, parameters $\left\{\gamma^{n,j}, \gamma^{n,jk}, \xi^n, \alpha^{n,j}, \iota^n\right\}_{n=1,j=1,k=1}^{N,J,J}$, elasticities $\left\{\theta^j\right\}_j^J$, ν and ρ_F and discount factor β; a sequential competitive equilibrium of the dynamic model under freight $\{F_t^{ni}\}_{n=1,i=1,t=0}^{N,N,\infty}$ is characterized by a sequence of labour prices $\{w_t^{n,j}\}_{n=1,j=1,t=0}^{N,J,\infty}$, sectoral reallocation shares $\{\mu_t^{n,jk}\}_{n=1,j=1,k=1,t=0}^{N,J,J,\infty}$, lifetime utilities $\{V_t^n\}_{n=1,t=0}^{N,\infty}$

[11] In the subsequent periods, the difference between the remittances and the income rentiers receive generates imbalances, and the the price of the infrastructures in each period match those imbalances to the trade deficits or superavits. In this way, trade imbalances become endogenous in the model.

and labour $\{L_t^n\}_{n=1,t=0}^{N,\infty}$, that satisfies equilibrium conditions (2), (3), (4), (5), (7), (8), (B.1), (B.2) and (B.3) for all countries i,n sectors j, k and time periods t.

3.5 Model solution

I use the dynamic version of "exact hat algebra" (developed in CDP, built on the static version of Dekle, Eaton and Kortum, 2008), to solve the model in relative time differences and to evaluate counterfactuals. The main advantage of the technique is that it does not require to have information about any of the exogenous state variables of the model (see the list of variables in the definition of equilibrium above). Further, the method allows the model to perfectly match the sector-level input-output and trade observable data, and reduces the computational burden considerably.

In summary, dynamic exact hat algebra first requires to express the system of equations that define the equilibrium of the model in relative time differences, which is done in Appendix B.3. Then, for each period t, the new system can be used to solve for the quantities of interest (factor prices, sectoral reallocation shares, lifetime utilities and labour) given the variables that are already known from the previous period $t-1$, and an assumption on the relative changes in the time-varying exogenous state variables, that I call hereafter fundamentals, and in freight. Thus, starting at $t = 1$, and by iterating, it is possible to solve for the full time paths of all variables of interest with observed information on a base year $t = 0$ and an anticipated convergent sequence of changes in fundamentals and freight. Thus, besides the set of parameters, elasticities and discount factor, the only pieces of information required for solving the model for a given sequence of changes in fundamentals and freight rates, are the allocation of labour in the base year $t = 0$, the transition matrix with the sectoral reallocation shares for the same year, and, in order to solve for factor prices in $t = 0$, the bilateral trade shares and sectoral output for the same year. Notice that the system at the base year is not necessarily in steady state, and hence even with constant fundamentals and freight, the economy can have transitional dynamics.

Once the paths of the endogenous state variables are found for a given sequence of changes in fundamentals and freight –call those paths as the "baseline economy"– it is possible to evaluate counterfactual scenarios. For this, the whole system in relative time differences representing the baseline economy can be re-expressed relative to a new system in relative time differences that represents the counterfactual one, which is done in Appendix B.4. With this new set of equations, it is possible to compute the impact of a given change in the initial sequence of relative changes in fundamentals and freight rates on the relative time differences of the real endogenous variables. The only additional piece of information needed is then the relative change in the sequences of fundamentals and freight rates between the baseline economy and the counterfactual one.

In order to isolate the impact derived from rises in transportation costs from other effects from the pandemic, in my empirical implementation I start by constructing a quarterly baseline economy that begins in a pre-pandemic year with available data (2018) and constant fundamentals and freight thereafter. Next, for the counterfactual economy, I change the paths of transportation costs according to the observable variation in freight rates during the pandemic, and keep constant the remaining set of fundamentals. Therefore, to evaluate the impact on the relative time differences of the endogenous variables the only extra information needed is the relative change in the sequences of transportation costs between the baseline economy and the counterfactual one, i.e.:

$$\frac{\left\{\frac{\kappa_t^{ni,j}}{\kappa_{t-1}^{ni,j}}\right\}_{t=1,counterfactual}^{\infty}}{\left\{\frac{\kappa_t^{ni,j}}{\kappa_{t-1}^{ni,j}}\right\}_{t=1,baseline}^{\infty}} = \left\{\frac{\kappa_t^{ni,j}}{\kappa_{t-1}^{ni,j}}\right\}_{t=1}^{\infty} = \left\{\frac{\left(F_t^{ni}\right)^{\rho_F^j}}{\left(F_{t-1}^{ni}\right)^{\rho_F^j}}\right\}_{t=1}^{\infty} \tag{9}$$

where the first equality follows from the fact that in the baseline economy fundamentals are constant, and the second one because the determinants of transportation costs other than freight rates do not change. The next section presents a procedure to compute (9), the main input for the counterfactual exercises, and Section 5 presents the results of the counterfactuals.

4 Identifying transportation costs shocks

In order to derive the paths of transportation costs shocks as a result of the Covid-19 pandemic, equation (9) requires estimates of ρ_F^j as well as values of F_t^{ni} for those country-pairs where freight rates are not available. Hence, in what follows I first present a model-consistent empirical strategy to estimate ρ_F^j and next a simple procedure to impute values of F_t^{ni} for those country-pairs with missing information on freight.

By taking logs of the gravity equation (8), the determinants of the bilateral sectoral flows can be rewritten in a linear form. The coefficients on the resulting linear equation can be estimated by the following regression of log-freight rates on log-bilateral flows, controlling for tariffs and the usual set of fixed effects:

$$\ln X_t^{ni,j} = \delta_t^{i,j} + \delta_t^{n,j} + \delta^{ni,j} + \beta_F \ln F_t^{ni} + \beta_\tau \ln\left(1 + \tau_t^{ni,j}\right) + \varepsilon_t^{ni,j} \tag{10}$$

In this equation, the exporter-industry-time fixed effect, $\delta_t^{i,j}$, absorbs $-\theta^j \ln x_t^{i,j} + \theta^j \gamma^{i,j} \ln A_t^{i,j}$, i.e. the sources of comparative advantage of the exporter; the importer-industry-time fixed effect, $\delta_t^{n,j}$, captures $\ln X_t^{n,j} - \ln \Psi_t^{n,j}$, i.e. importer's total demand and the resistance term for the importer; and the exporter-importer-industry fixed effect, $\delta^{ni,j}$, collapses $-\theta^j \ln \varUpsilon^{ni,j}$, i.e. time-invariant bilateral trade frictions (see Appendix B.2 for the proof). Further, the estimated coefficient $\hat{\beta}_\tau$ on tariffs identifies $\left(-\theta^j - 1\right)$, whereas the estimated coefficient $\hat{\beta}_F$ on freight rates identifies $-\theta^j \rho_F^j$. Thus, by estimating (10), it is possible to obtain values of

$-\theta^j$ and ρ_F^j that are both grounded in the theoretical model and appropriate for the selected set of countries and industries.

Regarding the estimation of (10), it has been established in the related literature (Martínez-Zarzoso and Suárez-Burguet, 2005; Jacks and Pendakur, 2010; Shapiro, 2016) that using OLS could deliver biased estimates, since container freight rates are arguably endogenous to bilateral flows. This is because container freight rates are nothing but the prices for shipping services, and as such, are a function of the supply of containers and the volume of trade demanded. This means that trade flows and container freight rates are simultaneously determined. Therefore, for dealing with this endogeneity, in what follows I estimate equation (10) using an IV strategy.

With the aim of taking advantage of the temporal variation of freight rates during the pandemic period, I use monthly sectoral trade data for the period 2017m1 to 2021m9, for the selection of 40 countries (see Table A.1 in Appendix A) and 15 tradable industries (Table A.2) that will be used in the model. Given that freight data is available only for the 18 regions displayed in Figure 1, I assign the 40 selected countries to the geographically closest available region as it shown in Table C.2.[12] Further, since monthly tariff data is not available I use instead annual data to control for tariffs, but, given their scarce temporal variation during the sample period, I prefer not using the estimates of $\hat{\beta}_\tau$ to derive structural parameters θ^j. Instead, as I comment below, I use recent estimates of θ^j from the literature available for the same 15 tradable industries, and focus the structural interpretation of my results only on the estimation of $\hat{\beta}_F$.

Regarding the instrument, it takes advantage of the heterogeneous timing of the lockdowns during the pandemic and of the pre-existent conditions in port infrastructure. Particularly, I construct a metric that interacts a combination of pre-pandemic measures of port infrastructure quality for both countries in each country-pair, with an indicator of whether both countries had lockdowns in a particular month. More specifically, the instrument Z_t^{ni} is given by:

$$Z_t^{ni} = PortQua_{2019}^n * PortQua_{2019}^i * \mathbb{D}_t^{ni},\ with\ \mathbb{D}_t^{ni} \begin{cases} 0 & n\ \wedge\ i\ are\ in\ lockdown\ in\ t \\ 1 & otherwise \end{cases}$$

where $PortQua_{2019}^n$ is the index of quality of port infrastructure in 2019 of country n, collected from the World Economic Forum (WEF),[13] see Figure D.1 in Appendix D for the

[12] Admitted not ideal, this imputation is necessary given the limitations of the data on freight rates. As a sensitivity test I present robustness checks when grouping bilateral trade data to 18 regions. It is worth to say that since for North America I have different freight rates for routes departing/arriving into each coast, I divide North American countries into west and east sub-countries according to the share that an aggregate of all western/eastern states or provinces has in the national annual trade flows. See Appendix A for more details about this procedure.

[13] The index is collected from the 2019 Global Competitiveness Report of the WEF, in which several metrics of countries' competitiveness are constructed based on the perceptions of a large number of business executives

variation of its values across the selected countries.[14] Formulated in this way, the routes in which the ports of the origin/destination of the ships' journey have a larger measured quality, a mutual lockdown in both trade partners have a larger decrease in the value of Z_t^{ni} due to the lockdowns. Further, in absence of lockdowns, the only variation in the value of Z_t^{ni} across country-pairs is the combined measure of the quality of the ports involved in the route.

Table 1 shows the baseline results using Z_t^{ni} as instrument under two different specifications for non-freight barriers $\Upsilon^{ni,j}$. In the first specification (columns 1-3) $\Upsilon^{ni,j}$ is included as a set of observable time-invariant geographical and cultural barriers, such as distance and indicators for having a common language, a common land border and a past colonial relationship. This is a common specification in the gravity literature, and the estimated elasticity is computed exploiting the variation in freight both over time and between country-pairs (conditional on observables). In the second specification (columns 4-6) $\Upsilon^{ni,j}$ is modeled as an exporter-importer-industry fixed effect, exactly as it is specified in the theoretical model. In this case, the estimated elasticity is computed exploiting the variation in freight rates only over time for each country-pair. All regressions control for average sectoral tariffs, for exporter-industry-time fixed effects (the exporter's time-varying comparative advantage) and importer-industry-time fixed effects (the importer's time-varying common demand). Moreover, the regressions exclude industries where tankers or bulk dry ships are the main transportation modes instead container ships (oil, chemicals, pharmaceutical and agriculture/food).

The results in Table 1 show that the estimated trade elasticities to container freight rates are significant, of the expected negative sign and economically meaningful. Both the F statistics and the estimated coefficients of the first stages suggest that the instrument is relevant in both specifications. I find a elasticity close to -5.5 when $\Upsilon^{ni,j}$ is modeled as a set of observables and close to -1 when it is included as an exporter-importer-industry fixed effect. Both elasticities lie inside the range found in the literature, that is between -0.42 in Fraser (2018) and -7.91 in Shapiro (2016) (see the literature review section for more details). The difference in their magnitudes would suggest that there are country-pair specific time-invariant omitted variables that are determinants of the trade flows and are correlated with freight, causing a bias in the estimation of the first specification. For this reason, and to keep the estimation the closest possible to the specification in the trade model, I consider as my baseline the estimated value of -1.03.

As a sensitivity analysis of the results, I explore the influence of zeros in the data and the robustness of standard errors. First, since zeros in bilateral flows are not likely to be random in the data, and the IV estimator simply drops those observations, they could introduce

(16936 in 2019) from 139 countries. The index range from 1 (port infrastructure considered extremely underdeveloped) to 7 (port infrastructure considered efficient by international standards); so $PortQua^n_{2019} * PortQua^i_{2019}$ ranges from 1 to 49. For landlocked countries the question changes to how accessible are port facilities. See Klaus (2019) for more details.

[14] Further, Figure D.2 in Appendix D shows the months in which each country had a lockdown.

Table 1 – IV Baseline results

	$\Upsilon^{ni,j}$ = observables			$\Upsilon^{ni,j}$ = Exp x Imp x Ind FE		
	(1)	(2)	(3)	(4)	(5)	(6)
	IV	First stage	Reduced form	IV	First stage	Reduced form
Dependent variable	ln(Trade)	ln(Freight)	ln(Trade)	ln(Trade)	ln(Freight)	ln(Trade)
ln(Freight)	-5.514***			-1.035**		
	(0.772)			(0.508)		
Instrument		-0.020***	0.109***		-0.014***	0.014**
		(0.002)	(0.011)		(0.001)	(0.007)
Importer x Industry x Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Exporter x Industry x Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes			
Exporter x Importer x Industry FE				Yes	Yes	Yes
Observations	80,787	80,787	80,787	80,787	80,787	80,787
F first stage (Kleibergen-Paap)		117.4			101.0	

*All regressions control for tariffs. Additional controls include distance and dummies for a common language, a common land border and a past colonial relationship. Industries where tankers or bulk dry ships are the main transportation modes are excluded (oil, chemicals, pharmaceutical and agriculture/food). Heteroskedasticity robust errors in parentheses.
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

sample-selection bias. The usual approach in the literature is to use the Poisson pseudo-maximum-likelihood (PPML) estimator proposed by Silva and Tenreyro (2006) that can be implemented in the balanced panel. However, in the presence of fixed effects, estimating a Poisson regression with an IV approach could suffer from the incidental parameters problem, so it does not guarantee consistent estimators. Instead, a feasible test to gauge the influence of zeros is to compare the results of the reduced-forms estimated by OLS (as in IV) and those estimated by PPML. This is done in Table C.3 in Appendix C, where it is shown that the estimated coefficient on the instrument is barely affected. An additional check consists in estimating the IV regression with a linear probability model (LPM) to assess the importance of the extensive margin in the results. This is, I replace $\ln X_t^{ni,j}$ by a dummy indicator that takes the value of 1 for positive values of $X_t^{ni,j}$ and 0 otherwise; and next I re-estimate equation (10) by IV. The results of the LPM are shown in Table C.4 in Appendix C, with the baseline IV results for comparison. The coefficient on freight rates estimated by the LPM is close to zero and not significant, meaning that the extensive margin does not play a role in the determination of the trade elasticities to container freight rates. A similar result is obtained for the reduced form estimated by the LPM.

Second, Table C.4 in Appendix C shows a re-computation of standard errors and first-stage F tests by clustering at different levels. First, I cluster standard errors at the importer-exporter-industry level, to allow for auto-correlations within trade-partners; and next at the exporter's region-importer's region-industry level, to allow for correlations within regions, besides auto-correlations. The baseline computed trade elasticity remain significant in both cases.

Now, in order to obtain ρ_F from the above results, I require a value for θ^j, since the estimated coefficient $\hat{\beta}_F$ on freight rates identifies $-\theta^j \rho_F$. As stated earlier, given the unavailability of monthly tariff data, I rely on values of θ^j derived from recent trade literature. Particularly, I use the trade elasticities obtained by Fontagné, Guimbard and Orefice (2022), who estimate θ^j based on product-level data by exploiting annual variation in bilateral tariffs for a large set of country-pairs (152 importing and 189 exporting countries) over the 2001-2016 period. More specifically, Fontagné, Guimbard and Orefice (2022) pool all HS6 products within each of my considered industries (we use the same OECD's Trade in Valued Added - TiVA aggregation) and obtain θ^j as the average tariff elasticity in sector j. Table C.6 in Appendix C shows the obtained elasticities. Using those elasticities, I finally make ρ_F sector-specific using $\rho_F^j = \hat{\beta}_F / \theta^j$.

Lastly, to construct the increases in transportation costs induced by the pandemic for each country-pair in my dataset, I need to deal with missing information on freight rates. For this, I fit a model of observable container freight rates on bilateral maritime distance D^{ni} (number of days to take a ship make a round trip between the primary port for each country, constructed by Feyrer, 2021) to fill missing information. Particularly, I fit the model:

$$F_t^{ni} = A_t^D \left(D^{ni}\right)^{\beta_{it}^D} \varepsilon_{ni,t}^D \; with \; \beta_{it}^D = \begin{cases} \beta_{E,t}^D & if \; i \in East \\ \beta_{W,t}^D & if \; i \in West \end{cases} \tag{11}$$

with A_t^D a common monthly shifter for all routes, that captures the overall monthly impact of the pandemic on the whole maritime transportation industry; β_{it}^D an elasticity of freight on distance, that, given the evidence commented in Section 2, I make time-variant and heterogeneous depending on the location of the exporter country (West/East); and $\varepsilon_{ni,t}^D$ a term that collapses other time-variant determinants of container freight apart from distance, and that I assume is, in logs, mean-zero and orthogonal to it. I estimate equation (11) in logs by OLS using time FE and the triple-difference $D^{ni} \times time \times \mathbb{I}_{i \in east}$. Figure D.3 in Appendix D shows the in-sample performance of the model, by comparing the model's predicted freight rates against their actual values, a plot that depicts a reasonable good fit. Some out-of-sample predictions are shown in Figure D.4 in Appendix D, where it can been seen that the model is able to replicate the heterogeneous behavior of freight rates depending on the region of departure, even for the same route.

Armed with F_t^{ni} for all country-pairs and the estimated values of ρ_F^j, it is possible to compute (9) to evaluate counterfactuals. The next section delivers the main results of these exercises.

5 Model results

In what follows I present the implementation of the dynamic trade model described in Section 3 and the main results from the counterfactual exercises. For this, I first comment on how the baseline economy with constant fundamentals is constructed, describing the data requirements and the assumptions on the labour markets' structure in the studied country (Colombia) and abroad. Next, I show the results of counterfactuals that involve: i) an increase in worldwide freight as observed in 2020 and 2021; ii) the same increase in freight but now only for routes involving Colombia as origin or destination; and iii) an increase in freight in all routes that do not involve Colombia. Finally, I present a sensitivity analysis of the results to changes in the calibrated parameters.

5.1 Baseline economy

As stated above, I set 2018 as my pre-pandemic base-year, and construct the baseline economy at a quarterly frequency with constant fundamentals from 2018 onwards. To do this, besides the set of constant parameters, I require data on the initial sectoral allocation of labour $L_{2018}^{n,j}$ and its associated transition matrix $\mu_{2017}^{n,jk}$, plus the initial bilateral trade shares $\pi_{2018}^{ni,j}$ and sectoral outputs $X_{2018}^{n,j}$. Following CDP, I assume that there is not labour migration across countries and that the only segmented labour market is that of the studied country, i.e. Colombia. This means that the labour transition matrix, the most challenging object among the data requirements, and the initial allocation of labour, are inputs that are only needed for Colombia.

Therefore, the collected dataset consists on: i) the matrices $\left\{\pi_{2018}^{ni,j}, X_{2018}^{n,j}\right\}$ for the same 40 countries and 15 tradable industries considered in the estimation of ρ_F^j, plus 17 non-tradable-sectors (see Tables A.1 and A.2 in Appendix A), that are obtained from the OECD's Inter-Country Input-Output (ICIO) tables and the TiVA database; ii) $L_{2018}^{Col,j}$, that is derived from the GEIH (Colombia's household survey), limiting the computations only for individuals between 25 and 65 years of age (around 23.8 millions of persons); and iii) $\mu_{2017}^{Col,jk}$ the matrix of transition probabilities across sectors between 2017 and 2018, that is estimated from PILA, the Colombian social security administrative data, that has full coverage of formal workers.[15] For more details on the construction of the dataset, see Appendix A.

The set of constant parameters is obtained as follows. Technological parameters are the I-O coefficients ($\gamma^{n,jk}$) and the value added shares ($\gamma^{n,j}$), that are collected from OECD's ICIO tables and the TiVA dataset for 2018 –so they match exactly the trade and output data above–; plus the shares of structures in value added (ξ^n), collected from the Penn World

[15]Here an implicit assumption is that the transition probabilities across sectors behave similar between the formal and informal segments of the labour market. Admitted not ideal, this assumption is necessary given the lack of the data on transitions among informal workers.

Tables (PWT) for 2018. Trade elasticities θ^j and transportation costs elasticities ρ_F^j are the same as in Section 4. Finally the only calibrated parameters are the quarterly discount factor $\beta = 0.99$ and the (inverse of) sectoral reallocation elasticity $\nu = 5.34$; both values come from CDP. In Section 5.3 I present robustness checks to variations in these calibrated parameters.

Once all data requirements are gathered, I construct the baseline economy following the procedure described in Section 3.5. It is worth to emphasize that the fact that I use constant fundamentals does not imply that there is not transitional dynamics in the baseline economy. Since the economy in 2018 is not in its steady state, the baseline economy delivers both reallocation of workers across sectors and adjustments in relative prices over time until it reaches its steady state. For example, Figure D.5 in Appendix D show the dynamics of labour reallocation in Colombia in the baseline economy for an aggregation of the main five sectors in the economy plus non-employment. Compared to its steady state, the fraction of the Colombian workforce in 2018 in services and non-employment is larger, generating thus a decreasing path in the labour share of those two segments over time; as opposed to what happens in agriculture.

5.2 Economies with transportation cost shocks

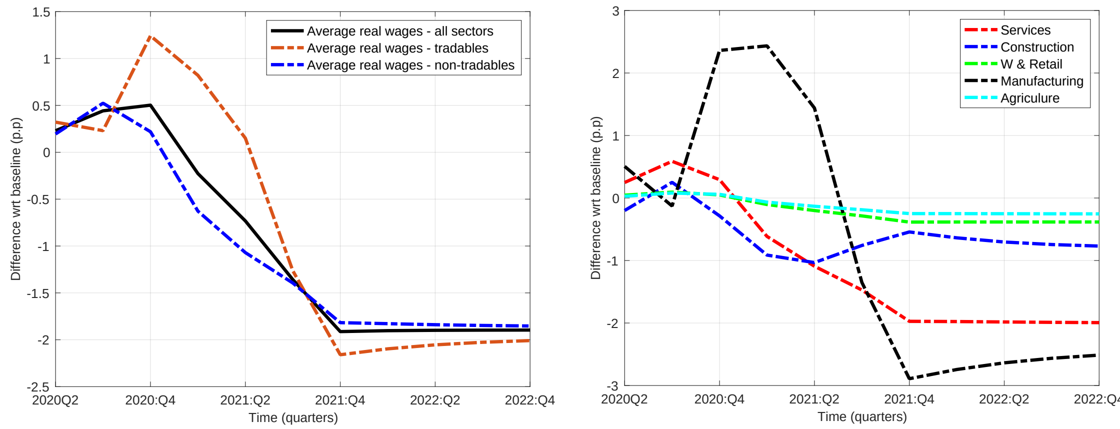
I start by solving for the dynamic impact on the variables of interest of a counterfactual in which container freight increases for all routes in the world as observed between 2019Q1 and 2021Q3, and are constant afterwards. That is, denoting by $\hat{y}_t \equiv \left(\frac{\dot{y}_t'}{\dot{y}_t}\right)$ the change in the relative time difference of a variable y_t between the counterfactual and the baseline (where y_t' corresponds to the value of the variable y_t in the counterfactual), I solve for equations (B.14)-(B.21) in Appendix B.4 using:

$$\hat{\kappa}_t = \left\{ \frac{\left(F_t^{ni}\right)^{\rho_F^j}}{\left(F_{t-1}^{ni}\right)^{\rho_F^j}} \right\}_{t=2019Q1}^{2021Q3}$$

and $\hat{\kappa}_t = 1$ for t after 2021Q3.

The series of transportation cost shocks generates effects on both relative prices and labour allocations. Concerning the former, real wages decline across all sectors of the economy. Figure 4 shows the differences in real wages between the economy with transportation cost shocks and the baseline economy, both for the division between tradable and non-tradable sectors (Panel A) and for the aggregation of the five main sectors (Panel B). Tradable sectors, particularly manufacturing, experience the most substantial real wage losses. It is important to note that since all real wages are deflated using the aggregate price index, variations in the paths of real wages across sectors are solely attributed to adjustments in relative wages. As I will explain below, these adjustments in relative wages depend on the extent to which the shocks shift the country towards a more open or closed economy in relation to the rest of the world.

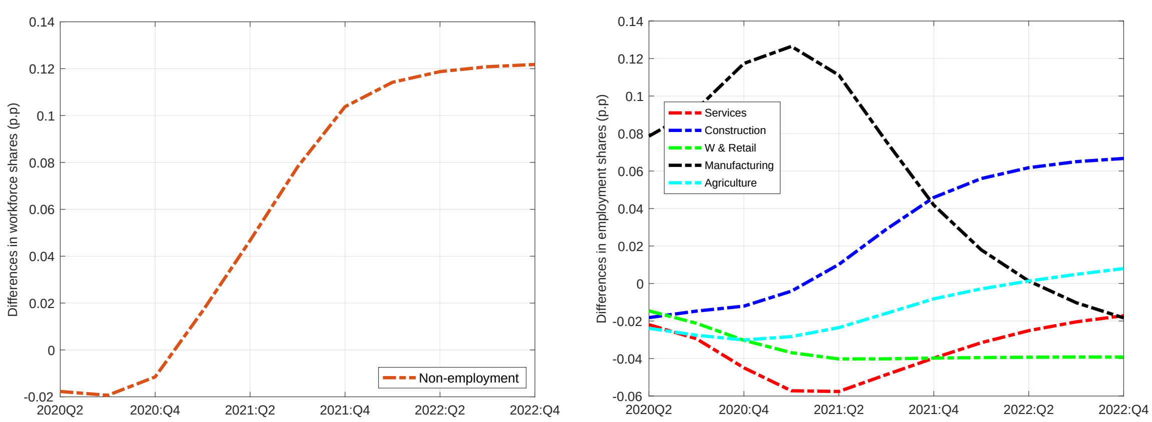
Figure 4 – Effects on the Levels of Real Wages



(a) Tradable and Non-tradable Sectors **(b)** Five Main Sectors

Regarding the employment effects, Figure 5 displays the absolute differences in the sectoral shares of Colombian workers between the counterfactual and baseline economies, illustrating how the reallocation of workers is affected by the transportation cost shocks. First, the global increase in container freight rates results in 0.12% of individuals (28.6K) transitioning into non-employment. When compared to the declining trend observed in the share of non-employees in the workforce in the baseline economy (Figure D.5) this impact is somewhat moderate. This effect stems from the overall decline in real wages, which in turn increases the relative value of home production. Furthermore, within employment, there is also reallocation of workers from tradable sectors towards non-tradable sectors, particularly to construction, where at the end of the horizon there is an increase of 0.07% in their employment share relative to the baseline economy, approximately 13.4K workers, a moderate impact.

Figure 5 – Impacts of Increases in Worldwide Freight on the Reallocation of Workers



(a) Towards Non-Employment **(b)** Within Employment

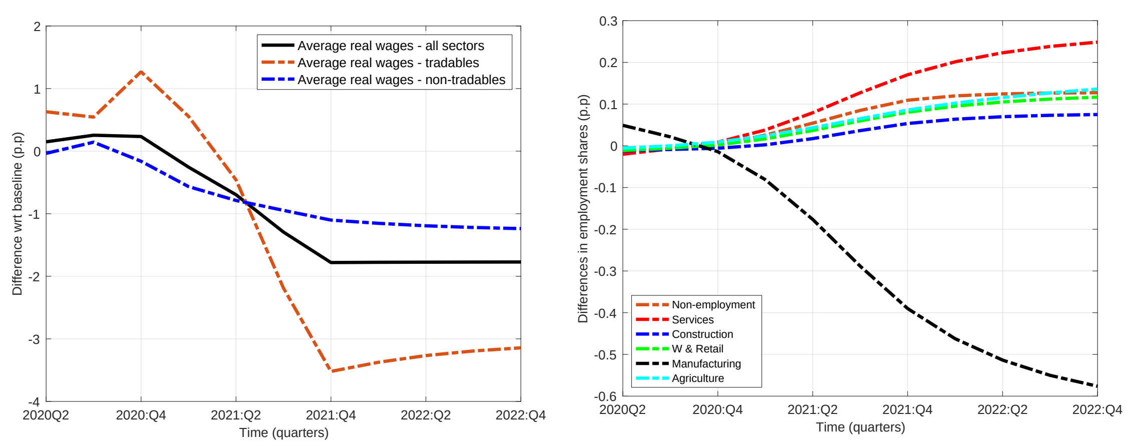
To quantify the impact on welfare, CDP show that in this type of dynamic trade models a measure of the change in welfare from a change in fundamentals that is model-consistent is the present discounted value of the expected change in real consumption relative to the change in the workers' option value, $\hat{\mu}^{n,jj}$, that is:

$$W e l \hat{f} a r e^{Col,j} = \sum_{t=1}^{\infty} \beta^t \ln \left(\frac{\hat{C}_t^{Col,j}}{(\hat{\mu}^{Col,jj})^{\nu}} \right) \tag{12}$$

Evaluating equation (12) by aggregating welfare by the initial share of workers in each sector j, the decrease in welfare as result of the increases in container freight rates all around the world is 1.35%, consistent with the obtained fall in real wages on average.

To understand better the latter results I divide the full set of shocks in worldwide container freight rates into a subset that includes shocks in freight only in routes that involve Colombia directly, and a subset with the shocks in all remaining routes. Figure 6 shows the effects on real wages (Panel A) and the allocation of labour (Panel B) of increases in freight rates only for routes that involve Colombia either as destination or as origin. The reallocation of workers is much stronger towards non-tradable sectors, with an important contraction of the employment in manufacturing (0.6% of total employment, 115K workers). This is because in this case the Colombian economy becomes more closed relative to the rest of the world, so the usual general equilibrium effects of moving towards autarky (an increase in relative wages of non-tradable sectors that leads to a contraction of the tradable sectors) operate in this case. However, average real wages move very similar to the counterfactual with full set of shocks, leading to a job loss that is similar (0.13%) and to welfare implications that are in the same order of magnitude: a welfare loss of 1,31%.

Figure 6 – Impacts of Increases in Freight Only for Routes that Involve Colombia*

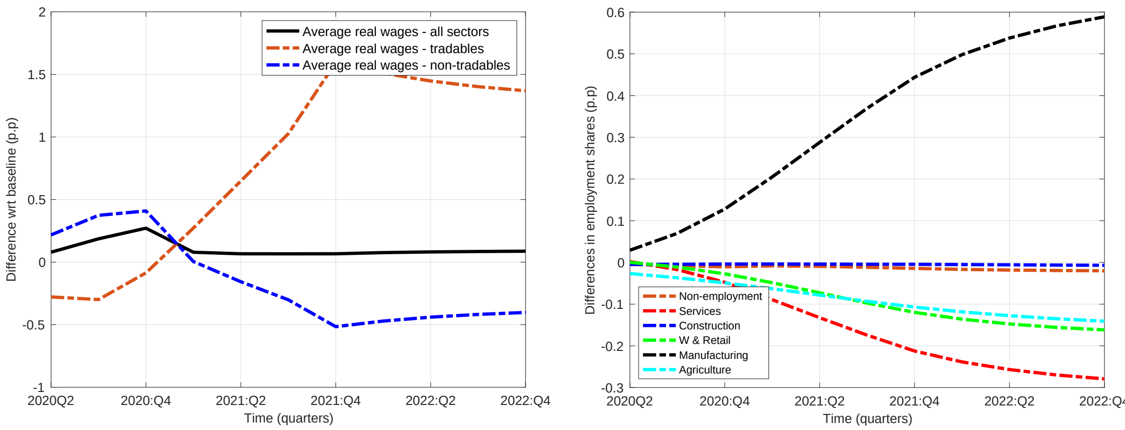


(a) Real Wages **(b)** Labour

*Note: In this case, the set of shocks is restricted only for $F_t^{ni,j}$ $for\ n \vee i = Col$.

Figure 7 replicates the latter impacts assuming instead that freight rates increase world-

Figure 7 – Impacts of Increases in Freight for Routes that do not Involve Colombia*



(a) Real Wages **(b)** Labour

*Note: In his case, the set of shocks is restricted only for $F_t^{ni,j}\, for\ n \wedge i \neq Col$.

wide, except for routes involving Colombia. In this counterfactual scenario, Colombia becomes relatively more open compared to the rest of the world, so the adjustment of relative wages takes an opposite direction to the previous case, and even the levels of real wages in the tradable sector rise. Consequently, manufacturing experiences significant expansion (similar in magnitude to the contraction observed in the previous case). This implies that the moderate effects on employment reallocation obtained in the counterfactual with the full set of shocks are the result of opposing forces on labour reallocation that partially offset each other. Furthermore, the increase in real wages in the tradable sector offsets the decline in real wages in the non-tradable sector. As a result, the average real wage undergoes a minimal adjustment, leading to almost no reallocation of workers from non-employment and even a slight increase in welfare, approximately 0.15%.

5.3 Robustness checks

I turn to explore the robustness of the counterfactual results to alternate values of the calibrated parameters of the model, particularly the (inverse of) sectoral reallocation elasticity ν. Columns (2) and (3) of Table 2 show the results for the main dimensions of interest of the counterfactual exercises when I consider $\nu = 4.0$ and $\nu = 7.0$ respectively, instead of the baseline value of 5.34. In the first case, a smaller value of ν means more reallocation of workers when relative wages changes. Thus, it is expected to obtain larger job losses for the same increase in freight. Column (2) of Table 2 shows that the new reallocation of labour points in that direction. Job losses increase from 0.12% in the original counterfactual to 0.16% in the counterfactual with a lower value of ν. However, the implications for the welfare impact of the shocks remain almost unchanged, implying that ν does not affect the transmission of freight to average real wages. And in the opposite direction, Column (3) shows that a larger value of ν causes the opposite effect: a smaller job loss but with almost null effects on the welfare implications derived from the set of full shocks in freight under the baseline parameterization.

Table 2 – Counterfactual Results for Alternative Parameterizations

	(1) Baseline	(2) Low ν	(3) High ν
Calibrated parameters			
ν	5.34	4.00	7.00
β	0.99	0.99	0.99
Results of counterfactual exercises			
Job losses	0.12%	0.16%	0.09%
Welfare impact	-1.35%	-1.33%	-1.38%

6 Conclusions

By using a state-of-the-art quantitative model of international trade, that incorporates a rich set of realistic features such as input-output linkages, out-of-the-steady-state transitional dynamics or barriers to sectoral mobility in the labour markets, the dynamic general equilibrium effects of the increases in container freight rates as result of the Covid-19 pandemic on a particular country of interest can be evaluated in a comprehensive way. Particularly, with the discipline of the dynamic model, and the technique used here to solve for the equilibrium of the model and evaluate counterfactuals (CDP's dynamic hat algebra), such evaluation can be performed not only in a systematic and integrated way, but also with a relatively few data requirements and a low computational burden.

The results of the conducted evaluation indicate that the worldwide increase in container freight rates resulted in a welfare loss of 1.4% for the Colombian economy, accompanied by moderate effects on labour reallocations. While these quantifications alone hold significant importance, an additional value provided by the model is its ability to shed light on the heterogeneous effects of the transportation cost shocks on the variables of interest given its globalised nature. For instance, it highlights that the impacts on employment reallocations depend on the magnitude of the freight rates increases in routes involving the analyzed country in comparison to those in other routes. In other words, these effects are contingent upon whether the shocks render the country more open or closed relative to the rest of the world.

Along the quantification exercise, one of the key inputs derived from the implementation of the model was the estimation of an elasticity of the unobservable trade costs to freight rates. In the process of deriving such elasticity, I obtain a trade elasticity to freight that is significant, of the expected negative sign and that lies inside the range found in the related literature. To obtain this elasticity, the empirical strategy took advantage of the heterogeneous timing of the mutual lockdowns across country-pairs. With the aim to alleviate concerns about the validity of the exclusion restriction in this strategy, the current agenda of this work is exploring other type of instruments that also exploit the restrictions derived from the sanitary measures, but that are constrained in scope to procedures related to the operations and logistics of ports.

Besides the latter point, other aspects worth of exploration are related to the assessment of the possible reversing effects from paths of normalization in freight rates; plus the evaluation of the robustness of the estimated trade elasticity by using customs data instead of the more direct, but at the same time incomplete, information on freight rates used here. Anyways, in spite of these considerations, it is evident that the quantitative exercises performed here already deliver relevant messages for policy analysis. Specially, in situations in which policy-makers seek to quantify how much of the welfare losses are derived from domestic or external factors.

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Appendix

A Data: Sources and selection of countries and sectors

A set of countries and sectors is selected to ensure both availability of the required variables of the model and relevance according to the routes where freight rates are available. Since value-added shares, input-output coefficients and gross output measures are required, the selection is based on the available countries and sectors in the OECD's Inter-Country Input-Output (ICIO) and Trade in Value Added (TiVA) databases (2021's release). Regarding countries, from the 65 available regions in ICIO-TiVA (64 countries plus an aggregate for the rest of the world), the 15 countries with the lowest participation in 2019-2021 Colombian trade flows were dropped. Further, since for the estimation of the trade elasticity to container freight (ρ_F) a dataset of monthly bilateral trade flows is required, an additional set of 10 countries was dropped for which monthly data was not available, or it was incomplete or with a significant publication lag. As a result, a set of 39 countries plus an aggregate for the rest of the world is selected, that is displayed with their corresponding ISO codes in Table A.1.

Table A.1 – List of Countries and ISO3 Codes

Europe		**Asia**		**Americas**	
BEL	Belgium	CHN	China	ARG	Argentina
DNK	Denmark	IND	India	BRA	Brazil
FRA	France	HKG	Hong Kong	CAN1,2	Canada
DEU	Germany	ISR	Israel	CHL	Chile
HUN	Hungary	JPN	Japan	COL	Colombia
ITA	Italy	KOR	Rep. of Korea	PER	Peru
ROU	Romania	MYS	Malaysia	MEX1,2	Mexico
NLD	Netherlands	PHL	Philippines	USA1,2	United States
POL	Poland	SGP	Singapore		
PRT	Portugal	THA	Thailand	**Africa / Oceania**	
RUS	Russian Federation	TUR	Turkey	AUS	Australia
SVK	Slovak Republic	VNM	Vietnam	MAR	Morocco
ESP	Spain			ZAF	South Africa
SWE	Sweden				
CHE	Switzerland			**Other**	
GBR	United Kingdom			ROW	Rest of the World

Regarding the set of sectors, it remains similar to the one used in ICIO-TiVA database, with a few aggregations. From the original 45 sectors involving the whole economy, five sectors are dropped that involve mining and activities of households as employers plus undifferentiated goods. From the remaining 40 sectors, 11 of them are aggregated into four categories according to the availability of monthly trade data and to ensure representativeness. Therefore, I use a total of 32 2-digit ISIC-rev. 4 sectors, that covers both tradable (15) and non-tradable industries. See Table A.2 for a description of the selected sectors.

Table A.2 – List of Sectors and ISIC codes

No.	2-dig ISIC*	Sector
		Tradable sectors
1	01 to 03	Agriculture, hunting, forestry, fishing and aquaculture
2	10 to 12	Food products, beverages and tobacco
3	13 to 15	Textiles, textile products, leather and footwear
4	16 to 18	Wood, products of wood and cork, paper products and printing
5	19	Coke and refined petroleum products
6	20	Chemical and chemical products
7	21	Pharmaceuticals, medicinal and chemical and botanical prod.
8	22 to 23	Rubber, plastics prod. and other non-methalic mineral prod.
9	24	Basic metals
10	25	Fabricated metal products
11	26	Computer, electronic and optical equipment
12	27	Electric equipment
13	28	Machiney and equipment, nec
14	29 to 30	Motor vehicles, trailers, and other transport equipment
15	31 to 33	Manufacturing nec; repair and installation of machinery equip.
		Non-Tradable sectors
16	35 to 39	Public serv. supply; sewerage, waste management
17	41 to 43	Construction
18	45 to 47	Wholesale and retail trade; repair of motor vehicles
19	49 to 53	Transport, warehousing, and postal/courier activities
20	55 to 56	Accommodation and food service activities
21	58 to 60	Publishing, audiovisual and broadcasting activities
22	61	Telecomunications
23	62 to 63	IT and other information services
24	64 to 66	Financial and insurance activities
25	68	Real estate activities
26	69 to 75	Professional, scientific and technical activities
27	77 to 82	Administrative and support services
28	84	Public administration and defense; compulsory s.s.
29	85	Education
30	86 to 88	Human health and social work activities
31	90 to 93	Arts, entertaiment and recreation
32	94 to 96	Other service activities

*Revision 4 of ISIC

Once the set of countries and sectors is defined, two datasets are required: i) a panel of monthly bilateral trade flows for tradable sectors in order to estimate the trade elasticity to freight and hence to obtain ρ_F; and ii) a dataset with technology coefficients and the observable allocations of trade and labour in the initial period to perform the counterfactual exercise with the quantitative model. The first dataset is constructed for the period 2017m1 to 2021m9 with information from the UN-Comtrade and the ITC. As it is explained in the text, since for North America I have different freight rates for routes departing/arriving into each coast, I divide North American countries (particularly US and Canada) into west and east sub-countries according to the share that an aggregate of all western/eastern states or provinces has in the national annual trade flows. For the US, the western states are HI, AK, WA, OR, CA, NV, ID, MT, WY, UT, CO, AZ and NM; and for Canada the western provinces are BC, AB, SK, MB, YT, NT and NU. Mexico is not disaggregated given the absence of regional trade data to make the division; so it is excluded from the regression.[16]

The second dataset is constructed using the sources mentioned in the text: the OECD's Inter-Country Input-Output (ICIO) tables and the TiVA database to construct matrices $\left\{\pi_{2018}^{ni,j}, X_{2018}^{n,j}\right\}$ and to compute the I-O coefficients ($\gamma^{n,jk}$) and the value added shares ($\gamma^{n,j}$); the Penn World Tables (PWT) for 2018 to obtain the shares of structures in value added (ξ^n); the Colombian Wide-scale Integrated Household Survey (GEIH by its acronym in Spanish) to derive the initial sectoral allocation of labour $L_{2018}^{Col,j}$;[17] and PILA, the Colombian social security administrative data, to estimate the workers' probabilities of transition across sectors between 2017 and 2018 $\mu_{2017}^{Col,jk}$.[18]

B Derivations and Additional Procedures

B.1 Goods and Factors Market-Clearing Conditions

The goods market-clearing condition is:

$$X_t^{n,j} = \sum_{k=1}^{J} \gamma^{n,kj} \sum_{i=1}^{N} \pi_t^{in,k} X_t^{ik} + \alpha^j \left(\sum_{k=1}^{J} w_t^{nk} L_t^{nk} + \iota^n \sum_{i=1}^{N} \sum_{k=1}^{J} r_t^{i,k} H^{i,k} \right) \tag{B.1}$$

with ι^n the constant share that structure renters of country n obtain from a global portfolio where all the structure owners invest their local rents. The labour market-clearing condition is:

$$w_t^{n,j} L_t^{n,j} = \gamma^{n,j} (1 - \xi^n) \sum_{i=1}^{N} \pi_t^{in,j} X_t^{i,j} \tag{B.2}$$

and the infrastructure market-clearing condition is:

$$r_t^{n,j} H^{n,j} = \gamma^{n,j} \xi^n \sum_{i=1}^{N} \pi_t^{in,j} X_t^{i,j} \tag{B.3}$$

B.2 Determinants of gravity equation (10)

First, notice that inserting (6) in (8) we obtain:

$$\frac{X_t^{ni,j}}{X_t^{n,j}} = \frac{p_t^{ni,j} q_t^{ni,j}}{X_t^{n,j}} = \frac{\left(x_t^{i,j} \left(1 + \tau_t^{ni,j}\right) \Upsilon^{ni,j} \left(F_t^{ni}\right)^{\rho_F} \varepsilon_t^{ni,j}\right)^{-\theta^j} (A_t^{i,j})^{\theta^j \gamma^{i,j}}}{\Psi_t^{n,j}} \tag{B.4}$$

[16] I also exclude Russia given the geographical difficulty to assign the country in one of the regions with available freight rates.

[17] The survey is produced by the National Administrative Department of Statistics (DANE by its acronym in Spanish), the official statistics bureau in Colombia. It is the largest monthly statistical operation in the country, with around 21 thousand face-to-face surveys per month in the 23 main metropolitan areas and a rural aggregate.

[18] These probabilities are estimated from the observable sectoral reallocations in job-to-job transitions and the allocations of new entries in the dataset, such that those reallocations satisfy the equations of the flows of workers between states (employment and non-employment).

Further, from equation (1) we have:

$$\frac{X_t^{ni,j}}{X_t^{n,j}} = \frac{p_t^{ni,j} q_t^{ni,j}}{X_t^{n,j}} = \frac{\left(1+\tau_t^{ni,j}\right)\psi_t^{ni,j} p_t^{i,j} q_t^{ni,j}}{X_t^{n,j}} \tag{B.5}$$

Now, notice that the estimation of equation (10) is performed using as bilateral trade flows the reported values of imports from each reporter country, which is a more reliable measure of the actual trade flows. According with UN-Comtrade, 92% of the countries in Comtrade report CIF values for imports. So, priced at CIF values (the CIF price is $\psi^{ni,j} p_t^{i,j}$), by combining (B.4) and (B.5), we obtain for the bilateral flows:

$$\frac{\psi_t^{ni,j} p_t^{i,j} q_t^{ni,j}}{X_t^{n,j}} = \frac{\left(x_t^{i,j}\left(1+\tau_t^{ni,j}\right)\Upsilon^{ni,j}\left(F_t^{ni}\right)^{\rho_F}\varepsilon_t^{ni,j}\right)^{-\theta^j}\left(A_t^{i,j}\right)^{\theta^j\gamma^{i,j}}\left(1+\tau_t^{ni,j}\right)^{-1}}{\Psi_t^{n,j}}$$

$$\left(X_t^{ni,j}\right)^{CIF} = \left(x_t^{i,j}\Upsilon^{ni,j}\varepsilon_t^{ni,j}\right)^{-\theta^j}\left(1+\tau_t^{ni,j}\right)^{-\theta^j-1}\left(F_t^{ni}\right)^{-\rho_F\theta^j}\left(A_t^{i,j}\right)^{\theta^j\gamma^{i,j}}\left(\frac{X_t^{n,j}}{\Psi_t^{n,j}}\right) \tag{B.6}$$

By taking logs in (B.6) we derive the determinants of the fixed effects and the estimated coefficients mentioned in the text.

B.3 System in relative time differences

Denote $\dot{y}_{t+1} \equiv \left(\frac{y_{t+1}}{y_t}\right)$ the proportional change in a variable y_t. Let $u_t^{n,j} \equiv \exp\left(V_t^{n,j}\right)$ and the real wages $\omega_{t+1}^{n,j} = \frac{w_{t+1}^{n,j}}{P_{t+1}^n}$. The system of equations (2), (3), (5), (7), (8), (B.1), (B.2) can be written in relative time differences as:

$$\mu_{t+1}^{n,jk} = \frac{\mu_t^{n,jk}(\dot{u}_{t+2}^{n,k})^{\beta/\nu}}{\sum_{h=0}^{J}\mu_t^{n,jh}(\dot{u}_{t+2}^{n,h})^{\beta/\nu}} \tag{B.7}$$

$$\dot{u}_{t+1}^{n,j} = \dot{\omega}_{t+1}^{n,j}\left(\sum_{k=0}^{J}\mu_t^{n,jk}(\dot{u}_{t+2}^{n,k})^{\beta/\nu}\right)^{\nu} \tag{B.8}$$

$$\dot{x}_{t+1}^{n,j} = (\dot{L}_{t+1}^{n,j})^{\gamma^{n,j}\xi^n}(\dot{w}_{t+1}^{n,j})^{\gamma^{n,j}}\prod_{k=1}^{J}(\dot{P}_{t+1}^{n,k})^{\gamma^{n,jk}} \tag{B.9}$$

$$\dot{P}_{t+1}^{n,j} = \left(\sum_{i=1}^{N}\pi_t^{ni,j}(\dot{x}_{t+1}^{i,j}\dot{\kappa}_{t+1}^{ni,j})^{-\theta^j}(\dot{A}_{t+1}^{i,j})^{\theta^j\gamma^{i,j}}\right)^{-1/\theta^j} \tag{B.10}$$

$$\pi_{t+1}^{ni,j} = \pi_t^{ni,j}\left(\frac{\dot{x}_{t+1}^{i,j}\dot{\kappa}_{t+1}^{ni,j}}{\dot{P}_{t+1}^{n,j}}\right)^{-\theta^j}(\dot{A}_{t+1}^{i,j})^{\theta^j\gamma^{i,j}} \tag{B.11}$$

$$\dot{w}_{t+1}^{n,j}\dot{L}_{t+1}^{n,j}w_t^{n,j}L_t^{n,j} = \gamma^{n,j}(1-\xi^n)\sum_{i=1}^{N}\pi_{t+1}^{in,j}X_{t+1}^{i,j} \tag{B.12}$$

$$X_{t+1}^{nj}=\sum_{k=1}^{J}\gamma^{n,kj}\sum_{i=1}^{N}\pi_{t+1}^{in,k}X_{t+1}^{i,k}+\alpha^{j}\left(\sum_{k=1}^{J}\dot{w}_{t+1}^{n,k}\dot{L}_{t+1}^{n,k}w_{t}^{n,k}L_{t}^{n,k}+\iota^{n}\sum_{i=1}^{N}\sum_{k=1}^{J}\frac{\xi^{i}}{1-\xi^{i}}\dot{w}_{t+1}^{i,k}\dot{L}_{t+1}^{i,k}w_{t}^{i,k}L_{t}^{i,k}\right) \tag{B.13}$$

Adding equation (4), and noticing that equation is satisfied by Walras's law (B.3), equations (B.7)-(B.13) form a non-linear system that can be used to solved for the paths of labour prices $\{w_t^{n,j}\}_{n=1,j=1,t=0}^{N,J,\infty}$, sectoral reallocation shares $\{\mu_t^{n,jk}\}_{n=1,j=1,k=1,t=0}^{N,J,J,\infty}$, lifetime utilities $\{u_t^{n}\}_{n=1,t=0}^{N,\infty}$ and labour $\{L_t^{n}\}_{n=1,t=0}^{N,\infty}$. The system is solved using the numerical algorithm proposed by CDP.

B.4 System to solve for counterfactuals

Denote a variable y_t that belongs to the counterfactual solution as y'_t, and $\hat{y}_t \equiv \left(\frac{\dot{y}'_t}{\dot{y}_t}\right)$ the proportional change in y_t in the counterfactual economy relative to the proportional change in the same variable in the baseline economy. As before, let $u_t^{n,j} \equiv \exp\left(V_t^{n,j}\right)$ and the real wages $\omega_{t+1}^{n,j} = \frac{w_{t+1}^{n,j}}{P_{t+1}^{n}}$. The system of equations that solves for the impacts in the endogenous state variables of moving from the baseline economy to the counterfactual one is:

$$\mu_t^{\prime n,jk}=\frac{\mu_{t-1}^{\prime n,jk}\dot{\mu}_t^{n,jk}\left(\hat{u}_{t+1}^{n,k}\right)^{\beta/\nu}}{\sum_{h=0}^{J}\mu_{t-1}^{\prime n,jh}\dot{\mu}_t^{n,jh}\left(\hat{u}_{t+1}^{n,h}\right)^{\beta/\nu}} \tag{B.14}$$

$$\hat{u}_t^{nj}=\hat{\omega}_t{}^{nj}\left(\sum_{i=1}^{N}\sum_{k=0}^{J}\mu_{t-1}^{\prime nj,ik}\dot{\mu}_t^{nj,ik}\left(\hat{u}_{t+1}^{ik}\right)^{\beta/\nu}\right)^{\nu} \tag{B.15}$$

$$L_{t+1}^{\prime nj}=\sum_{i=1}^{N}\sum_{k=0}^{J}\mu_t^{\prime ik,nj}L_t^{\prime ik} \tag{B.16}$$

$$\hat{x}_{t+1}^{n,j}=(\hat{L}_{t+1}^{n,j})^{\gamma^{n,j}\xi^{n}}(\hat{w}_{t+1}^{n,j})^{\gamma^{n,j}}\prod_{k=1}^{J}(\hat{P}_{t+1}^{n,k})^{\gamma^{n,jk}} \tag{B.17}$$

$$\hat{P}_{t+1}^{n,j}=\left(\sum_{i=1}^{N}\pi_t^{\prime ni,j}\dot{\pi}_{t+1}^{ni,j}(\hat{x}_{t+1}^{i,j}\hat{\kappa}_{t+1}^{ni,j})^{-\theta^j}(\hat{A}_{t+1}^{i,j})^{\theta^j\gamma^{i,j}}\right)^{-1/\theta^j} \tag{B.18}$$

$$\pi_{t+1}^{\prime n,ij}=\pi_t^{\prime ni,j}\dot{\pi}_{t+1}^{ni,j}\left(\frac{\hat{x}_{t+1}^{i,j}\hat{\kappa}_{t+1}^{ni,j}}{\hat{P}_{t+1}^{n,j}}\right)^{-\theta^j}(\hat{A}_{t+1}^{i,j})^{\theta^j\gamma^{i,j}} \tag{B.19}$$

$$\hat{w}_{t+1}^{n,k}\hat{L}_{t+1}^{n,k}=\frac{\gamma^{n,j}(1-\xi^{n})}{w_t^{\prime n,k}L_t^{\prime n,k}\dot{w}_{t+1}^{n,k}\dot{L}_{t+1}^{n,k}}\sum_{i=1}^{N}\pi_{t+1}^{\prime in,j}X_{t+1}^{\prime i,j} \tag{B.20}$$

$$X_{t+1}^{\prime n,j}=\sum_{k=1}^{J}\gamma^{n,kj}\sum_{i=1}^{N}\pi_{t+1}^{\prime in,k}X_{t+1}^{\prime i,k}+\alpha^{j}\left(\sum_{k=1}^{J}\hat{w}_{t+1}^{n,k}\hat{L}_{t+1}^{n,k}w_t^{\prime n,k}L_t^{\prime n,k}\dot{w}_{t+1}^{n,k}\dot{L}_{t+1}^{n,k}+\iota^{n}\sum_{i=1}^{N}\sum_{k=1}^{J}\frac{\xi^{i}}{1-\xi^{i}}\hat{w}_{t+1}^{i,k}\hat{L}_{t+1}^{i,k}w_t^{\prime i,k}L_t^{\prime i,k}\dot{w}_{t+1}^{i,k}\dot{L}_{t+1}^{i,k}\right) \tag{B.21}$$

Equations (B.14)-(B.21) form a non-linear system that can be used to solved for the impacts on the paths labour prices $\{\hat{w}_t^{n,j}\}_{n=1,j=1,t=0}^{N,J,\infty}$, sectoral reallocation shares $\{\hat{\mu}_t^{n,jk}\}_{n=1,j=1,k=1,t=0}^{N,J,J,\infty}$, lifetime utilities $\{\hat{u}_t^n\}_{n=1,t=0}^{N,\infty}$ and labour $\left\{\hat{L}_t^n\right\}_{n=1,t=0}^{N,\infty}$. The system is solved using the numerical algorithm proposed by CDP.

C Additional Tables

Table C.1 – Routes with Available Information on Freight Rates

Original route name	Source	Assigned Origin Region Code*	Assigned Destination Region Code*
Los Angeles to Shanghai	Drewry	15	7
New York to Rotterdam	Drewry	14	3
Rotterdam to New York	Drewry	3	14
Rotterdam to Shanghai	Drewry	3	7
Shanghai to Genoa	Drewry	7	1
Shanghai to Los Angeles	Drewry	7	15
Shanghai to New York	Drewry	7	14
Shanghai to Rotterdam	Drewry	7	3
China to Mediterranean	Freightos/Baltic	7	1
China to US East Coast	Freightos/Baltic	7	14
China to US West Coast	Freightos/Baltic	7	15
China to Europe	Freightos/Baltic	7	2
Europe to US East Coast	Freightos/Baltic	2	14
Europe to China	Freightos/Baltic	2	7
Europe to South America Atlantic	Freightos/Baltic	2	12
Europe to South America Pacific	Freightos/Baltic	2	13
Mediterranean to China	Freightos/Baltic	1	7
US East Coast to China	Freightos/Baltic	14	7
US East Coast to Europe	Freightos/Baltic	14	2
US West Coast to China	Freightos/Baltic	15	7
Ningbo to Australia/New Zealand	Ningbo	7	16
Ningbo to Black Sea	Ningbo	7	4
Ningbo to East US	Ningbo	7	14
Ningbo to Japan	Ningbo	7	11
Ningbo to East Mediterranean	Ningbo	7	9
Ningbo to East South America	Ningbo	7	12
Ningbo to Europe	Ningbo	7	2
Ningbo to India/Pakistan	Ningbo	7	8
Ningbo to North Africa	Ningbo	7	17
Ningbo to Philippines	Ningbo	7	5
Ningbo to South Africa	Ningbo	7	18
Ningbo to Singapore/Malaysia	Ningbo	7	10
Ningbo to Thailand/Vietnam	Ningbo	7	6
Ningbo to West US	Ningbo	7	15
Ningbo to West Mediterranean	Ningbo	7	1
Ningbo to West South America	Ningbo	7	13

* The corresponding 18 regions for the displayed codes are available in Table C.2

Table C.2 – List of Regions

Region Code	Region Name	Countries* (ISO3) in Region
1	West Mediterranean	ESP, ITA, POR,
2	North Europe	DNK, DEU, POL, RUS, SWE
3	Central Europe & UK	BEL, FRA, NLD, CHE, GBR
4	Black Sea	HUN, ROU, SVK
5	Philippines	PHL
6	Thailand & Vietnam	THA, VNM
7	China	CHN, HKG
8	India	IND
9	East Mediterranean	ISR, TUR
10	Singapore & Malaysia	SGP, MYS
11	Japan & Korea	JPN, KOR
12	East South America	ARG, BRA
13	West South America	CHL, COL, PER
14	East North America	CAN1, MEX1,USA1
15	West North America	CAN2, MEX2, USA2
16	Australia	AUS
17	North Africa	MAR
18	South Africa	ZAF

* The corresponding names of the countries are displayed in Table A.1

Table C.3 – PPML Results for Reduced Forms

	IV	PPML
Dependent variable	ln(Trade)	Trade
Instrument	0.014**	0.017***
	(0.007)	(0.006)
Importer x Industry x Time FE	Yes	Yes
Exporter x Industry x Time FE	Yes	Yes
Exporter x Importer x Industry FE	Yes	Yes
Observations	80,787	80,980

Notes: Results correspond to the reduced forms of the specification with $\Upsilon^{ni,j}$ as an exporter-importer-industry FE. All regressions control for tariffs. Heteroskedasticity robust errors in parentheses.

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

Table C.4 – Results for Linear Probability Model (LPM)

	Second stages		Reduced forms	
	IV	LPM	IV	LPM
Dependent variable	ln(Trade)	Binary trade	ln(Trade)	Binary trade
ln(Freight)	-1.035**	-0.005		
	(0.508)	(0.026)		
Instrument			0.014**	0.000
			(0.007)	(0.000)
Importer x Industry x Time FE	Yes	Yes	Yes	Yes
Exporter x Industry x Time FE	Yes	Yes	Yes	Yes
Exporter x Importer x Industry FE	Yes	Yes	Yes	Yes
Observations	80,787	81200	80,787	81,200
F first stage (Kleibergen-Paap)	101.0	101.0		

Notes: All regressions control for tariffs. Results correspond to the reduced forms of the specification with $\Upsilon^{ni,j}$ as an exporter-importer-industry FE. Heteroskedasticity robust errors in parentheses.
* p<0.1, ** p<0.05, *** p<0.01

Table C.5 – IV Results with Clustered Errors

	(1)	(2)	(3)
	ln(Trade)	ln(Trade)	ln(Trade)
ln(Freight)	-1.035**	-1.035*	-1.035**
	(0.508)	(0.550)	(0.497)
Importer x Industry x Time FE	Yes	Yes	Yes
Exporter x Industry x Time FE	Yes	Yes	Yes
Exporter x Importer x Industry FE	Yes	Yes	Yes
Observations	80,787	80,787	80,787
F first stage (Kleibergen-Paap)	101.0	54.1	81.0

Notes: All regressions control for tariffs. (1) Corresponds to the baseline results.
(2) Clustered standard errors at the exporter-importer-industry level in parentheses
(3) Clustered standard errors at the exporter's region-importer's region-industry level in parentheses. * p<0.1, ** p<0.05, *** p<0.01

Table C.6 – Trade Elasticities θ^j from Fontagné, Guimbard and Orefice (2022)

No.	Sector	$1/\theta^j$
1	Agriculture, hunting, forestry, fishing and aquaculture	2.91
2	Food products, beverages and tobacco	4.17
3	Textiles, textile products, leather and footwear	4.71
4	Wood, products of wood and cork, paper products and printing	8.51
5	Coke and refined petroleum products	3.67
6	Chemical and chemical products	10.56
7	Pharmaceuticals, medicinal and chemical and botanical prod.	10.56
8	Rubber, plastics prod. and other non-methalic mineral prod.	5.77
9	Basic metals	7.39
10	Fabricated metal products	4.22
11	Computer, electronic and optical equipment	5.14
12	Electric equipment	4.11
13	Machinery and equipment, nec	5.00
14	Motor vehicles, trailers, and other transport equipment	8.95
15	Manufacturing nec; repair and installation of machinery equip.	4.06

D Additional Figures

Figure D.1 – Quality of Port Infrastructure in 2019 in Selected Countries ($PortQua^n_{2019}$)

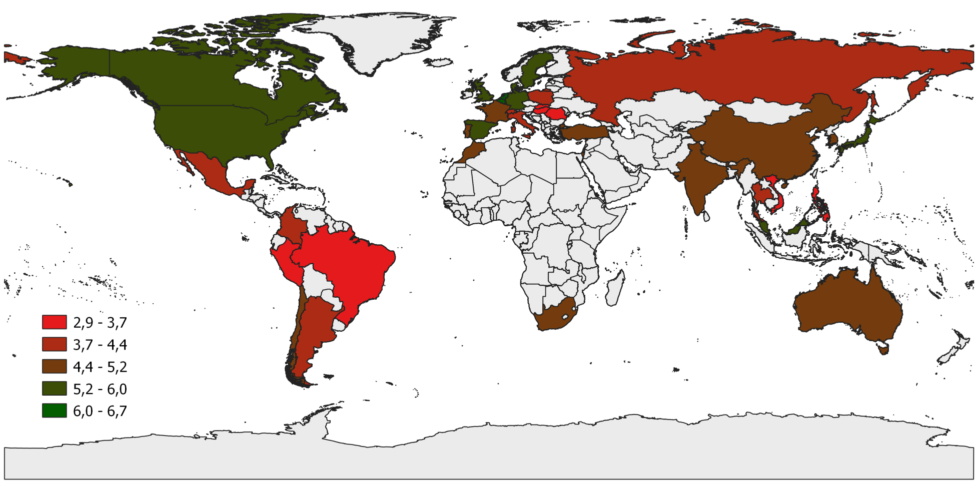


Figure D.2 – Timing of Covid-19 Lockdowns in Selected Countries

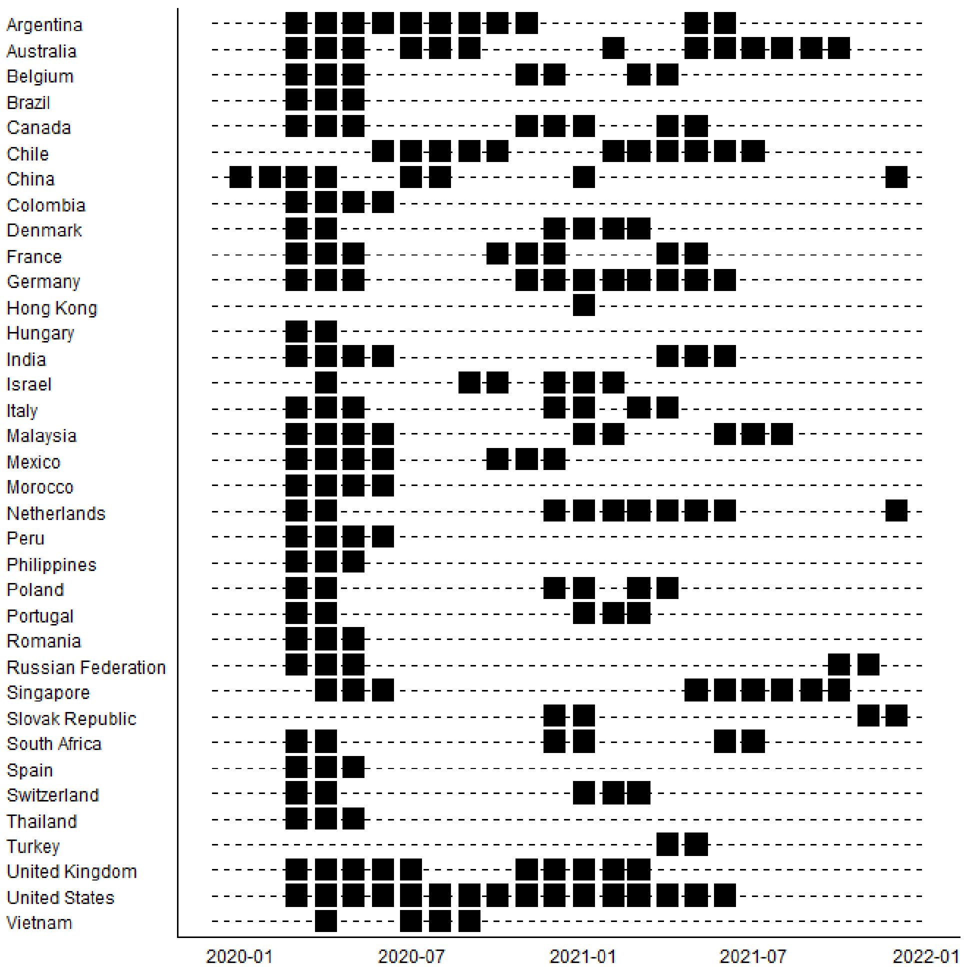


Figure D.3 – Fit of the Estimated Equation (11)

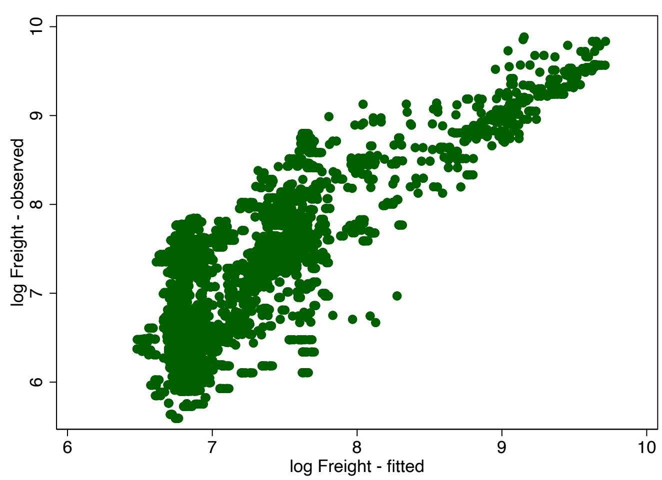
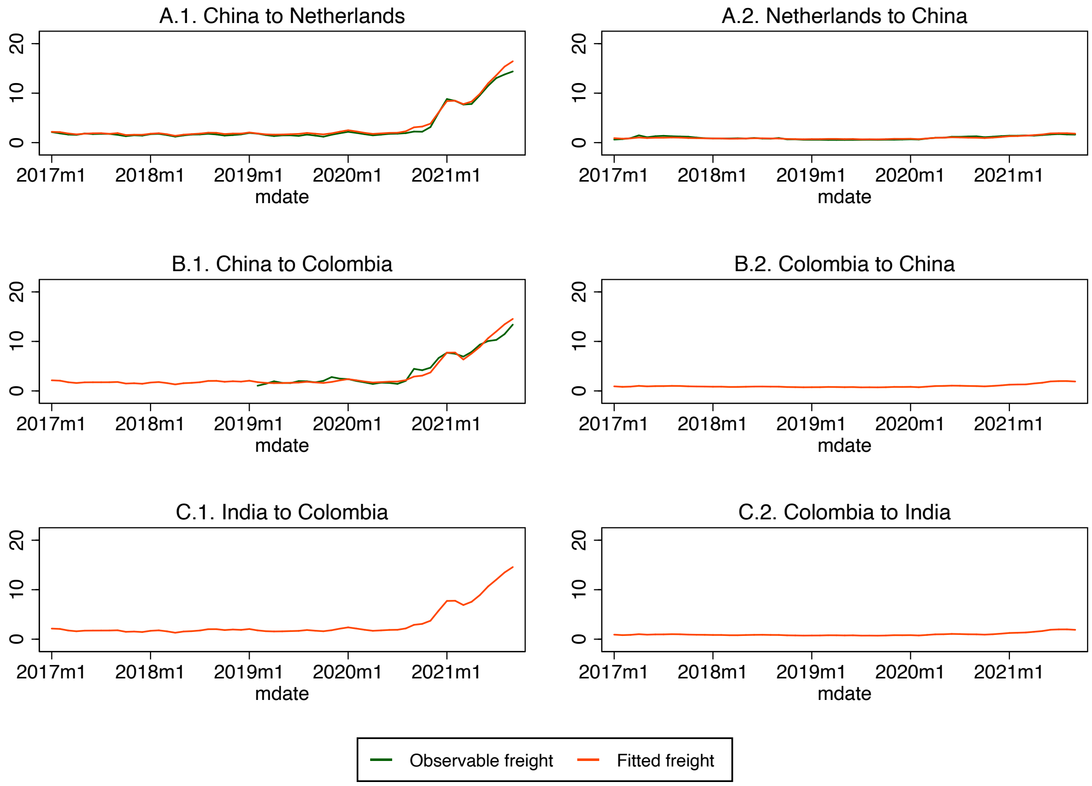
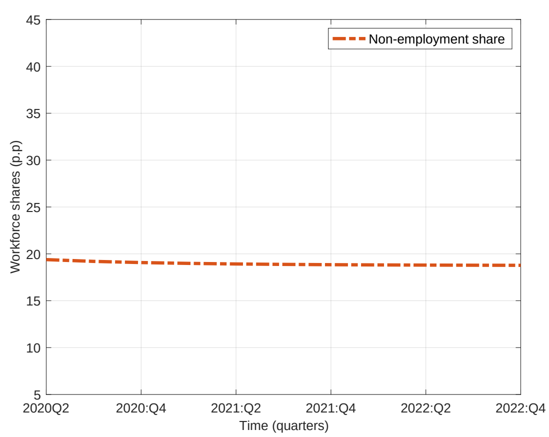


Figure D.4 – Examples of Forecasts for Three Country-Pairs*

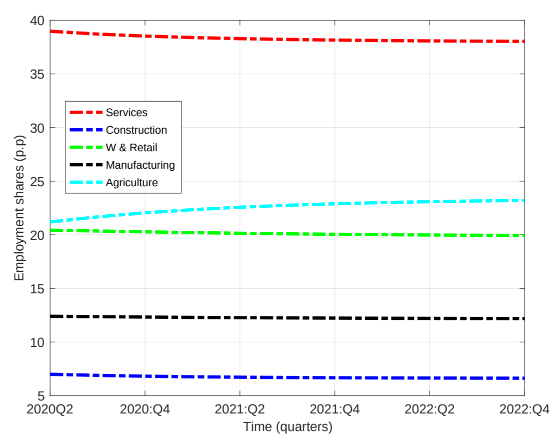


*Note: Panel A (first row) includes a country-pair with information of freight for both directions; Panel B (second row) includes a country-pair with information of freight in only one-direction; Panel C (third row) includes a country-pair with no freight information.

Figure D.5 – labour Reallocation in the Baseline Economy



(a) Non-employment (as % of the workforce)



(b) Within-employment (as % of total employment)