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

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Abstract

The Covid-19 pandemic disrupted the international transportation industry, causing container freight rates to reach record highs from late 2020 and into 2021. I evaluate the dynamic effects of the observed increases in container freight rates all around the world on the domestic inflation, real consumption, and the allocation of labor of a particular country (Colombia). For this, I use a quantitative model of international trade with out-of-steady-state transitional dynamics, input and output linkages and frictions in the labor markets. The framework allows for a quantification not only of the direct impact of the freights for the goods shipped in and out of Colombia, but also of the indirect impact of the increases in freights in the rest of the world. To identify the transportation costs shocks in the model, I estimate trade elasticities to freight rates, using an IV estimator that takes advantage of the heterogeneous timing of the lockdowns. Results indicate that worldwide increases in container freight rates caused a sizable impact on Colombian domestic inflation (2.4% on average), a welfare loss of 1.4%, and moderate effects on labor reallocations.

Keywords: International trade, container freights, Covid-19 pandemic, welfare effects, general equilibrium.

JEL: F16, F62, F17

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1 Introduction

Around 80% of international trade is carried by sea (Heiland and Ulltveit-Moe, 2020*a*; UNCTAD, 2021*b*). Hence, global production networks and value chains depend on a fluid operation of maritime transport. Of the total value of all seaborne trade, container ships account for 60% (Heiland et al., 2019), with particular importance for merchandise trade. Thus, a worldwide disruption of containerized operations and logistics, such that the produced in the aftermath of the Covid-19 pandemic, that led to container freight rates to reach record highs, can trigger a cascade of both nominal and real effects on the economies.

In this paper I quantify the dynamic impacts of the observed increases in container freight rates during 2020 and 2021 on the domestic inflation, the real consumption and the allocation of labor of a particular country, Colombia. Given the increasing importance of global trade networks, I estimate not only the effects of the increases in freight rates for the goods shipped in and out of Colombia, but also the indirect impacts on the Colombian economy derived from the increases in freights in all other routes around the globe. For this, I use a dynamic quantitative model of international trade that features multiple countries and sectors and an input-output structure as in Caliendo and Parro (2015), plus out-of-steady-state transitional dynamics and reallocation costs for workers as in Caliendo, Dvorkin and Parro (2019) (hereafter CDP). Building on those frameworks, I model bilateral trade costs as a function of sector-specific duties and total transportation costs, which in turn are a function of observed container freight rates and an elasticity of transportation costs to freights. In this way, the model features a detailed economic structure that can incorporate a wide range of general equilibrium adjustments that occur once container freight rates rise in any particular route.

The elasticity of transportation costs to container freights, which is a key input to the quantification exercise, is estimated in a model-consistent way. Particularly, the gravity equation of the model implies that such elasticity can be obtained by combining two trade elasticities that are feasible to estimate: one with respect to freights and the other with respect to tariffs. Since bilateral freights are arguably endogenous to bilateral trade flows, to obtain the first elasticity I employ an IV approach using an instrument that takes advantage of both the heterogeneous timing of the lockdowns during the pandemic and of the pre-existent conditions in port infrastructure. The empirical strategy delivers a trade elasticity to freights close to -1, that is statistically significant and that lies inside the range found in the related literature. Combining this elasticity with estimates of the sectoral trade elasticities to tariffs derived from recent literature, I obtain elasticities of transportation costs to container freights, that, together with the evolution of observable freights, allows me to compute the transportation costs shocks derived from the pandemic.

With the obtained transportation costs shocks, I use the quantitative trade model to evaluate counterfactual scenarios in which the studied economy is hit by those shocks. 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 thereafter evolves towards its steady state under the assumption that freights and other exogenous state variables (e.g. sectoral productivity levels, mobility costs across sectors, other bilateral international trade costs, etc.) remain constant. Next, I compute the implications for domestic inflation, the allocation of labor and welfare of several counterfactuals in which I only change the transportation costs according to the observable variation in freights during the pandemic, keeping unaltered the remaining set of exogenous state variables. Those quantitative exercises can be performed without needing to estimate the values of all exogenous state variables. Particularly, since the model's equilibrium conditions can be expressed in relative time differences, and because the observed allocations in 2018 are sufficient statistics for setting the exogenous state variables in the initial year, the dynamic impact of the changes in freights for the transitions of the observables can be obtained without knowing the values of the set of exogenous state variables and other deep parameters. This solution method, recently proposed by CDP, and known as "dynamic exact-hat algebra", it is a dynamic extension of the "exact-hat algebra" approach of Dekle, Eaton and Kortum (2008) to perform counterfactual analysis in static trade models.

The results of my counterfactual exercises suggest that the observed increases in container freight rates generated sizable effects on Colombian inflation and real consumption (and thus on welfare) and moderate impacts on labor reallocation. Regarding inflationary effects, from the beginning of the pandemic and up to the end of 2022, the rise in worldwide container freights caused an average increase of 2.4% of the annual growth of the Colombian aggregate price index, a metric that can be understood as the overall inflation, led by the adjustments on prices of tradable goods.[1] Further, the shock induces a generalized decrease in real wages that impacts the path of real consumption and hence welfare, which displays a loss of 1.4%. Finally, regarding the employment effects, the rise in worldwide freights leads to 0.12% of the workers (28.6K) to move towards non-employment, and, within employment, a reallocation of workers towards non-tradable sectors, particularly construction, that ends with an increase of 0.07% in their employment share (13.4K workers). These effects in the labor market, although sizable in absolute terms, are moderate compared to the paths of reallocation of labor that exhibit the baseline economy in absence of shocks.

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 freights only in routes that involve Colombia directly (i.e. freights for its imports and exports), and a subset with the increases in freights in all remaining routes. By doing so, the results of the corresponding counterfactuals show that in the current globalized world, for a country's domestic inflation it is very important not only what occurs

[1] These nominal impacts are identified up to choice of a nominal anchor in the model, i.e. a reference inflation in which the remaining variations in prices are identified. I choose the inflation of a non-tradable sector (education) in China as the reference inflation; and the counterfactual exercises assume that the increases in freights do not affect such inflation.

with the transportation costs for its imports and exports, but also how those costs evolve abroad. In the Colombian case, the increase of freights in routes that do not involve Colombia directly contributes in around 79% of the full adjustment of its domestic prices. Further, while the inflationary pressures of each of those two subsets of shocks are additive, the effects on employment reallocations work instead 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 freights only in routes that involve Colombia the country becomes relatively more closed with respect to the rest of the world, inducing an decrease on relative wages in tradable sectors, in the case in which freights increase only in routes that do not involve Colombia the country becomes relatively more open, and hence the opposite effect over 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 labor reallocation that partially offset each other.

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) and Caliendo et al. (2021). 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 labor market frictions within sectors, to study the response of labor markets in six countries to technology, trade and preference shocks.

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). Usually, transportation costs are measured either in a direct way using available freights 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 freights 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.

Finally, this study belongs to a vast literature that explores implications of the Covid-19 pandemic in different dimensions. 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*); the transmission of the rise in import prices to total domestic inflation (see for example Amiti, Heise and Wang, 2021; LaBelle and Santacreu, 2022 for the U.S.); and the impacts of the pandemic on the Colombian economy; more specifically on domestic inflation and 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*).

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 Container freight rates during the Covid-19 pandemic

As the world economy emerged from the severe and sudden dip in economic activity that the Covid-19 pandemic caused in early 2020, a mix of several factors triggered a notorious

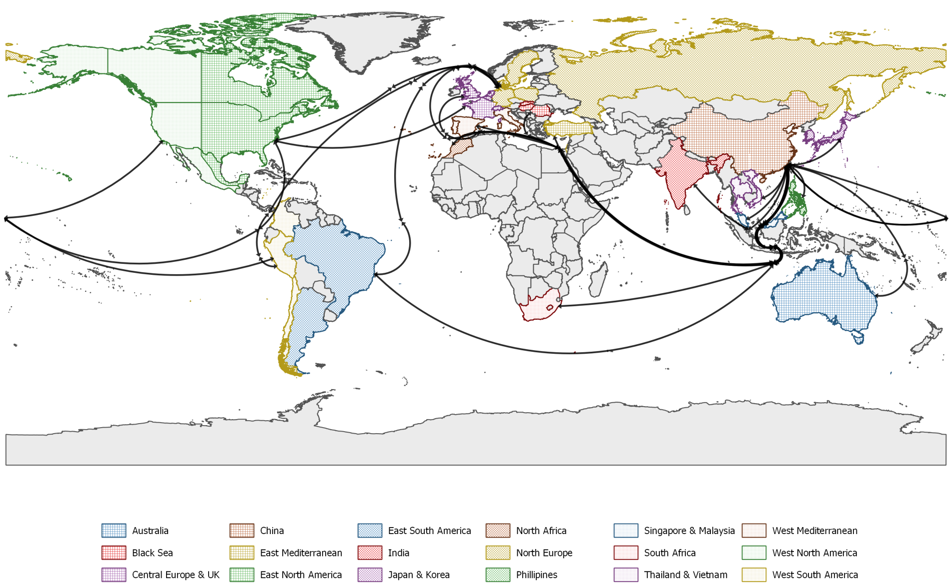
[2]CIF: Cost, Insurance and Freight; FoB: Free on Board. Since CIF is the sum of FOB and transport costs, CIF/FOB equals one plus the ad valorem freight and insurance rate.

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

increase in container freight rates all around the world, starting by late 2020. Some of these factors included the extra congestion and delays at ports derived from lockdowns and other sanitary measures; the bottlenecks that many manufacturing sectors faced due to supply chain disruptions; the presence of logistic problems that distribution faced to keep pace of a faster recovery in demand than the anticipated; and even some exogenous shocks (e.g., the obstruction of the Suez Canal) (see Brooks, Fortun and Pingle 2020*a*,*b*; Reserve, 2021; UNCTAD, 2021*a*). Most of these factors, initially considered as transitory ones, lasted longer than expected, causing delivery times and freight rates to reach historical peaks in 2021. Even as 2022, there are increasing concerns about how long would it take these issues to be solved (Hoffmann, 2021; Friessen, 2021).

To analyze the evolution of container freight rates, 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 Freights



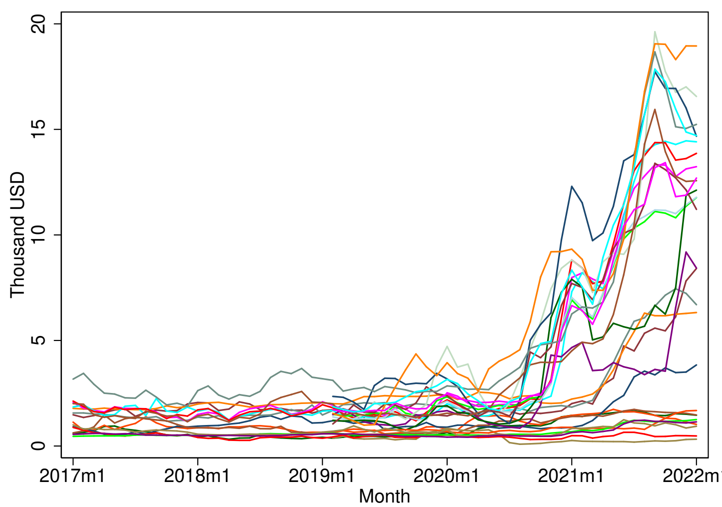
Note: The sources for each route are indicated in Table C.1, and the countries that belong to each of the displayed regions are listed in Table C.2.

Figure 2 jointly depicts the monthly evolution of all available container freight rates since

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

2017. In the aftermath of the Covid-19 pandemic, 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 freights between the same pair of regions. For instance, the 2021 average container freight rate 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



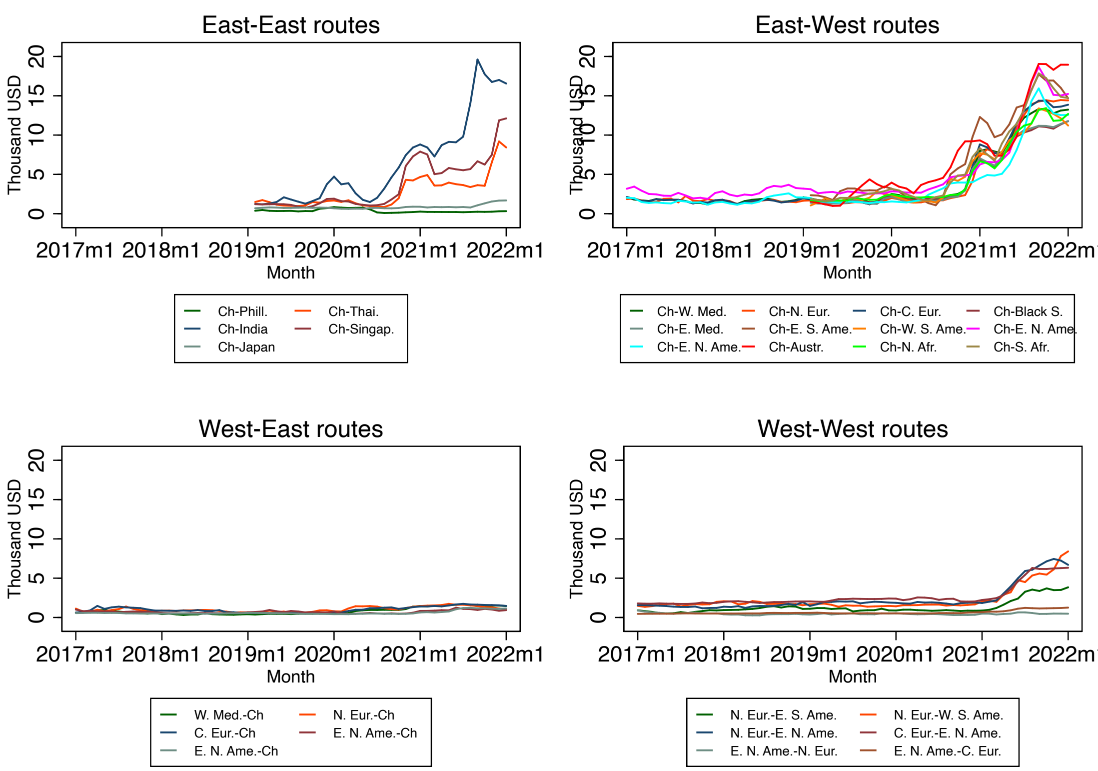
Note: All rates are reported in thousand USD per forty foot container. Sources: Drewry, Freightos and Ningbo container indexes.

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 freights 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 freights in the aftermath of the Covid-19 pandemic. First, freights are clearly time-variant as Figure 2 shows. And second, even in a cross-section, the distance effect is 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 labor market is segmented, with barriers to mobility across sectors,[5] represented by a time-invariant sector-pair specific labor relocation cost $\zeta^{n,jk}$ measured in terms of utility.[6] Thus, workers in sector j supply a unit of labor 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 labor 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

[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 labor market is assumed; i.e. with free labor mobility and the same wage across sectors.

given sector j and the transitions of labor across sectors.[7] Particularly, denoting the expected 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 labor ($l_t^{n,j}$) 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

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

[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 $\gamma^{n,j} + \sum_{k=1}^{J} \gamma^{n,jk} = 1$

added and $q_t^{n,j}$ the units of the variety produced. Cost minimization in perfect competition 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 freights), that I call non-freight barriers; $\varepsilon_t^{ni,j}$ collapses other time-variant determinants of transportation costs apart from container freights and orthogonal to them, plus mean-zero measurement errors; and ρ_F^j is the key elasticity of transportation costs to observable freights. 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

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

given by the minimum unit cost across all countries, taking into account trade costs:

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

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 labor 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 vari-

[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.

ables $\{A_t^{n,j}, \tau_t^{ni,j}, \varepsilon_t^{ni,j}\}_{n=1,i=1,j=1,t=0}^{N,N,J,\infty}$, 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 freights $\{F_t^{ni}\}_{n=1,i=1,t=0}^{N,N,\infty}$ is characterized by a sequence of labor 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 $\{V_t^n\}_{n=1,t=0}^{N,\infty}$ and labor $\{L_t^n\}_{n=1,t=0}^{N,\infty}$, 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 Nominal impacts

Finally, in order to identify nominal impacts with the model, a choice of a numeraire is in order. Since in the nominal side I am not interested in level effects, but only in assessing the inflationary pressures derived from the transportation cost shocks, a choice of the growth of the price of a single good is enough to pin down the variations in prices of the remaining goods. Thus, denoting by $\dot{y}_{t+1} \equiv \left(\frac{y_{t+1}}{y_t}\right)$ the proportional change in a variable y_t, I can interpret the growth of prices in the sequential equilibrium as actual metrics of inflation by imposing:

$$\dot{p}_{t+1}^{n,j} = \left\{\dot{p}_{t+1}^{n,j}\right\}_{data} \forall\ t \tag{9}$$

for a particular (n, j) in the set of countries and sectors. With an eye towards the evaluation of counterfactuals, I choose for the reference growth in prices a country-sector where the increases in container freights could arguably have a minimal impact on its prices: Education services in China. Note that this choice only scales up or down all the variations in prices between periods, but the real effects are identified even without the choice of this reference inflation.

3.6 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 labor) 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 freights. 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 freights. 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 freights, are the allocation of labor 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 freights, 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 freights –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 freights 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 freights between the baseline economy and the counterfactual one. And to obtain in addition the impacts on the relative time differences of the nominal variables, an assumption on the impact on the numeraire is required.

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 freights thereafter. Next, for the counterfactual economy, I change the paths of transportation costs according to the observable variation in freights during the pandemic, and keep constant the remaining set of fundamentals and the path of the numeraire. 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.:

$$\frac{\left\{\frac{\kappa_t^{ni,j}}{\kappa_{t-1}^{ni,j}}\right\}_{t=1,counterfactual}^{\infty}}{\left\{\frac{\kappa_t^{ni,j}}{\kappa_{t-1}^{ni,j}}\right\}_{t=1,baseline}^{\infty}} = \left\{\frac{\kappa_t^{ni,j}}{\kappa_{t-1}^{ni,j}}\right\}_{t=1}^{\infty} = \left\{\frac{\left(F_t^{ni}\right)^{\rho_F^j}}{\left(F_{t-1}^{ni}\right)^{\rho_F^j}}\right\}_{t=1}^{\infty} \tag{10}$$

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 freights do not change. The next section presents a procedure to compute (10), 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 (10) requires estimates of ρ_F^j as well as values of F_t^{ni} for those country-pairs where freights 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 freights.

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:

$$\ln X_t^{ni,j} = \delta_t^{i,j} + \delta_t^{n,j} + \delta^{ni,j} + \beta_F \ln F_t^{ni} + \beta_\tau \ln\left(1 + \tau_t^{ni,j}\right) + \varepsilon_t^{ni,j} \tag{11}$$

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 $-\theta^j \ln \Upsilon^{ni,j}$, 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 (11), 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 (11), 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 (11) 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

[12]Admitted not ideal, this imputation is necessary given the limitations of the data on freigths. As a

instead annual data to control for tariffs, but, given their scarce temporal variation during the sample period, I prefer not using the estimates of $\hat{\beta}_{\mathcal{T}}$ 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 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 freights 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-

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 freights 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 (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 $PortQua_{2019}^n * PortQua_{2019}^i$ 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.

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 freights 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).

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.
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

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 freights, 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 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 (11) 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 freights 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:

$$F_t^{ni} = A_t^D \left(D^{ni}\right)^{\beta_{it}^D} \varepsilon_{ni,t}^D \; with \; \beta_{it}^D = \begin{cases} \beta_{E,t}^D & if \; i \in East \\ \beta_{W,t}^D & if \; i \in West \end{cases} \quad (12)$$

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 freights 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 freights apart from distance, and that I assume is, in logs, mean-zero and orthogonal to it. I estimate equation (12) 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 freights 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 freights 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 (10) 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 labor markets' structure in the studied country (Colombia) and abroad. Next, I show the results of counterfactuals that involve: i) an increase in worldwide freights as observed in 2020 and 2021; ii) the same increase in freights but now only for routes involving Colombia as origin or destination; and iii) an increase in freights 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 Constructing the 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 labor $L_{2018}^{n,j}$ 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 labor migration across countries and that the only segmented labor market is that of the studied country, i.e. Colombia. This means that the labor transition matrix, the most challenging object among the data requirements, and the initial allocation of labor, are inputs that are only needed for Colombia. Finally, to evaluate nominal impacts, following the discussion in Section 3.5, I set as the reference growth in prices the quarterly inflation of education services in China.

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); 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] and iv) the reference growth in prices $\dot{p}_t^{Chn,edu}$, i.e. the quarterly inflation of education services in China, that is collected from 2018Q1 to 2022Q3.[16] 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 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 3.6. 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 labor 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 labor share of those two segments over time; as opposed to what happens in agriculture.

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

[16]From there on, the quarterly inflation converges to its average in that time frame.

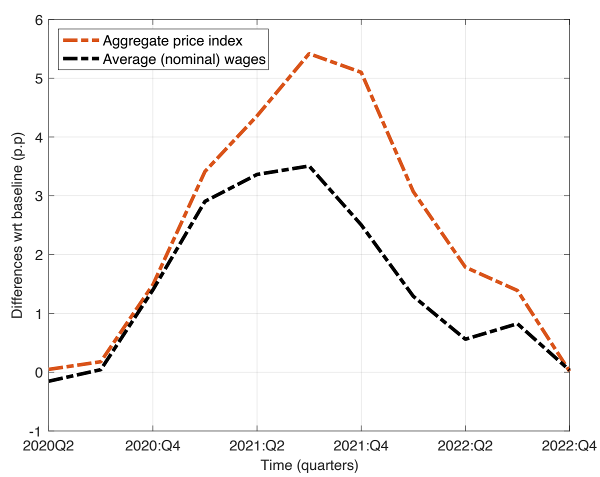
5.2 Counterfactual results

I start by solving for the dynamic impact on the variables of interest of a counterfactual in which container freights increase 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.[17] These transportation costs shocks generate effects both on relative prices and labor allocations. First, regarding nominal effects, it is possible to compute the impact on the annual growth of the Colombian aggregate price index, i.e. $100 * \left(P_t^{Col}/P_{t-4}^{Col} - 1\right)$, as a metric of the domestic inflationary pressure derived from the transportation cost shocks. Figure 4 shows the impact on this metric, defined as the difference between its values in the counterfactual and in the baseline. The rise in worldwide container freights increases Colombian annual inflation on average by 2.4% between the start of the pandemic (2020Q2) and the end of 2022, having a maximum impact on 2021Q3 (5.3%). This effect can also be obtained separately for tradable and non-tradable sectors, which is shown in Figure D.6 in Appendix D. Naturally, the aggregate impact is led by larger increases in inflation of tradable goods (4.2% on average); however, given I-O linkages, there are non-negligible increases in prices of non-tradable goods (1.8% on average).

Figure 4 – Effects of Increases in Worldwide Freights on the Annual Inflation of Prices and Wages

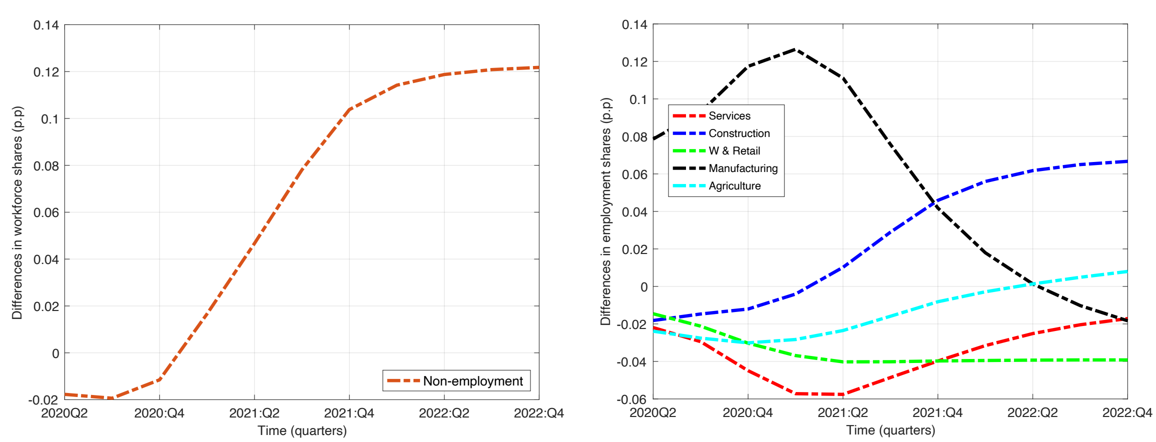


[17] For all remaining time-varying fundamentals, call them z_t, $\hat{z}_t = 1 \; \forall \; t$, and for the impact on the reference inflation, $\hat{p}_t^{Chn,edu} = 1 \; \forall \; t$. This last assumption is needed only to infer nominal impacts.

Figure 4 also shows the response of the annual inflation of nominal wages to the shocks.[18] The annual growth in nominal wages is also impacted by the transportation costs, but in a lesser extent than the growth in prices. Figure D.6 in Appendix D shows that this is also true for wages in tradable and non-tradable sectors. The lower adjustments of nominal wages are the result of the decrease of real wages, in both tradable and non-tradable sectors, which are the determinants of real consumption and welfare (see below). The impacts on the levels of real wages are depicted in Figure D.7 of Appendix D for the division between tradable and non-tradable sectors, and for the aggregation of main five sectors. Real wages in tradable sectors display the largest losses, lead by manufacturing. Notice that since all real wages are deflated with the aggregate price index, the differences in the real wage paths across sectors are only due to the adjustments in relative wages. And as I explain below, those adjustments in relative wages depend on how much the shocks shift the country towards a more open or closed economy respect to the rest of the world.

Regarding the employment effects, Figure 5 displays the absolute differences in the shares of Colombian workers between the counterfactual and the baseline economy, this is, how the workers' reallocation is affected by the transportation cost shocks. First, the rise in worldwide container freights leads to 0.12% of the individuals (28.6K) to move towards non-employment. Compared to the decreasing trend that the share of non-employees in the workforce exhibits in the baseline economy (Figure D.5), this impact is somewhat moderate. This effect is derived from the generalized fall of real wages that increases the relative value of home production. 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 Freights on the Reallocation of Workers

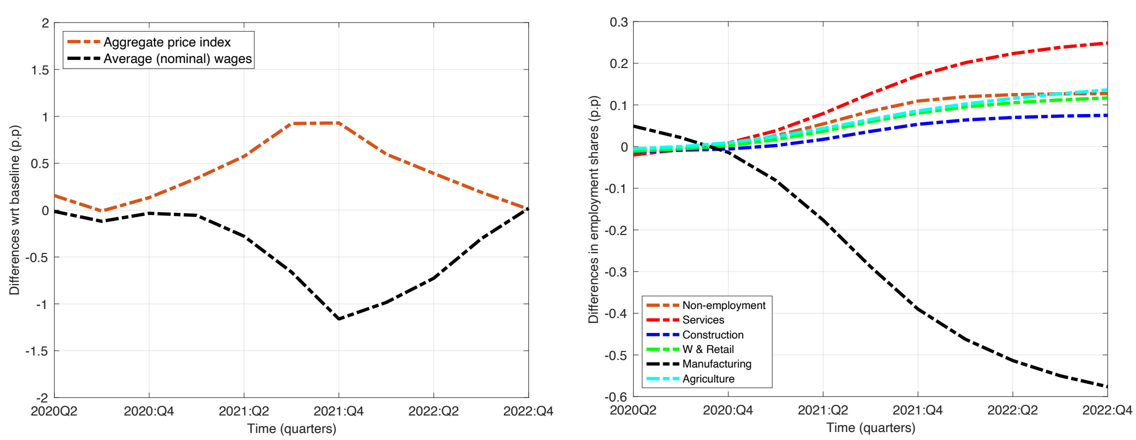


(a) Towards Non-Employment **(b)** Within Employment

[18]The relative time differences of wages are weighted by the initial labor share in each sector..

To understand better the latter results I divide the full set of shocks in worldwide container freights into a subset that includes shocks in freights only in routes that involve Colombia directly, and a subset with the shocks in all remaining routes. Figure 6 shows the effects on the annual growth of prices and nominal wages and the impacts on the allocation of labor of increases in freight rates only for routes that involve Colombia either as destination or as origin. The average effect on the metric of inflation in the studied period is 0.4%, only 17% of the impact in the counterfactual with the full set of shocks. This suggests that the indirect effects of the increases in freights in routes that do not involve the studied country are really important for quantifying the impact on its domestic inflation in a world with global trade networks. On the real side, 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 (compare Figure D.7 and D.8 of Appendix D), leading to a job loss that is similar (0.13%) and, as we comment below, to welfare implications that are in the same order of magnitude.

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



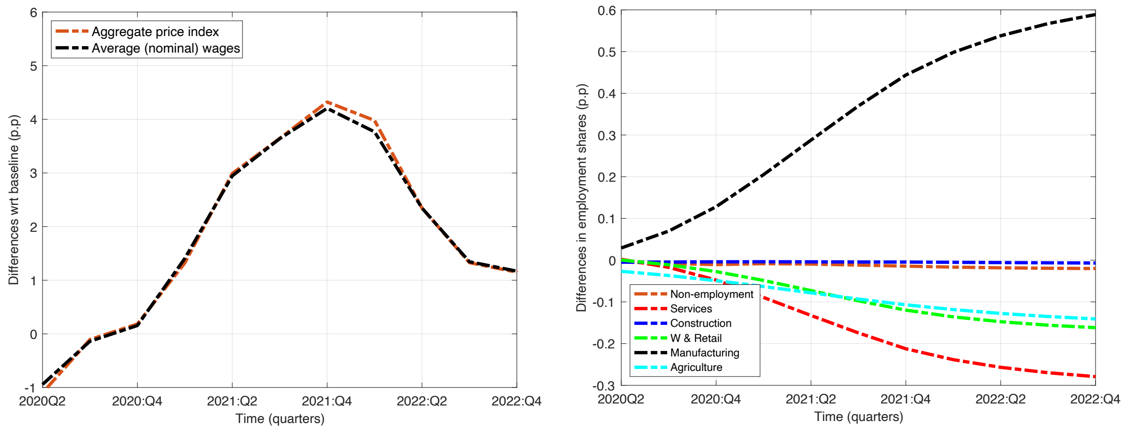
(a) Annual Inflation of Prices and Wages

(b) Labor

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

Figure 7 shows replicates the latter impacts if instead freights would have increased worldwide except for routes that involve Colombia. In this case, the average effect on the metric of inflation is 1.9%, around 79% of the impact in the counterfactual with the full set of shocks. Once again, this shows the importance for domestic inflation of what occurs in transportation costs outside of the country in a globalized world, and the fact that for inflation, the two sets of shocks have an additive impact. In terms of real effects, since in this counterfactual

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



(a) Annual Inflation Prices and Wages **(b)** Labor

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

Colombia becomes relatively more open with respect to the rest of the world, the adjustment of the relative wages is the opposite than in the latter case, and thus manufacturing strongly expands (in a similar magnitude that the contraction in the case before). This means that the moderate employment reallocation effects that I obtain in the counterfactual with the full set of shocks on, are the result of the sum of opposite forces on labor reallocation that partially compensate each other. Finally, in this case the growth in average nominal wages is impacted in the same magnitude than the growth in prices. This means the average real wage barely adjusts (Figure D.8 of Appendix D), leading to an almost null reallocation of workers from non-employment and to very small effects on welfare, as I proceed to comment on.

Regarding welfare effects, 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:

$$\hat{Welfare}^{Col,j} = \sum_{t=1}^{\infty} \beta^t \ln \left(\frac{\hat{C}_t^{Col,j}}{(\hat{\mu}^{Col,jj})^{\nu}} \right) \tag{13}$$

Evaluating equation (13) by aggregating welfare by the initial share of workers in each sector j, the decrease in welfare as result of the increases in container freights all around the world is 1.35%, consistent with the fall in real wages obtained in the counterfactual with the full set of shocks. This result is similar to the welfare loss obtained when freights only change for routes involving Colombia (1,31%), given that the decrease in average real wages was in this case of the same magnitude. Instead, when freights increase only for routes that do not involve Colombia, the fact that the country becomes relatively more open compensates the impact on welfare derived from costs, generating even a small increase in welfare, of 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 freights. Column (2) of Table 2 shows that the new reallocation of labor 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 both inflation and the welfare impact of the shocks remain almost unchanged, implying that ν does not affect the transmission of freights to aggregate prices or 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 inflationary pressures or the welfare implications derived from the set of full shocks in freights 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			
Average increase of annual inflation	2.4%	2.4%	2.3%
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 labor markets, the dynamic general equilibrium effects of the increases in container freights 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 performed evaluation indicate that worldwide increases in container freight rates caused significant effects on Colombian domestic inflation, with an impact of 2.4% on average between the start of the pandemic (2020Q2) and the end of 2022. Further, the shock produced a welfare loss of 1.4%, measured as the present discounted value of the expected change in real consumption relative to the change in the workers' option value. Finally, there were moderate effects on the reallocations of labor. Although these quantifications by themselves are important enough, an additional value added from the model is that it helps to understand that the globalized nature of the shocks implies heterogeneous effects on such variables of interest. For instance, the fact that while the effects of increases of container freights anywhere in the world affect domestic inflation directly, the effects on employment reallocations depend on how large are the freights increases in the routes involving the analyzed country with respect to the increases in other routes. That is, those effects depend on whether the shocks make 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 freights. In the process of deriving such elasticity, I obtain a trade elasticity to freights 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 freights; 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 freights 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 increases in observed inflation 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 freights (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 freights and hence to obtain ρ_F; and ii) a dataset with technology coefficients and the observable allocations of trade and labor 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 freights 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.[19]

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 labor $L_{2018}^{Col,j}$;[20] and PILA, the Colombian social security administrative data, to estimate the workers' probabilities of transition across sectors between 2017 and 2018 $\mu_{2017}^{Col,jk}$.[21]

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 labor 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 (11)

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

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

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

[20] 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.

[21] 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 (11) 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:

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

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

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 labor 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 labor $\{L_t^n\}_{n=1,t=0}^{N,\infty}$. 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:

$$\mu_t'^{n,jk} = \frac{\mu_{t-1}'^{n,jk} \dot{\mu}_t^{n,jk} \left(\hat{u}_{t+1}^{n,k}\right)^{\beta/\nu}}{\sum_{h=0}^{J} \mu_{t-1}'^{n,jh} \dot{\mu}_t^{n,jh} \left(\hat{u}_{t+1}^{n,h}\right)^{\beta/\nu}} \tag{B.14}$$

$$\hat{u}_t^{nj} = \hat{\omega}_t^{nj} \left(\sum_{i=1}^{N} \sum_{k=0}^{J} \mu_{t-1}'^{nj,ik} \dot{\mu}_t^{nj,ik} \left(\hat{u}_{t+1}^{ik}\right)^{\beta/\nu} \right)^{\nu} \tag{B.15}$$

$$L_{t+1}'^{nj} = \sum_{i=1}^{N} \sum_{k=0}^{J} \mu_t'^{ik,nj} L_t'^{ik} \tag{B.16}$$

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

$$\hat{P}_{t+1}^{n,j} = \left(\sum_{i=1}^{N} \pi_t'^{ni,j} \dot{\pi}_{t+1}^{ni,j} (\hat{x}_{t+1}^{i,j} \hat{\kappa}_{t+1}^{ni,j})^{-\theta^j} (\hat{A}_{t+1}^{i,j})^{\theta^j \gamma^{i,j}} \right)^{-1/\theta^j} \tag{B.18}$$

$$\pi_{t+1}'^{n,ij} = \pi_t'^{ni,j} \dot{\pi}_{t+1}^{ni,j} \left(\frac{\hat{x}_{t+1}^{i,j} \hat{\kappa}_{t+1}^{ni,j}}{\hat{P}_{t+1}^{n,j}} \right)^{-\theta^j} (\hat{A}_{t+1}^{i,j})^{\theta^j \gamma^{i,j}} \tag{B.19}$$

$$\hat{w}_{t+1}^{n,k} \hat{L}_{t+1}^{n,k} = \frac{\gamma^{n,j}(1-\xi^n)}{w_t'^{n,k} L_t'^{n,k} \dot{w}_{t+1}^{n,k} \dot{L}_{t+1}^{n,k}} \sum_{i=1}^{N} \pi_{t+1}'^{in,j} X_{t+1}'^{i,j} \tag{B.20}$$

$$X_{t+1}'^{n,j} = \sum_{k=1}^{J} \gamma^{n,kj} \sum_{i=1}^{N} \pi_{t+1}'^{in,k} X_{t+1}'^{i,k} + \alpha^j \left(\sum_{k=1}^{J} \hat{w}_{t+1}^{n,k} \hat{L}_{t+1}^{n,k} w_t'^{n,k} L_t'^{n,k} \dot{w}_{t+1}^{n,k} \dot{L}_{t+1}^{n,k} + \iota^n \sum_{i=1}^{N} \sum_{k=1}^{J} \frac{\xi^i}{1-\xi^i} \hat{w}_{t+1}^{i,k} \hat{L}_{t+1}^{i,k} w_t'^{i,k} L_t'^{i,k} \dot{w}_{t+1}^{i,k} \dot{L}_{t+1}^{i,k} \right) \tag{B.21}$$

Equations (B.14)-(B.21) form a non-linear system that can be used to solved for the impacts on the paths labor 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 labor $\left\{\hat{L}_t^n\right\}_{n=1,t=0}^{N,\infty}$. The system is solved using the numerical algorithm proposed by CDP.

C Additional Tables

Table C.1 – Routes with Available Information on Freights

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 ($PortQua^n_{2019}$)

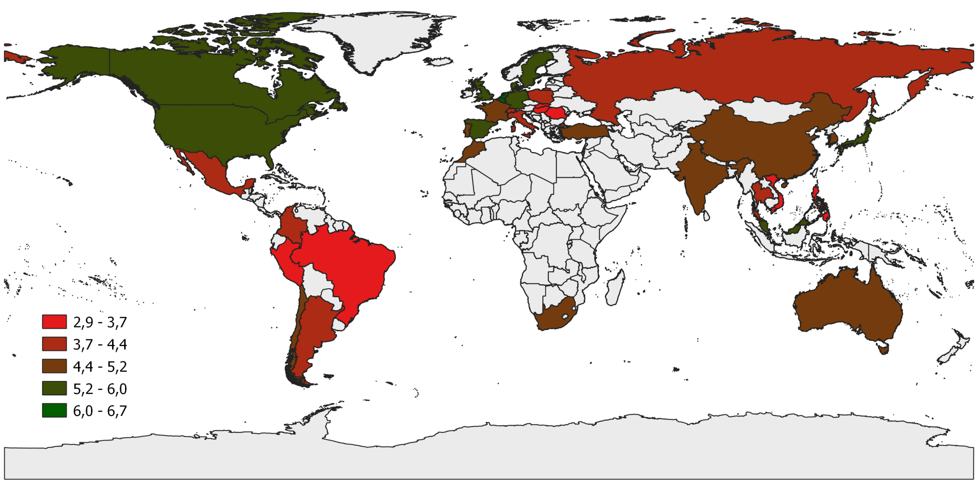


Figure D.2 – Timing of Covid-19 Lockdowns in Selected Countries

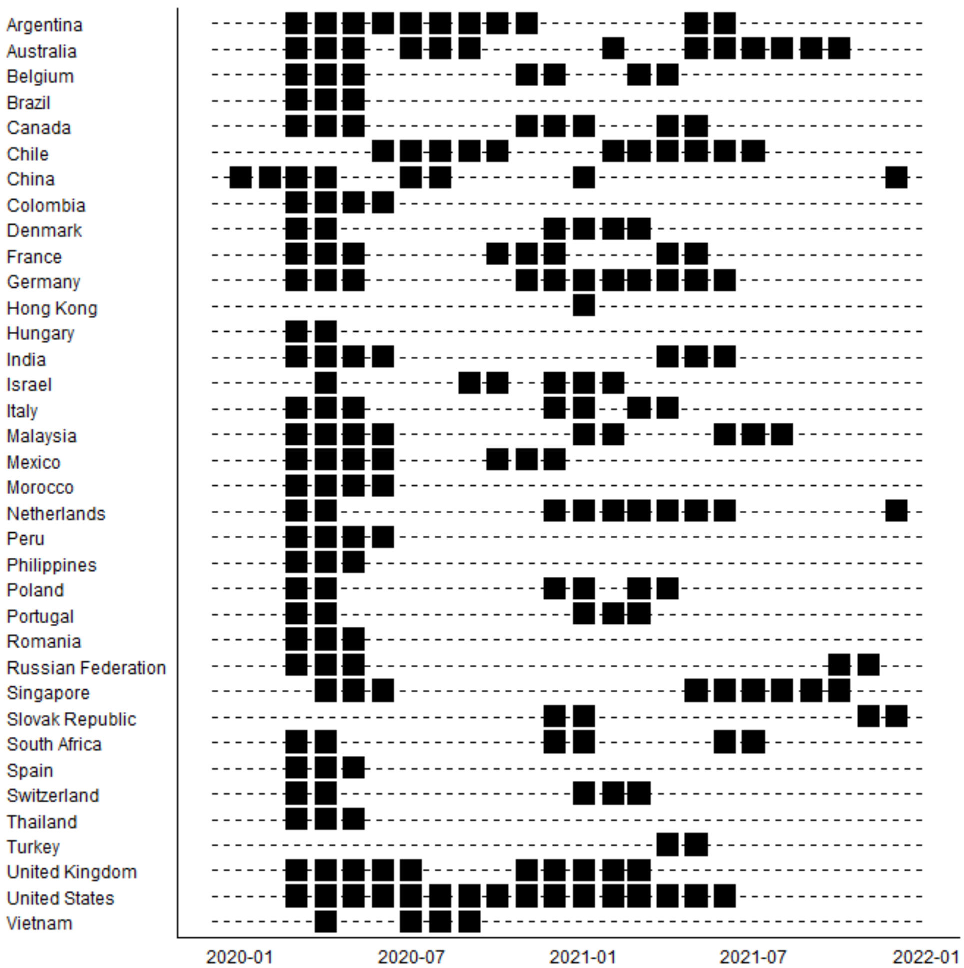


Figure D.3 – Fit of the Estimated Equation (12)

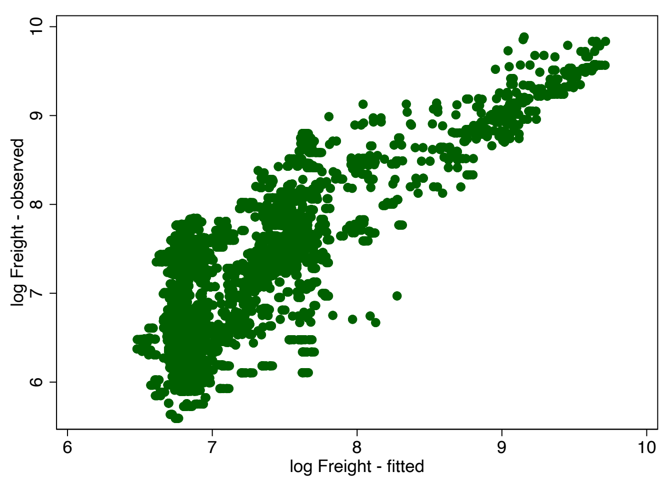
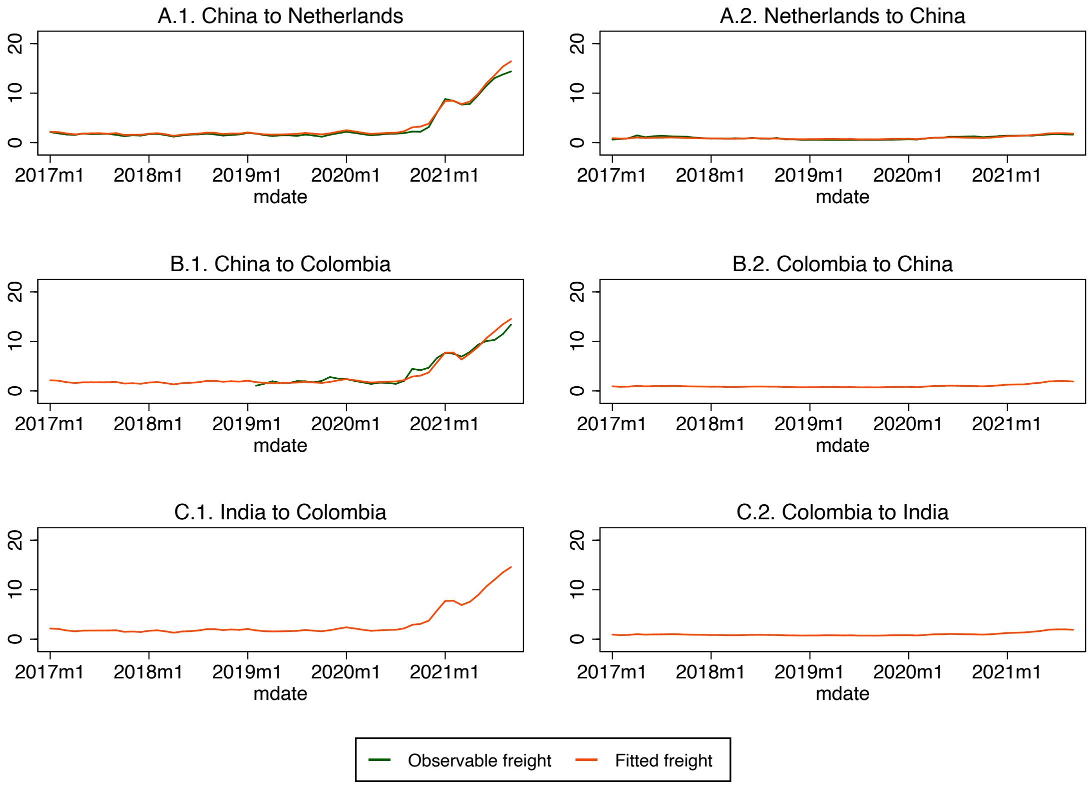
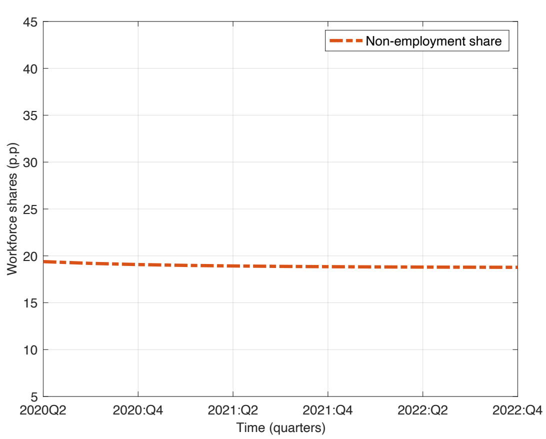


Figure D.4 – Examples of Forecasts for Three Country-Pairs*

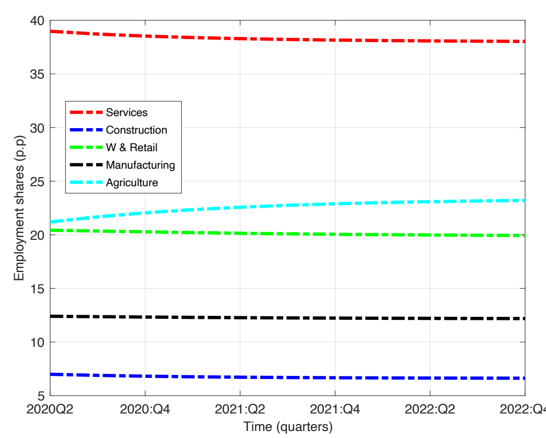


*Note: Panel A (first row) includes a country-pair with information of freights for both directions; Panel B (second row) includes a country-pair with information of freights in only one-direction; Panel C (third row) includes a country-pair with no freight information.

Figure D.5 – Labor Reallocation in the Baseline Economy

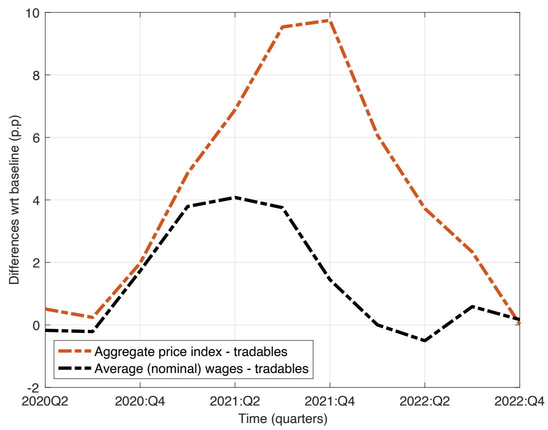


(a) Non-employment (as % of the workforce)

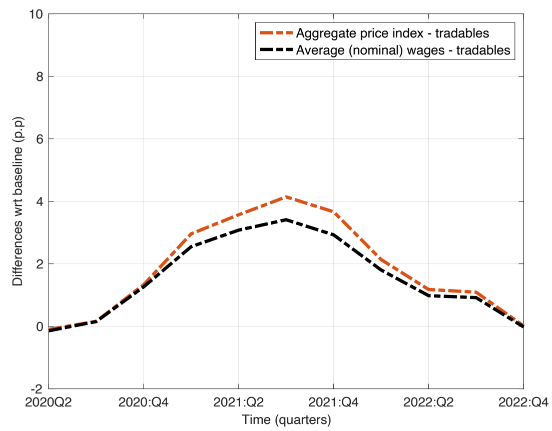


(b) Within-employment (as % of total employment)

Figure D.6 – Effect on Annual Inflation of Prices and Wages for Tradable and Non-Tradable Sectors



(a) Tradable Sectors



(b) Non-tradable Sectors

Figure D.7 – Effect on the Levels of Real Wages

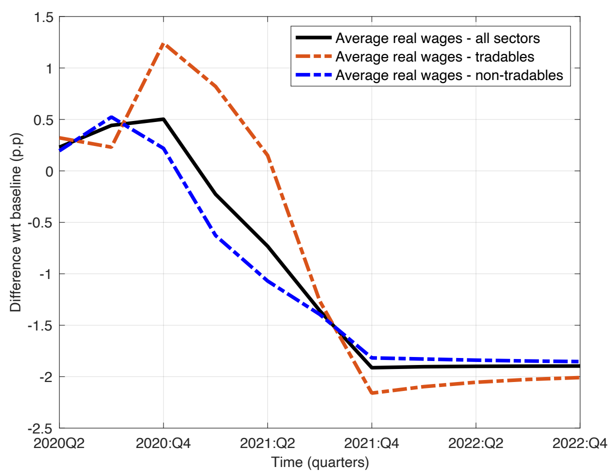
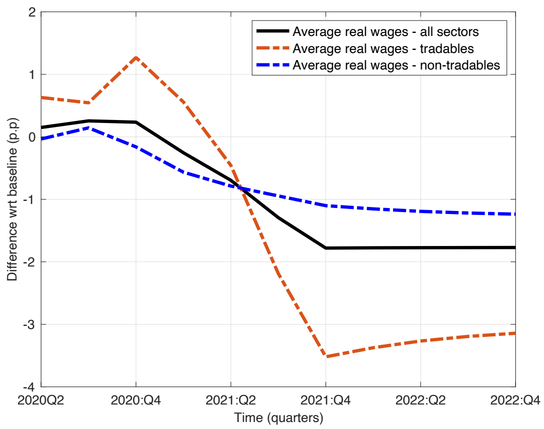
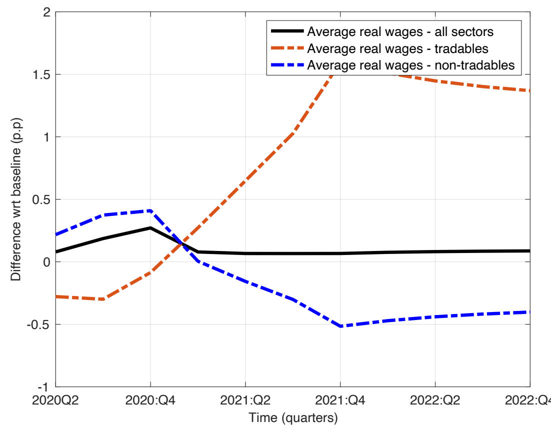


Figure D.8 – Effect on the Levels of Real Wages for Subsets of Freights



(a) Shocks Only for Freights Involving Colombia



(b) Shocks for Freights not Involving Colombia