Trade Elasticities in General Equilibrium: Demand, Supply, and Aggregation

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Abstract

We develop a model of international trade that simultaneously incorporates three important microeconomic channels, imperfect factor mobility, internal and external returns to scale, into a unified framework. Directly estimating the parameters governing these channels is infeasible given existing data and methodologies. We thus recast the model from the standard treatment of supply and demand in factor markets to a new solution based on product markets. We demonstrate composite export supply and import demand elasticities along with readily observable product market outcomes are sufficient for general equilibrium analysis. We estimate the sufficient elasticities by developing a heteroskedastic estimator for international product markets. Our methodology allows these elasticities to vary across both countries and industries, and requires only publicly available data on trade, production, and tariffs. Employing our estimated model, we evaluate the impact of recent US protectionist policies, and highlight the importance of our estimates and general equilibrium linkages.

Keywords: General equilibrium, Trade, Returns to scale, Labor mobility, Tariff pass-through
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1 Introduction

Understanding the impact of trade policies and foreign economic shocks on domestic and global economies has seen a resurgence in the public debate. Cases range from revisiting traditional questions (e.g., gains from trade) to tracing contemporary shocks through economies (e.g., evaluating the impact of recent US protectionist policies). A long-standing tradition has established that examining the consequences of trade shocks requires general equilibrium analysis. Quantification depends on elasticity parameters meant to inform margins of adjustment across and within economies. Recently, the trade literature has vigorously established the importance of three supply-side microeconomic channels: imperfect factor mobility, internal returns to scale, and external returns to scale. Nonetheless, the elasticity parameters that discipline these channels have been estimated and analyzed in isolation and by assuming they do not differ across countries. Embedding these microeconomic channels in a unified framework and jointly estimating their governing elasticity parameters in order to perform counterfactual analysis has remained a largely incomplete task.

In this paper, we advance this task a step forward by taking a relatively unconventional approach in formulating general equilibrium models of trade. The usual approach in the trade literature conducts general equilibrium analyses through the lens of factor markets – since many models of trade readily generate tractable equations of demand for factors of production. In contrast, we recast the problem into one of supply and demand in product markets. This approach brings substantial advantages for our theory, estimation, and applications. On the theoretical side, it helps us shrink the space of sufficient elasticities in a wide class of trade models for conducting equilibrium policy analysis. Explicitly, we show how import demand and export supply fundamentals characterize the general equilibrium problem and are sufficient for counterfactual analysis as well as establishing uniqueness. As we transition to model estimation, it enables us to derive model-consistent export supply elasticities which allows us to apply robust data and methodology for estimating supply and demand. We then employ the model with estimated elasticities to provide new insight into recent US tariffs against China and the general equilibrium effects of trade policy more generally. Fundamentally, export supply governs pass-through rates from tariffs to consumers. We show that recent US tariffs are perfectly passed through to US consumers in partial equilibrium, but as the Chinese economy reallocates resources in general equilibrium it partially absorbs some of the effects of the tariff, and passthrough falls to around 70% on average.

The starting point of our analysis is to show that by recasting the general equilibrium into a product market supply and demand problem does not require one to know, or take a stand on, the individual supply-side elasticities governing the three microeconomic channels of the model (i.e., imperfect labor mobility, internal returns to scale, and external returns to scale). Under this reformulation, these three individual-level sets of elasticities collapse into two sets of composite elasticities that summarize the precise way they interact to move general equilibrium in response to policy. One of these composites is the elasticity of each industry's aggregate output to the average price of products within that industry, which we refer to as the *supply elasticity*. The other is the elasticity of each industry's aggregate price index to the average product-level price in that industry, referred to as the *aggregation elasticity*. On the demand side, our model allows for conventional within-industry elasticity of substitution across supplying countries through the *demand elasticity*. We show that these demand, supply, and aggregation elasticities, together with baseline observable market shares, are sufficient for conducting general equilibrium analysis in our unified framework, which in turn nests many commonly-used models of trade. Having shown this sufficiency result, we shift our attention from the underlying microeconomic channels to the above-mentioned demand, supply, and aggregation elasticities, which henceforth we refer to as the sufficient elasticities.

Central to how we bring our model to data is our derivation of *export supply elasticities*, which we show are determined by a nonlinear combination of supply, aggregation, and demand elasticities. The literature has relied on reduced-form specifications of export supply which are, despite all their practicalities, disconnected from general equilibrium theories. Our formula shows that the export supply elasticity for an exporter serving an import market is endogenous to the exporter's share of sales to that import market, and in addition only depends on the sufficient elasticities. By intersecting export supply and import demand, we then aim at estimating demand, supply, and aggregation elasticities, which provide us with all we need for quantitative equilibrium analysis.

In addition to shrinking the space of sufficient elasticities, our reformulation paves the way for estimating the full model. Consider an alternative approach whereby one would estimate the microeconomic channels of the model individually. Such a task would require detailed factor market data and an identification strategy that separately identifies labor mobility frictions and internal and external returns to scale. Since we are interested in the estimation across countries and industries, we would require data on factor allocations at the country-industry level, possibly over time, and an instrumental variable approach that separates factor mobility frictions from returns to scale within countries across industries. Simply put, detailed data of this sort are not broadly available for the majority of countries. Furthermore, we are not aware of an instrument that can separately identify labor mobility frictions from returns to scale, and the two types of returns to scale from each other.

Conversely, our method takes advantage of abundant data on international trade quantities and unit values in order to estimate supply and demand for product markets. We thus develop an estimator of supply and demand for every observable country and industry, which we bring to publicly accessible data on international trade, production, and tariffs. Specifically, we apply our methodology to data combining CEPII-BACI (trade flows), UNIDO (production), and MacMap (tariffs) from 1994-2017.

Our structural estimator builds upon heteroskedastic methods to identify supply and demand. Heteroskedastic estimators in the international trade literature have largely complemented the IV-based estimation procedures, and their resulting estimates have been used extensively across the literature. These methods, however, still lack a model-consistent export supply curve. This limitation has been in turn responsible for a gap between the welfare analysis in this empirical literature and general equilibrium applications. Our approach helps us address this gap. To do so, we describe how to rely on similar, but somewhat weaker, identification assumptions as employed by the literature in order to estimate model-consistent export supply curves.[1] As we mentioned, underlying export supply elasticities are demand, supply, and aggregation elasticities interacted with time-varying share of sales by an exporting country across purchasing markets. As a result, export supply elasticities are importer-exporter-industry specific under no sign restriction and vary over time with observed trade shares.

Before putting our estimates into quantitative applications, we compare them with the literature. Our import demand elasticities are broadly similar to those elsewhere. The two composite elasticities of supply and aggregation are specific to this paper, meaning that comparison with the literature is more subtle. We, hence, provide a consistent metric for such a comparison through the lens of the Arkolakis et al. (2012)'s (ACR) welfare formula. Specifically, the ratio of aggregation elasticity to supply elasticity controls the welfare impact of the cross-industry specialization beyond the classic ACR term. The supply-to-aggregation elasticity ratio, which we refer to as the *specialization* elasticity, collapses to the combined effect from scale elasticities under perfect labor mobility, and to the (negative) inverse of labor mobility elasticity under no scale economies. For almost all industry-country pairs, we find positive specialization elasticities, which means that, according to our estimates, returns to scale dominate labor mobility frictions across most country-industry pairs. In terms of magnitude, our specialization elasticities are lower than, but comparable across industries

[1] Since Feenstra (1994) heteroskedastic estimates of supply and demand in the international trade literature has relied on the assumption that the relative shifts of export supply and import demand are uncorrelated. The structure of our model allows us to unpack these shifters and demonstrate a weaker set of assumptions to establish consistency. Specifically, assuming supply and demand shocks are independent combined with (sensible) structure on supply and demand shocks individually is sufficient. The derivation of our result is presented in Appendix **1.6**.

to, scale elasticity estimates in recent studies that assume away from labor mobility frictions (c.f., Lashkaripour and Lugovskyy (2021) and Bartelme et al. (2021)).[2]

Equipped with our estimates of supply and demand, we provide a focused application through an analysis of the recent US-China trade war. We find Chinese industries to be particularly resilient to tariffs (i.e., fully pass through tariffs to imported prices) from the US when evaluated based on partial equilibrium analysis. The main reason is that, according to our estimates, export supply elasticities of Chinese products to the US are nearly perfectly elastic. This result confirms the recent findings of perfect pass-through to prices onto US consumers, e.g., Amiti et al. (2019)) and Fajgelbaum et al. (2020). However, trade policy is rarely limited to a single industry, and this episode is no exception. The breadth of tariffs suggest economy-wide tradeoffs as a country attempts to reallocate away from targeted industries. Our general equilibrium analysis highlights these mechanisms and provides interesting contrast to the partial equilibrium results. In general equilibrium, pass-through rates are almost complete if tariffs were imposed on an isolated Chinese industry. However, the application of tariffs by the US simultaneously against multiple Chinese manufacturing industries alters the outcome. In general equilibrium with broad tariffs, tariff pass-through falls to 70% for the average Chinese export. These quantitative results highlight strong tariff complementarities that are in line with recent theories of optimal policy, c.f. (Beshkar and Lashkaripour, 2020).

To be specific, when tariffs are applied simultaneously across all industries, general equilibrium complementarities effectively increase importer market power. Crucially, complementarities rely on the underlying parameters governing the costs of factor reallocation in the exporting country. Our formalization of export supply embodies these channels, which allows us to trace reallocations throughout the economy and quantify the effects on passthrough rates. Given our estimates, we find tariff complementarities drive down pass-through of tariffs by Chinese exporters from nearly 100% to only around 70% on average. Intuitively, under more comprehensive tariffs simultaneously applied by the US, China cannot readily allocate resources away from targeted industries. This inability to escape the policy effects is then absorbed by the exporter through a lowering of shipped prices in response to tariffs as export supply shifts and rotates.

The rest of the paper is organized as follows. The following section discusses related literature and our position therein in greater detail. Section 2 presents the model. There we derive export supply

[2] In addition, we conduct three exercises to put our estimates into perspective. First, we report the gains from trade as a vehicle to compare our model with benchmarks in the literature. Second, we leverage the channels embodied to export supply to more broadly decompose general equilibrium reallocations and welfare in response to trade liberalization. Third, we compute a series of quantitative exercises to identify industry-country pairs that feature weak or strong home market effects following Costinot et al. (2019).

elasticities, demonstrate sufficient elasticities for quantitative analyses, and compare them across several commonly used models nested by our framework. Section 3 shows how to structurally estimate the model. Section 4 applies our estimates to general equilibrium analyses and counterfactuals centered around recent US tariffs. Section 5 concludes.

Related Literature. This work contributes to several areas of the literature. First, this paper complements a large body of work that examines aggregate implications of micro-level mechanisms in general equilibrium trade models. In particular, our framework examines the impact of accounting for labor mobility frictions jointly with internal and external returns to scale in an international setting. Each of these mechanisms have only received independent consideration in the literature. Specifically see, Galle et al. (2021) for labor mobility frictions, Lashkaripour and Lugovskyy (2021) for internal returns, Bartelme et al. (2021) for external returns. In contrast to these papers, we examine and estimate the combined operation of these microeconomic channels. In doing so, our work builds on efforts to employ the sufficient statistic approach in trade-related equilibrium analysis, such as Dekle et al. (2007), Arkolakis et al. (2012), and more recently by Allen et al. (2020). Specifically, we show that by shifting the focus of analysis from factor markets to product markets we can target sufficient composites embodied by supply and demand rather than disentangling the individual micro-level elasticities from one another.

Second, we complement studies that employ heteroskedastic estimators, as inspired by Leamer (1981), applied originally to international trade by Feenstra (1994), and subsequently by Broda and Weinstein (2006) and Soderbery (2015). Recent efforts in this literature have improved existing methodologies to obtain richer welfare analyses. In doing so, for instance, Feenstra et al. (2018) estimate trade elasticities at different tiers of demand, Soderbery (2018) allows export supply elasticities to be heterogeneous across exporters, and Redding and Weinstein (2020) design an estimation procedure that exploits information in demand residuals. Our derivations, in turn, allow us to characterize the similarities and differences between the export supply curve stemming from general equilibrium structure and the reduced form partial equilibrium curves employed in the literature. We, therefore, bridge the gap between the analysis of welfare, policy, or pass-through of prices that have been traditionally approached with partial equilibrium estimates in this literature, and our structure that employs general equilibrium analysis.

Lastly, our paper is also related to a vast empirical literature on the impact of trade policy.[3]

[3] See Caliendo and Parro (2021) for a detailed survey of theoretical and empirical studies of trade policy.

Estimating trade elasticities, in particular, plays a pivotal role in quantifying the implications of trade policy for prices and welfare. In this regard, various studies use tariff changes as a source of exogenous variation or as an instrument to estimate import demand or export supply elasticities. For instance, to evaluate the impact of recent US-China trade war, Amiti et al. (2019) and Fajgelbaum et al. (2020) exploit recent changes to US tariffs. Since such an identification exploits tariff changes across industries between two time periods, its resulting elasticity estimates are likely not to have an adequate statistical power to identify industry-specific elasticities. Alternative approaches exploit tariff variation across countries at a given time period (c.f., Caliendo and Parro (2015)). These methods are also limited in the sense that they produce elasticity estimates that are not country-specific. In contrast, we structurally derive supply and demand elasticities which vary across industries and countries. Although our identification arguably requires a stronger stance on demand and supply residuals (i.e., residuals of import demand and export supply are independent over time), it has the benefit of delivering heterogeneous elasticities across both industries and countries. In particular, allowing for disaggregation in the product space and heterogeneity in export supply elasticities has significant impact on estimated pass-through rates of tariffs (c.f., Fajgelbaum and Khandelwal (2021) in the context of US-China trade war).

2 Theory

Here we construct a general equilibrium model of trade that incorporates all three microeconomic channels developed in isolation by the literature; labor mobility frictions, and both internal and external returns to scale. We will demonstrate how our model nests a wide class of new and old trade models by shutting down combinations of these channels. Beginning with Section **2.1**, we develop a framework that integrates a CES demand structure with supply-side channels of frictional labor mobility and scale economies that operate both internally and externally. In Section **2.2** we recast the model into one of supply and demand. Our derivations of (import) demand and (export) supply elasticities at the origin-destination-industry level provide unique insight into the mechanisms of the model. Section **2.3** characterizes the sufficient statistics, including our composite elasticities, for conducting general equilibrium policy analysis. In Section **2.4**, we show and discuss how our model nests several commonly-used models of trade. These sections in turn set the stage for our estimation.

2.1 Theoretical Framework

Environment. The global economy consists of multiple countries, indexed by i or $n \in N$, and multiple industries, indexed by $k \in K$. Labor is the only factor of production, and every country n is endowed by a given supply of L_n workers. In each industry, goods are differentiated by country of origin, and within each country by firms that produce differentiated products. Markets are characterized by monopolistic competition.

Preferences. The representative consumer in country n receives utility C_n as a Cobb-Douglas combination of aggregate industry level goods,

$$C_n = \prod_{k \in K} C_{n,k}^{\beta_{n,k}},$$

where $\beta_{n,k}$ is the expenditure share in n on industry k with $\sum_{k \in K} \beta_{n,k} = 1$. The industry-level composite $C_{n,k}$ aggregates varieties that are differentiated by origin countries in a CES fashion:

$$C_{n,k} = \Big[\sum_{i \in N} b_{ni,k}^{\frac{1}{\sigma_{n,k}}} C_{ni,k}^{\frac{\sigma_{n,k}-1}{\sigma_{n,k}}} \Big]^{\frac{\sigma_{n,k}}{\sigma_{n,k}-1}},$$

where $C_{ni,k}$ denotes consumption quantity of origin variety i. The Armington (1969) elasticity of substitution between country-level varieties within industry k in the eyes of consumers in market n is denoted by $\sigma_{n,k}$. We allow for a variety level demand shifter $b_{ni,k}$ that is importer-exporter-industry specific. Lastly, firms (or equivalently, products) within origin country i are denoted by ϖ. The variety level composite $C_{ni,k}$ is a CES aggregation across shipped quantities of product ϖ in industry k from origin i to market n,

$$C_{ni,k} = \Big[\int_{\varpi \in \Omega_{in,k}} C_{ni,k}(\varpi)^{\frac{\eta_{i,k}-1}{\eta_{i,k}}} d\varpi \Big]^{\frac{\eta_{i,k}}{\eta_{i,k}-1}}.$$

Here, $\Omega_{ni,k}$ is the set of products sold from origin-industry (i, k) to market n, and $\eta_{i,k}$ is the elasticity of substitution across products within industry k in country i. This demand system is standard in the literature. To get a brief sense of its positioning, when $\sigma_{n,k} = \eta_{i,k} = \bar{\sigma}_k$, varieties of every industry k are differentiated to the same extent across supplying countries and across products within a supplying country as in a standard multi-sector Krugman (1980) model. Alternatively, when varieties are perfect substitutes, $\eta_{i,k} \to \infty$, the demand system collapses to a standard Armington (1969) model such as Anderson and Wincoop (2003).

Resource Allocation across Industries. Workers are imperfectly mobile across industries and immobile across countries. A worker φ in country i is endowed by a vector of efficiency units $(z_{i,1}(\varphi)e_{i,1}, ...z_{i,k}(\varphi)e_{i,k}, ..., z_{i,K}(\varphi)e_{i,K})$ across industries. $z_{i,k}(\varphi)$ is a random variable drawn independently from a Fréchet distribution with dispersion parameter $\varepsilon_i > 1$, and a scale parameter normalized to ensure $\mathbb{E}[z_{i,k}e_{i,k}] = e_{i,k}$.[4] For each country i, we denote industry k's wage per unit of efficiency by $w_{i,k}$. The share of workers who select industry k is given by $L_{i,k}/L_i = e_{i,k}w_{i,k}^{\varepsilon_i}\Phi_i^{-\varepsilon_i}$, where

$$\Phi_i \equiv \Big[\sum_{k\in K} e_{i,k}w_{i,k}^{\varepsilon_i}\Big]^{1/\varepsilon_i}. \tag{1}$$

Aggregate efficiency units supplied to country-industry (i,k) are given by $E_{i,k} = L_i\Phi_i^{1-\varepsilon_i}e_{i,k}w_{i,k}^{\varepsilon_i-1}$. The elasticity of labor mobility across industries with respect to wage per unit of efficiency is governed by ε_i. To provide some insight, if $\varepsilon_i \to \infty$, then the variance of efficiency draws across industries for a worker converges to zero. As such, the model collapses to one with perfect labor mobility. In the other extreme, as $\varepsilon_i \to 1$, our framework collapses to a specific factor model in which efficiency units employed in every industry is inelastically given. Lastly, total income in country i equals total payments to workers, $\Sigma_k w_{i,k}E_{i,k} = L_i\Phi_i$, and Φ_i is thus income per capita.

Wedges, and Returns to Scale. Total units of efficiency required to produce $q_{ni,k}(\varpi)$ units of product ϖ of variety (i,k) to be delivered at market n are such that $q_{ni,k}(\varpi) = \frac{d_{ni,k}q_{ni,k}(\varpi)}{A_{i,k}} + f_{ni,k}$, where $d_{ni,k} \geq 1$ is the standard iceberg trade cost.[5] Productivity in country-industry (i,k) is denoted as $A_{i,k}$, and depends on an exogenous productivity shifter $a_{i,k}$ along with total efficiency units employed there $E_{i,k}$, such that,

$$A_{i,k} = a_{i,k}E_{i,k}^{\phi_{i,k}}.$$

Here, $\phi_{i,k}$ governs the extent to which the scale of industry k affects productivity of a firm in that industry. We allow this elasticity to vary by industry and country. Since a firm does not internalize the effect of its production on the industry-level aggregates, every firm takes $A_{i,k}$ as given.

[4]Specifically, $\Pr(z_{i,k}(\varphi) \leq z_{i,k}) = \exp(-\mu_i z_{i,k}^{-\varepsilon_i})$ where without loss of generality μ_i is normalized at $\Gamma(1 + 1/\varepsilon_i)$, with Γ denoting the gamma function.

[5]Trade costs satisfy the triangle inequality and they are normalized such that $d_{ii,k} = 1$.

International trade is subject to standard iceberg trade costs, $d_{ni,k}$, and import tariffs, $t_{ni,k}$. We denote by $\tau_{ni,k} = d_{ni,k}(1+t_{ni,k})$ as the wedge between price at the location of production (i), and that of consumption (n). Since firms are symmetric within country-industry, they charge the same price to each destination, such that product-level prices inclusive of tariffs ($p_{ni,k}$) are:

$$p_{ni,k} \equiv p_{ni,k}(\varpi) = \frac{\eta_{i,k}}{\eta_{i,k}-1}\frac{\tau_{ni,k}w_{i,k}}{a_{i,k}E_{i,k}^{\phi_{i,k}}} \quad \forall \quad \varpi \in \Omega_{ni,k}.$$

Holding wages fixed and supposing $\phi_{i,k} > 0$, prices are decreasing in the industry-level of employed efficiency units $E_{i,k}$, reflecting *external returns to scale*. $E_{i,k}$ itself depends on wages through labor supply. Combining, we can connect product-level prices to wages as,

$$p_{ni,k} = \frac{\eta_{i,k}/(\eta_{i,k}-1)}{a_{i,k}(L_i\Phi_i^{1-\varepsilon_i}e_{i,k})^{\phi_{i,k}}}\tau_{ni,k}w_{i,k}^{1-(\varepsilon_i-1)\phi_{i,k}}. \tag{2}$$

A higher wage (i) increases the price directly through the marginal cost, and (ii) decreases the price indirectly due to external scale economies. The latter dominates the former if and only if $(\varepsilon_i - 1)\phi_{i,k} > 1$. Therefore, we see how external returns to scale mediate how wages are passed through to product-level prices in general equilibrium.

Additionally, the number of firms in each country i that produce differentiated products in industry k is pinned down by the free entry condition, amounting to $M_{i,k} = E_{i,k}/(\eta_{i,k}F_{i,k})$ where $F_{i,k} = \Sigma_{n\in N} f_{ni,k}$ aggregates exporting fixed costs. A greater number of firms in an industry scales up the aggregate supply of the industry reflecting *internal returns to scale*. These internal returns are stronger within a country-industry pair when products are more differentiated. Specifically, industries with lower $\eta_{i,k}$, will exhibit a greater number of products ($M_{i,k}$), all else equal.

The value of gross output of industry k in country i, $Y_{i,k}$, and its revenue share, $r_{i,k}$, are then;

$$\begin{aligned} Y_{i,k} &= L_i\Phi_i^{1-\varepsilon_i}e_{i,k}w_{i,k}^{\varepsilon_i} \\ r_{i,k} &\equiv \frac{Y_{i,k}}{\sum_k Y_{i,k}} = e_{i,k}w_{i,k}^{\varepsilon_i}\Phi_i^{-\varepsilon_i}. \end{aligned} \tag{3}$$

As intended, supply side behavior is characterized by three microeconomic channels, which are disciplined by the elasticity of labor mobility (ε_i), the degree of internal returns to scale ($1/(\eta_{i,k}-1)$), and that of external returns to scale ($\phi_{i,k}$).

Price Indices and Trade Shares. The price indices associated with consumption aggregates $C_{ni,k}$, $C_{n,k}$ and C_n are:

$$P_{ni,k} = M_{i,k}^{\frac{1}{1-\eta_{i,k}}} p_{ii,k} \tau_{ni,k} \qquad \text{Variety Level Price Index} \tag{4}$$

$$P_{n,k} = \left(\sum_{i \in N} b_{ni,k} P_{ni,k}^{1-\sigma_{n,k}} \right)^{1/(1-\sigma_{n,k})} \qquad \text{Industry Level Price Index} \tag{5}$$

$$P_n = \prod_{k \in K} P_{n,k}^{\beta_{n,k}} \qquad \text{Country Level Price Index} \tag{6}$$

The share of expenditure of destination n on origin i in industry k, denoted by $\pi_{ni,k}$, equals

$$\pi_{ni,k} = b_{ni,k} \Big(P_{ni,k} / P_{n,k} \Big)^{1-\sigma_{n,k}}. \tag{7}$$

Recasting to Product Markets. At this point the standard treatment of this class of models would launch into closing the model through factor market clearing conditions to study aggregate implications of the microeconomics channels. We suspend such analysis for the time being in order to provide an alternative perspective by recasting the model as one of supply and demand in product markets. Looking ahead, simultaneously estimating the microeconomic channels through factor market (re)allocations is hindered by the scarcity of reliable disaggregated wage and employment data across industries and countries. That is to say, with the appropriate set of assumptions and instrumental variables for each analysis, one could approach estimation through a mixture of gravity style analysis to estimate $\sigma_{n,k}$ and detailed disaggregated data on production and employment in order to separately estimate the micro channels of the model governing returns to scale $(\phi_{i,k}, \eta_{i,k})$ and labor mobility (ε_i). However, we are unaware of a methodology or data set that can jointly identify these parameters across many countries and industries.

In contrast, data on prices and quantities in product markets are abundant in international trade. Moreover, we show that recasting the model as one of product market supply and demand is a useful tool to locate sufficient elasticities required to perform comparative statics analysis. We show sufficient elasticities that emerge from this novel approach constitute a smaller set of parameters than the set of $\{\sigma_{i,k}, \phi_{i,k}, \eta_{i,k}, \varepsilon_i\}$ because they encapsulate the interactions between the microeconomic channels that determine aggregate equilibrium outcomes in response to shocks.

Consider a destination-origin-industry triple (n, i, k). Let $D_{ni,k}$ denote import demand of n from

i in industry k, and let $S_{ni,k}$ denote export supply of i to n in industry k.[6] The model delivers:

$$\begin{aligned} D_{ni,k} &= \pi_{ni,k}\beta_{n,k}X_n && (8) \\ S_{ni,k} &= Y_{i,k} - \sum_{m\neq n} D_{mi,k}. && (9) \end{aligned}$$

Total expenditure in country n, X_n, is the sum of wage incomes, tariff revenues, and trade deficits, which is a fraction ν_n of wage incomes. As such,

$$X_n = L_n\Phi_n(1+\nu_n) + \sum_{i,k} t_{ni,k}D_{ni,k}. \quad (10)$$

An equilibrium consists of the vector of product-level prices $\mathbf{p} = [p_{ii,k}]_{i=1,k=1}^{N,K}$ such that Equations (1)-(10) hold, and *product* market clearing conditions hold for all n, i, k,[7]

$$D_{ni,k}(\mathbf{p}) = S_{ni,k}(\mathbf{p}). \quad (11)$$

Throughout the paper, to distinguish between export supply or import demand schedules and their intersections as equilibrium values of trade, we denote by $X_{ni,k}$ the equilibrium values of trade occurring when $X_{ni,k} = S_{ni,k} = D_{ni,k}$.

2.2 Import Demand and Export Supply: Demand, Supply, and Aggregation Elasticities

In this section, we derive export supply and import demand elasticities in general equilibrium. We first turn to characterizing the export supply schedule, whose value for industry k from origin i to destination n equals total supply of (i,k) net of sales to all markets except n. The challenge will be understanding export supply schedules both at and off equilibrium. First, we express total supply of industry k from origin i, as given by Equation (3), as a function of wages such that, $Y_{i,k} = L_i\Phi_i^{1-\varepsilon_i}e_{i,k}w_{i,k}^{\varepsilon_i}$. Replacing wage $w_{i,k}$ by its corresponding product price $p_{ii,k}$ using Equation (2),

[6] Note, our use of the terminology import and export also includes domestic purchases in case of $n = i$.

[7] An equilibrium in product markets implies equilibrium in labor markets and the other way around. Let $\mathbf{w} = [w_{i,k}]_{i=1,k=1}^{N,K}$. We can replace wage and price for each other using Equation (2), which is a one-to-one relationship provided that equilibrium is unique. Then, demand and supply for products in country-industry (i,k) are equal if and only if they do so for labor there:

$$D_{ni,k}(\mathbf{p}) = S_{ni,k}(\mathbf{p}) \Leftrightarrow D_{ni,k}(\mathbf{p}) = Y_{i,k}(\mathbf{p}) - \sum_{m\neq n} D_{mi,k}(\mathbf{p}) \Leftrightarrow \sum_{m=1}^{N} D_{mi,k}(\mathbf{p}) = Y_{i,k}(\mathbf{p}) \Leftrightarrow \sum_{m=1}^{N} D_{mi,k}(\mathbf{w}) = Y_{i,k}(\mathbf{w})$$

total production as a function of product-level price at the location of production $p_{ii,k}$ equals:

$$Y_{i,k} = y_{i,k} p_{ii,k}^{\omega_{i,k}^{(1)}},$$

where $y_{i,k}$ is the non-price component of total production.[8] The *supply elasticity* is denoted by $\omega_{i,k}^{(1)}$, and is defined as the elasticity of industry-level output $Y_{i,k}$ with respect to the average product-level price $p_{ii,k}$,

$$\omega_{i,k}^{(1)} \equiv \frac{\partial \ln Y_{i,k}}{\partial \ln p_{ii,k}} = \frac{\varepsilon_i}{1-(\varepsilon_i-1)\phi_{i,k}}. \tag{12}$$

Next, we use Equations (7) and (8) to express import demand of market n in industry k from producer country i as $D_{ni,k} = \delta_{ni,k} P_{ii,k}^{1-\sigma_{n,k}}$, where $\delta_{ni,k}$ combines all variables that shift this demand schedule. This expression simply falls from the CES demand that aggregates country-level varieties in each industry. Our goal, however, is to express export supply and import demand as functions of product-level prices. Invoking Equation (4), we can express the demand schedule accordingly as:

$$D_{ni,k} = \delta_{ni,k} p_{ii,k}^{(1-\omega_{i,k}^{(2)})(1-\sigma_{n,k})}, \tag{13}$$

where $(1-\omega_{i,k}^{(2)})$ denotes the elasticity of the aggregate price index at the location of production ($P_{ii,k}$) with respect to average product-level price there ($p_{ii,k}$), which we henceforth refer to as the *aggregation elasticity.* This aggregation elasticity $\omega_{i,k}^{(2)}$ is defined formally as:

$$\omega_{i,k}^{(2)} \equiv 1 - \frac{\partial \ln P_{ii,k}}{\partial \ln p_{ii,k}} = \frac{(\varepsilon_i-1)}{1-(\varepsilon_i-1)\phi_{i,k}} \frac{1}{(\eta_{i,k}-1)}. \tag{14}$$

In turn, Equation (13) readily delivers the elasticity of imports ($D_{ni,k}$) with respect to average product-level price ($p_{ni,k}$), which we denote by $\omega_{ni,k}^{(D)}$,[9]

$$\omega_{ni,k}^{(D)} \equiv \frac{\partial \ln D_{ni,k}}{\partial \ln p_{ni,k}} = (1-\omega_{i,k}^{(2)})(1-\sigma_{n,k}). \tag{15}$$

Fundamentally, export supply is excess supply. That is to say, total output less exports to all

[8] A detailed derivation of the equations in this section is reported in Appendix A.

[9] Note that $\frac{\partial \ln D_{ni,k}}{\partial \ln p_{ni,k}} = \frac{\partial \ln D_{ni,k}}{\partial \ln p_{ii,k}} / \frac{\partial \ln p_{ni,k}}{\partial \ln p_{ii,k}}$ where the denominator equals one because trade costs are multiplicative. If instead trade costs were additive, we would need to extend the model to take into account a nontrivial relationship between $P_{ni,k}$ and $P_{ii,k}$ (c.f., Atkin and Donaldson (2015)). The same caveat applies to our derivation of export supply elasticity.

other destinations defines export supply. Following this definition, we can express export supply as:

$$\begin{aligned} S_{ni,k} &\equiv Y_{i,k} - \sum_{m\neq n} D_{mi,k} \\ &= y_{i,k} p_{ii,k}^{\omega_{i,k}^{(1)}} - \sum_{m\neq n} \delta_{mi,k} p_{ii,k}^{(1-\omega_{i,k}^{(2)})(1-\sigma_{m,k})}. \end{aligned} \tag{16}$$

We now turn to deriving the export supply elasticity, which we denote by $\omega_{ni,k}^{(S)}$. We are particularly interested in how industry-level exports from i to n change in response to a change in the product-level price charged by firms in industry k. We must again emphasize that an econometrician does not observe the model-implied industry-level price index ($P_{ni,k}$), which is why we express demand and supply as functions of product-level prices ($p_{ni,k}$). In addition, we note that general equilibrium models of trade directly deliver export supply in an explicit form only at equilibrium by way of intersecting it with import demand. Deriving the export supply elasticity, however, requires us to characterize how export supply operates off the equilibrium point. To this end, we can use Equation (16) to derive the following expression:

$$\omega_{ni,k}^{(S)} \equiv \frac{\partial \ln S_{ni,k}}{\partial \ln p_{ni,k}} = \frac{\omega_{i,k}^{(1)} Y_{i,k} - \sum_{m\neq n}(1-\omega_{i,k}^{(2)})(1-\sigma_{m,k}) D_{mi,k}}{Y_{i,k} - \sum_{m\neq n} D_{mi,k}}. \tag{17}$$

Equation (17) presents the slope of log export supply as a function of log product-level price for movements along the curve. Interpreting observed data as the baseline equilibrium of our model, we can then derive the slope of log export supply based on a local change from the baseline equilibrium point (the intersection of export supply and import demand, $D_{ni,k} = S_{ni,k} = X_{ni,k}$) to an off-equilibrium point along the export supply curve. To do so, let $\lambda_{ni,k} \equiv {}^{S_{ni,k}}/_{Y_{i,k}}$ be the share of sales of origin i to destination n in industry k, which we will refer to as *export penetration*.[10] In the baseline equilibrium, export supply equals import demand, $S_{ni,k} = D_{ni,k} = X_{ni,k}$, and so $Y_{i,k} - \Sigma_{m\neq n} X_{mi,k} = X_{ni,k}$. Therefore,

$$\frac{Y_{i,k}}{(Y_{i,k} - \sum_{m\neq n} X_{mi,k})} = \frac{1}{\lambda_{ni,k}} \qquad \text{and} \qquad \frac{X_{mi,k}}{(Y_{i,k} - \sum_{m\neq n} X_{mi,k})} = \frac{\lambda_{mi,k}}{\lambda_{ni,k}}.$$

Now we can rewrite the export supply elasticity as a function of export penetration and elasticity

[10] In contrast, $\pi_{ni,k} = \frac{D_{ni,k}}{\sum_i D_{ni,k}}$ denotes the share of expenditures of destination n on origin i in industry k, which we refer to as *import penetration*.

parameters of demand, supply, and aggregation, $(\sigma_{n,k}, \omega_{i,k}^{(1)}, \omega_{i,k}^{(2)})$,

$$\omega_{ni,k}^{(S)} = \frac{1}{\lambda_{ni,k}}\omega_{i,k}^{(1)} - \sum_{m\neq n}\frac{\lambda_{mi,k}}{\lambda_{ni,k}}(1-\omega_{i,k}^{(2)})(1-\sigma_{m,k}). \tag{18}$$

The export supply elasticity is an endogenous object rather than a given parameter, as it depends on the relative importance of market n to i's sales (i.e., export penetration $\lambda_{ni,k}$). Immediately, export supply curves are more elastic in smaller destinations, and perfectly elastic as $\lambda_{ni,k} \to 0$ leads to $\omega_{ni,k}^{(S)} \to \infty$. Effectively, this is the relevant assumption underlying a small open economy imposed in much of the trade and international macroeconomics literature. Intuitively, if n's consumption of industry k is negligible relative to the global consumption of industry k, shocks to n's imports do not tangibly impact global markets.[11]

Controlling for export penetration $(\lambda_{ni,k})$, the export supply elasticity $(\omega_{ni,k}^{(S)})$ thus contains information about changes to; (1) total industry-level supply $Y_{i,k}$, whose response is controlled by $\omega_{i,k}^{(1)}$ weighted by the inverse of export penetration, and (2) sales elsewhere, whose response is summarized by a weighted sum of import demand elasticities $(1-\sigma_{m,k})$ multiplied by the aggregation elasticity $(1-\omega_{i,k}^{(2)})$ with corresponding weights given by export shares of all markets $m \neq n$ relative to n $(\lambda_{mi,k}/\lambda_{ni,k})$. The former shows that an exporter reacts to a higher price in industry k by reallocating resources to that industry. The latter describes how other markets react to a higher price in k by altering their purchase from that industry.

In addition, export supply can be downward sloping due to (i) the interaction between the trade elasticity $(1-\sigma_{m,k})$ and aggregation elasticity $(1-\omega_{i,k}^{(2)})$, and (ii) the interaction between the elasticity that governs external returns $(\phi_{i,k})$ and the one that governs imperfections in factor mobility (ε_i). Costinot et al. (2019) describe this feature of supply in the presence of returns to scale. Our model nests the models they discuss, but adds considerable richness through heterogeneity and an explicit formulation of export supply. We can thus decompose the mechanisms across various dimensions.

For instance, notice interactions between external returns and factor mobility frictions are fully captured by the supply elasticity $(\omega_{i,k}^{(1)})$, which can be negative if returns to scale dominate factor mobility frictions (i.e., $\phi_{i,k} > 1/(\varepsilon_i - 1)$). Similarly, the aggregation elasticity $(1-\omega_{i,k}^{(2)})$ summarizes nontrivial interactions between internal and external scale economies and labor mobility, and can be in principle negative or positive. All interactions captured by $(1-\omega_{i,k}^{(2)})$ will be shut down if products within an industry are perfectly substitutable (i.e., $\eta_{i,k} \to \infty$). In this special case, the aggregation

[11] As a complementary approach, we also derive the export supply elasticity using the method of hat algebra which allows us to trace the change in exports when a demand shock shifts import demand curve. See Appendix **1.2.3** for details.

elasticity collapses to unity (i.e., $\omega^{(2)}_{i,k} \to 0$), reflecting that the aggregate price index is the same as the product-level price.

Two implications of our approach as they pertain to empirical applications are immediately worth emphasizing. First, since the export supply elasticity $\omega^{(S)}_{ni,k}$ is endogenous, we will need to estimate the set $(\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{i,k})$ of parameters, which in turn will generate the export supply elasticity evaluated at observed trade shares. Second, for general equilibrium analyses we can entirely bypass the need for individual micro-level elasticities $(\phi_{i,k}, \eta_{i,k}, \varepsilon_i, \sigma_{i,k})$ and rely on the set $(\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{i,k})$. Next, we formalize this sufficiency result.

2.3 Sufficient Elasticities for General Equilibrium Analysis

Recasting the model as one of supply and demand in the product markets proves useful for shrinking the space of sufficient elasticities for general equilibrium analysis. We illustrate this claim by characterizing the precise set of data and parameters required to perform counterfactual policy analysis.

For a generic variable x, let $\widehat{x} \equiv x'/x$ denote the ratio of its corresponding value x' in a new equilibrium to that of the baseline equilibrium x. Consider a set of shocks, or "policy," as changes to iceberg trade costs $d_{nik,}$ and tariffs $t_{ni,k}$, along with productivity and demand shifters, $\mathscr{P} = \left\{\widehat{d}_{ni,k}, \widehat{t}_{ni,k}, \widehat{a}_{i,k}, \widehat{\beta}_{n,k}, \widehat{b}_{ni,k}\right\}$. We specify baseline equilibrium values as $\mathscr{B} = \left\{X_n, \nu_n, Y_{n,k}, t_{ni,k}, X_{ni,k}\right\}$. Note that the baseline trade shares equal $\pi_{ni,k} = {}^{X_{ni,k}}/_{\sum_\ell X_{n\ell,k}}$, and changes to trade costs are given by $\widehat{\tau}_{ni,k} = \widehat{d}_{ni,k}(1 + \widehat{t}_{ni,k} t_{ni,k})/(1 + t_{ni,k})$. Then, given a policy $\mathscr{P}$, baseline values $\mathscr{B}$, and the set of parameters $\{\omega^{(1)}_{i,k},\ \omega^{(2)}_{i,k},\ \sigma_{n,k}\}$, a general equilibrium in changes consists of changes to product-level prices $\widehat{p}_{ii,k}$, such that Equations (19)–(24) hold:

$$\widehat{Y}_{i,k} = \widehat{a}_{i,k}^{\omega^{(1)}_{i,k}} \widehat{\Phi}_i^{1-\omega^{(1)}_{i,k}} \widehat{p}_{ii,k}^{\omega^{(1)}_{i,k}} \qquad \text{(Supply)} \qquad (19)$$

$$\widehat{\Phi}_i = \frac{\sum_{k\in K} \widehat{Y}_{i,k} Y_{i,k}}{\sum_{k\in K} Y_{i,k}} \qquad \text{(Income per worker)} \qquad (20)$$

$$\widehat{X}_n X_n = (1+\nu_n) \sum_k \widehat{Y}_{n,k} Y_{n,k} + \sum_i \sum_k \frac{\widehat{t}_{ni,k} t_{ni,k}}{1 + \widehat{t}_{ni,k} t_{ni,k}} \widehat{X}_{ni,k} X_{ni,k} \qquad \text{(Total expenditure)} \qquad (21)$$

$$\widehat{P}_{ni,k} = \widehat{a}_{i,k}^{-\omega^{(2)}_{i,k}} \widehat{\Phi}_i^{\omega^{(2)}_{i,k}} \widehat{p}_{ii,k}^{1-\omega^{(2)}_{i,k}} \widehat{\tau}_{ni,k} \qquad \text{(Price index)} \qquad (22)$$

$$\widehat{X}_{ni,k} = \frac{\widehat{b}_{ni,k} \widehat{P}_{ni,k}^{1-\sigma_{n,k}}}{\sum_{\ell \in N} \pi_{n\ell,k} \widehat{b}_{n\ell,k} \widehat{P}_{n\ell,k}^{1-\sigma_{n,k}}} \widehat{\beta}_{n,k} \widehat{X}_n \qquad \text{(Trade flows)} \qquad (23)$$

$$Y_{i,k} \widehat{Y}_{i,k} = \sum_{n\in N} \frac{1}{1 + \widehat{t}_{ni,k} t_{ni,k}} X_{ni,k} \widehat{X}_{ni,k} \qquad \text{(Market clearing)} \qquad (24)$$

Provided that baseline values $\mathscr{B}$ are observed and Equations (19)–(24) have a solution, the set of supply, aggregation and demand elasticities $\{\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{n,k}\}$ are sufficient for quantifying the full vector of equilibrium changes to prices, trade flows, revenues, and expenditures $\{\widehat{p}_{ii,k}, \widehat{P}_{ni,k}, \widehat{X}_{ni,k}, \widehat{Y}_{i,k}, \widehat{\Phi}_i, \widehat{X}_n\}$ in response to any policy $\mathscr{P}$. In particular, once $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$ are known, one does not require estimates of the microeconomic elasticities governing labor mobility (ε_i), external ($\phi_{i,k}$) or internal ($\eta_{i,k}$) economies of scale to perform counterfactuals.[12]

In turn, the corresponding change to welfare for every country n equals:

$$\widehat{W}_n = \underbrace{\prod_k \widehat{\pi}_{nn,k}^{-\frac{\beta_{n,k}}{\sigma_{n,k}-1}}}_{\widehat{TR}} \underbrace{\prod_k \widehat{r}_{n,k}^{\frac{\beta_{n,k}\left(\omega^{(2)}_{n,k}-1\right)}{\omega^{(1)}_{n,k}}}}_{\widehat{SP}}. \tag{25}$$

Here, the change to domestic expenditure share $\widehat{\pi}_{nn,k}$ and revenue share $\widehat{r}_{n,k}$ can be generically obtained from the solution to Equations (19)–(24).[13] Expenditure shares $\beta_{n,k}$ are given by the upper tier Cobb-Douglas demand specification, and the three sufficient elasticities are of demand, supply, and aggregation $(\sigma_{nk}, \omega^{(1)}_{n,k}, \omega^{(2)}_{n,k})$. The first component ($\widehat{TR}$), which we call the *trade channel*, is governed by $\widehat{\pi}_{nn,k}$ and ${}^{\beta_{n,k}}/_{(\sigma_{n,k}-1)}$, and has been studied extensively in the literature beginning with Arkolakis et al. (2012). The second component ($\widehat{SP}$), which we call the *specialization channel*, has been relatively less studied. It equals the geometric weighted average of the change to each industry's revenue share $\widehat{r}_{n,k}$ with the corresponding weight $\beta_{n,k}(\omega^{(2)}_{n,k} - 1)/\omega^{(1)}_{n,k}$. We refer to the ratio $(\omega^{(2)}_{n,k} - 1)/\omega^{(1)}_{n,k}$ as *specialization elasticity*, which governs the response from total supply of each industry and the impact of resource reallocations on welfare.

Given the flexibility provided by our sufficiency statement, we continue by examining $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$ across existing models by way of dissecting the elements that form these elasticities.[14] We high-

[12] We present equations that more classically define equilibrium in changes with respect to wages $\{w_{i,k}\}$ in Appendix **1.1**. We compute the model equilibrium according to numerical algorithms described in Appendix **1.5**. The algorithm readily handles multiple strategies. Our main method solves the model through supply and demand. Given $\{\phi_{i,k}, \eta_{i,k}, \varepsilon_i\}$, we can calculate $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$, then compute equilibrium in changes using Equations (19)–(24). Alternatively, we can solve for wages $w_{i,k}$ using $\{\phi_{i,k}, \eta_{i,k}, \varepsilon_i, \sigma_{n,k}\}$ then compute equilibrium in changes using Equations (A.2)–(A.6). We confirm that the two exercises produce exactly the same aggregate equilibrium variables.

[13] Specifically,

$$\widehat{\pi}_{ni,k} = \frac{\widehat{X}_{ni,k} X_{ni,k}}{\sum_{\ell \in N} \widehat{X}_{n\ell,k} X_{n\ell,k}}, \qquad \widehat{r}_{n,k} = \frac{\widehat{Y}_{n,k} Y_{n,k}}{\sum_{k \in K} \widehat{Y}_{n,k} Y_{n,k}}$$

[14] In addition, we show the conditions by which the general equilibrium is unique. Specifically, we show that $(1 - \sigma_{n,k})(1 - \omega^{(2)}_{i,k})/\omega^{(1)}_{i,k}) \leq 1$ serves as the uniqueness condition in our model. This result is in line with the analytic results developed by Kucheryavyy et al. (2021) if we were to substitute in the definitions of $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$. As such, $\{\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{n,k}\}$ is not only sufficient for quantitative policy analysis, but also determines conditions for the uniqueness of equilibrium in our model.

light how differences in underlying channels translate into implications for export supply elasticity. Dissecting the model mechanisms will inform our empirical methodology to follow in Section **3**.

2.4 Discussion: Across Model Comparisons

To collect intuition linking the sufficient elasticities to the microeconomic channels of the model, here we spell out forces at work behind $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$ in simpler models nested within ours. Table 1 selects a few prominent models from the literature for explicit analysis.[15]

Table 1: Supply, Aggregation, and Specialization Elasticities Across Models

Model	Parameters	$\omega^{(1)}_{i,k}$	$\omega^{(2)}_{i,k}$	$\frac{\omega^{(2)}_{i,k}-1}{\omega^{(1)}_{i,k}}$
(1) Multi-sector Armington[(a)]	$\varepsilon_i \to \infty$, $\eta_{i,k} \to \infty$, $\phi_{i,k} = 0$	∞	0	0
(2) + ext econ[(b)]	$\varepsilon_i \to \infty$, $\eta_{i,k} \to \infty$, $\phi_{i,k} > 0$	$\frac{-1}{\phi_{i,k}}$	0	$\phi_{i,k}$
(3) + imp mob[(c)]	$\varepsilon_i > 1$, $\eta_{i,k} \to \infty$, $\phi_{i,k} = 0$	ε_i	0	$\frac{-1}{\varepsilon_i}$
(4) + imp mob + ext econ	$\varepsilon_i > 1$, $\eta_{i,k} \to \infty$, $\phi_{i,k} > 0$	$\frac{\varepsilon_i}{1-(\varepsilon_i-1)\phi_{i,k}}$	0	$\frac{-1}{\varepsilon_i} + \frac{\varepsilon_i-1}{\varepsilon_i}\phi_{i,k}$
(5) Multi-sector Krugman	$\varepsilon_i \to \infty$, $\eta_{i,k} = \sigma_{nk} = \bar{\sigma}_k$, $\phi_{i,k} = 0$	∞	∞	$\frac{1}{\bar{\sigma}_k-1}$
(6) + nested CES[(d)]	$\varepsilon_i \to \infty$, $\eta_{i,k} = \bar{\eta}_k \neq \sigma_{nk} = \bar{\sigma}_k$, $\phi_{i,k} = 0$	∞	∞	$\frac{1}{\bar{\eta}_k-1}$
(7) + ext econ	$\varepsilon_i \to \infty$, $\eta_{i,k} = \sigma_{nk} = \bar{\sigma}_k$, $\phi_{i,k} > 0$	$\frac{-1}{\phi_{i,k}}$	$\frac{-1}{\phi_{i,k}(\bar{\sigma}_k-1)}$	$\frac{1}{\bar{\sigma}_k-1} + \phi_{i,k}$
(8) + imp mob	$\varepsilon_i > 1$, $\eta_{i,k} = \sigma_{nk} = \bar{\sigma}_k$, $\phi_{i,k} = 0$	ε_i	$\frac{\varepsilon_i-1}{\bar{\sigma}_k-1}$	$\frac{-1}{\varepsilon_i} + \frac{\varepsilon_i-1}{\varepsilon_i}\frac{1}{\bar{\sigma}_k-1}$
(9) + imp mob + ext econ	$\varepsilon_i > 1$, $\eta_{i,k} = \sigma_{nk} = \bar{\sigma}_k$, $\phi_{i,k} > 0$	$\frac{\varepsilon_i}{1-(\varepsilon_i-1)\phi_{i,k}}$	$\frac{\varepsilon_i-1}{1-(\varepsilon_i-1)\phi_{i,k}}\frac{1}{\bar{\sigma}_k-1}$	$\frac{-1}{\varepsilon_i} + \frac{\varepsilon_i-1}{\varepsilon_i}\left(\frac{1}{\bar{\sigma}_k-1} + \phi_{i,k}\right)$

Notes: We abbreviate imperfect labor mobility as "imp mob", and external economies of scale as "ext econ". The letter labels in parentheses report that the corresponding model aggregates are isomorphic to (a) Costinot et al. (2012) (b) Kucheryavyy et al. (2021). (c) Galle et al. (2021) (d) Lashkaripour and Lugovskyy (2021).

First, consider a class of multi-sector Armington models in which products within every pair of industry-country are perfectly substitutable with one another, as $\eta_{ik} \to \infty$. This class of models is isomorphic to multi-industry versions of Eaton and Kortum (2002).[16] In those models, there are no internal returns to scale, and the aggregation elasticity $(1-\omega^{(2)}_{i,k})$ is necessarily unity. Put another way, models without within-industry product differentiation do not generate direct export supply linkages

[15] Notice, since we have defined export supply elasticities in terms of *value* of exports with respect to price, an elasticity of unity means that *quantity* of exports remains unchanged with respect to a price change.

[16] We can replace Armington in the table with EK (i.e., Eaton and Kortum (2002)) keeping in mind that the trade elasticity $(\sigma_k - 1)$ equals the dispersion of Fréchet productivity shocks in EK. In addition, while it is understood that our product space differs from that of EK – since in Ricardian models goods are not differentiated by origin countries – our model nests EK in terms of aggregate predictions of prices, trade flows, revenues, expenditures, and welfare.

across countries. However, extensions of Eaton and Kortum (2002) allow for a flexible range of total supply elasticities ($\omega^{(1)}_{i,k}$) through the interaction between parameters governing resource mobility (ε_i) and external returns to scale (ϕ_{ik}). This interaction is summarized in the elasticity of total supply ($\omega^{(1)}_{i,k}$). Scanning down the first four rows of Table 1, we see total supply is more elastic (flatter) the greater are external returns to scale or when resources are more mobile across industries. Specifically, for a given change to prices there is a nonlinear change to the wage in that industry, which induces changes to employment and output. The following spells out the interaction of these forces:[17]

$$\omega^{(1)}_{i,k} \equiv \frac{\partial \ln Y_{i,k}}{\partial \ln p_{ii,k}} = \underbrace{\left(\frac{\partial \ln Y_{i,k}}{\partial \ln w_{i,k}}\right)}_{\varepsilon_i} \Big/ \underbrace{\left(\frac{\partial \ln p_{ii,k}}{\partial \ln w_{i,k}}\right)}_{1-(\varepsilon_i-1)\phi_{i,k}}.$$

Allowing for both imperfect labor mobility and external returns, the slope of total supply in principle may take any real-valued number. Relevant to our subsequent empirical analysis, there is no general restriction on the sign of the supply elasticity, $\omega^{(1)}_{i,k}$. In contrast, the most restrictive case removes external returns and assumes perfect labor mobility.[18]

Next, consider a class of multi-sector Krugman (1980) models in which products within a country-industry pair are not perfect substitutes. Then, internal returns to scale operate through an endogenous mass (number) of product varieties produced by each country-industry. The resulting relationship between the aggregate price index and the product-level price can be spelled out using the

[17] To provide a specific example, the model developed by Galle et al. (2021) analyzes a special case in which labor is imperfectly mobile ($\infty > \varepsilon_i > 1$) and there are no external returns ($\phi_{i,k} = 0$). This model implies a textbook total supply curve with a constant positive slope given by $1/\omega^{(1)}_{i,k} = 1/\varepsilon_i$. This result makes clear that production and exports in countries with more mobile resources (i.e., greater ε_i) will be more elastic. A complementary example is Kucheryavyy et al. (2021). There, positive external returns to scale ($\phi_{i,k} > 0$) interact with perfect labor mobility ($\varepsilon_i \to \infty$). Labor supply to any industry is consequently perfectly elastic, which implies there will be no dampening effect on the extent to which external returns to scale lower marginal costs of production. In other words, a rise in wage $w_{i,k}$ directly increases price $p_{ii,k}$ and simultaneously lowers marginal costs as the scale of industry (supply of efficiency units $E_{i,k}$) expands. The indirect force lowering marginal cost dominates the otherwise standard wage effect if resources can be reallocated across industries with sufficient mobility. In the Kucheryavyy et al. (2021) case of perfect mobility and positive external returns, resources are sufficiently mobile to drive the slope of total supply to a negative value. The slope of total supply is then $1/\omega^{(1)}_{i,k} = -\phi_{i,k}$, which is negative and steeper in country-industry pairs with stronger external returns to scale.

[18] These assumptions deliver the standard multi-sector Eaton and Kortum (2002) as in Costinot et al. (2012). Export supply is then perfectly elastic as supply in an industry responds fully to price changes in the face of costless factor reallocation given the linear relationship between wages and prices. Tangentially, this is the implicit assumption underlying identification of import demand in the empirical gravity literature (e.g., Anderson and Wincoop (2003)) as supply and demand simultaneity is assumed away through perfectly elastic export supply.

following decomposition:

$$1-\omega_{i,k}^{(2)} \equiv \frac{\partial \ln P_{ii,k}}{\partial \ln p_{ii,k}} = \underbrace{\left(\frac{\partial \ln P_{ii,k}}{\partial \ln p_{ii,k}}\Big| M_{i,k}\right)}_{1} - \underbrace{\left(\frac{\partial \ln P_{ii,k}}{\partial \ln M_{i,k}}\Big| p_{ii,k}\right)}_{\frac{1}{\eta_{i,k}-1}} \underbrace{\left(\frac{\partial \ln M_{i,k}}{\partial \ln p_{ii,k}}\right)}_{\frac{(\varepsilon_i-1)}{1-(\varepsilon_i-1)\phi_{i,k}}}.$$

Here, by putting the two channels $\left(\partial \ln M_{i,k}/\partial \ln p_{ii,k}\right)$ and $\left(\partial \ln P_{ii,k}/\partial \ln M_{i,k}|p_{ii,k}\right)$ together, $\omega_{i,k}^{(2)}$ summarizes the relationship between the marginal cost at the product level and the aggregate price index that disciplines the demand behavior.[19]

Consider the elasticity of the mass of firms ($M_{i,k}$) with respect to the price charged by a typical firm ($p_{ii,k}$). Extensions of the Krugman model typically assume zero external returns to scale ($\phi_{i,k} \to 0$) and perfect labor mobility ($\varepsilon_i \to \infty$). As a result, the marginal cost does not change when the mass of firms $M_{i,k}$ rises. For this reason, the product level price is perfectly inelastic with respect to the mass of firms (i.e., $\left(\partial \ln M_{i,k}/\partial \ln p_{ii,k}\right)^{-1} = 0$). In an extension in which labor is imperfectly mobile ($\infty > \varepsilon_i > 1$) and scale economies are purely internal ($\phi_{i,k} = 0$), an increase in the product-level price $p_{ii,k}$ implies an increase in wage $w_{i,k}$. In turn the scale of employment ($E_{i,k}$) and, by relation the mass of firms ($M_{i,k}$), increase with prices. The extent of this relationship is governed by the elasticity of labor mobility as $\partial \ln M_{i,k}/\partial \ln p_{ii,k} = (\varepsilon_i - 1)$. That is to say, countries with more mobile factors of production (higher ε_i) experience larger increases of $M_{i,k}$ in response to the product-level price as resources can be more flexibly reallocated to the higher paying industry.

Alternatively, Row 7 of Table 1 demonstrates that if labor is perfectly mobile ($\varepsilon_i \to \infty$), but we allow for positive external returns to scale ($\phi_{i,k} > 0$), an increase in the price that firms charge in an industry has to be accompanied by a decrease in the scale of production in that industry (i.e., the supply elasticity is downward-sloping as $1/\omega_{i,k}^{(1)} = -\phi_{i,k}$). Declining output then means less prospective profits for a typical firm which in turn implies less entry. In this case, $\partial \ln M_{i,k}/\partial \ln p_{ii,k} = (-1/\phi_{i,k}) < 0$, reflecting a negative relationship between the mass of firms ($M_{i,k}$) and price ($p_{ii,k}$). In other words, a larger $\phi_{i,k}$ leads to a more downward-sloping total supply. The second channel at work $\left(\partial \ln P_{ii,k}/\partial \ln M_{i,k}|p_{ii,k}\right)$, highlights the well-studied margin of gains from variety. This literature asserts that an increase in the mass of varieties within an exporter-industry pair lowers the associated price index faced by consumers as consumers inherently value a greater set of varieties. This relationship is governed by the degree of differentiation among product varieties within exporter-

[19] We refer the reader to Appendix 1.2.1 for the full derivation.

industry pairs, reflected by $1/(\eta_{i,k}-1)$.[20]

Lastly, we briefly discuss the specialization elasticities that enter the welfare Equation (25) and are reported across models in the last column of Table 1. Consider the model in Row (3) with no scale economies and imperfect labor mobility. This model delivers ${\omega^{(2)}_{n,k}-1}/{\omega^{(1)}_{n,k}} = {-1}/{\varepsilon_n} < 0$. In this case, controlling for the trade channel, the industry to which more resources will be allocated in response to shocks decreases welfare through adjustment costs of reallocation. Consider the thought experiment where productivity in services increases relative to manufacturing industries due to a technological shock. Consequently, some fraction of high efficiency workers in manufacturing reallocate from the contracting manufacturing sector to the expanding service sector. This selection margin compresses the average efficiency of workers in services inducing a negative contribution to welfare through the specialization channel. The opposite effect takes place in manufacturing: Since a more selected set of workers stay in manufacturing, the selection margin tends to increase the productivity in manufacturing industries. Convoluting the adjustment cost channel are economies of scale. Consider the same thought experiment where manufacturing is contracting, but shut down the adjustment cost channel by assuming workers are perfectly mobile (i.e., $\varepsilon_n \to \infty$) as in Row (7). Then, ${\omega^{(2)}_{n,k}-1}/{\omega^{(1)}_{n,k}} = \frac{1}{\eta_{n,k}-1} + \phi_{n,k} > 0$. Resources allocated to an industry positively contribute to welfare through scale economies. Again, the opposite would take place in the compressed industry.[21]

Since our model nests a wide range of general equilibrium trade models with different perspectives on the range and magnitudes of supply and aggregation elasticities, our empirical application will aim to be agnostic as to the precise model generating the data. Specifically, instead of targeting microeconomic parameters in isolation $\{\varepsilon_i, \phi_{i,k}, \eta_{i,k}, \sigma_{i,k}\}$ we aim at estimating supply, aggregation, and demand elasticities $\{\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{i,k}\}$. The benefits of targeting these elasticities are an abundance of publicly available cross country and trade data. We have shown supply, aggregation, and demand elasticities are sufficient to conduct policy analysis as they efficiently summarize the interaction between the micro parameters. Our estimates will thus readily highlight the channels at work and

[20] Our choice of models in this section is based on those which we nest directly. Incorporating additional margins typically adds new parameters to our analysis. For example, in an extension à la Melitz (2003) in which firm productivities are drawn from a Pareto distribution, the Pareto shape parameter enters in the expression of export supply elasticities. Similarly, in other extensions such as the ones with input-output linkages (e.g., Caliendo and Parro (2015)) or fixed non-labor factors, the underlying expression for export supply elasticities incorporates the parameters driving the additional channel(s).

[21] Regarding welfare analysis, note that passing the combined channels to welfare, as shown by Equation (25), depends on the response to the vector of industry-level revenue shares ($\widehat{r}_{n,k}$) and the specialization elasticity weighted by the expenditure share on the industry ($\beta_{n,k}$). Since the welfare effects from different industries may offset each other to some extent, the overall contribution of the specialization channel must be understood only as the sum of the effects from all industries, which in logs equals $\sum_k \frac{\omega^{(2)}_{n,k}-1}{\omega^{(1)}_{n,k}} \beta_{n,k} \log \widehat{r}_{n,k}$.

their magnitudes across countries and industries as we refer back to Table 1.

3 Estimation

Our goal is to utilize minimal data and constraints in order to estimate demand, supply, and aggregation elasticities, which in turn deliver import demand and export supply elasticities across all available countries and products.[22]

3.1 Estimating Import Demand and Export Supply: An Overview

For each period t trade flows from exporter i to importer n in industry k, our model yields export supply and import demand locally of the form:

$$\begin{aligned} \ln S_{ni,kt} &= \omega^{(S)}_{ni,kt} \ln p_{ni,kt} + \upsilon_{n,kt} + \upsilon_{ni,k} + \varphi_{ni,kt} && \text{(Export Supply)} \\ \ln D_{ni,kt} &= \omega^{(D)}_{ni,k} \ln p_{ni,kt} + \psi_{n,kt} + \psi_{ni,k} + \rho_{ni,kt} && \text{(Import Demand)}, \end{aligned} \tag{26}$$

where $S_{ni,kt}$ is the value of exports from i to n, $D_{ni,kt}$ is the value of imports by n from i, and $p_{ni,kt}$ is the average product-level price (unit value). Both supply and demand contain shifters that vary across different dimensions. We denote these shifters as import demand fixed effects ψ and export supply fixed effects υ. Generically, supply and demand fixed effects vary at the level of importer-exporter-industry and industry-year. For the sake of space, we refer the reader to Appendix **1.6** for the structural composition of the fixed effects and error terms. Here we provide a quick overview. For instance, $\psi_{n,kt}$ represents the importer price index and total expenditure for industry k in period t. Additionally, supply and demand contain importer-exporter-industry-year shifters $\varphi_{ni,kt}$ and $\rho_{ni,kt}$. For supply, $\varphi_{ni,kt}$ is mainly comprised of unobserved productivity shocks, and, for demand, $\rho_{ni,kt}$ is mainly comprised of unobserved demand shocks. Product market elasticities are the export supply ($\omega^{(S)}_{ni,kt}$) and import demand ($\omega^{(D)}_{ni,k}$) elasticities.[23]

[22] In Section **4.4** we will use our estimates of the supply and aggregation elasticities $\{\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}\}$ to back out the supply-side micro parameters of our model $\{\varepsilon_i, \phi_{i,k}, \eta_{i,k}\}$ for completeness.

[23] To remind the reader, export supply and import demand elasticities derived in Section **2.2** are,

$$\begin{aligned} \omega^{(S)}_{ni,kt} &\equiv \frac{\partial \ln S_{ni,kt}}{\partial \ln p_{ni,kt}} = \frac{1}{\lambda_{ni,kt}} \omega^{(1)}_{i,k} - \sum_{m \neq n} \frac{\lambda_{mi,kt}}{\lambda_{ni,kt}} (1 - \sigma_{m,k})(1 - \omega^{(2)}_{i,k}) \\ \omega^{(D)}_{ni,k} &\equiv \frac{\partial \ln D_{ni,kt}}{\partial \ln p_{ni,kt}} = (1 - \sigma_{n,k})(1 - \omega^{(2)}_{i,k}), \end{aligned}$$

Beyond functional forms, the takeaways from mapping the theory to supply and demand estimation are threefold. First, we should not be constraining demand and supply elasticity estimates to the orthant where demand slopes downward and supply slopes upward. Second, export supply elasticities ($\omega^{(S)}_{ni,kt}$) are structurally composed of the demand, supply and aggregation elasticities ($\sigma_{n,k}$, $\omega^{(1)}_{i,k}$, $\omega^{(2)}_{i,k}$), and export penetration ratios $\lambda_{ni,kt}$. Third, when using unit values (given by trade data) in place of the aggregate price indices (implied by the model), the unit value import demand elasticity ($\omega^{(D)}_{ni,k}$) is importer-exporter-industry specific and is confounded by the aggregation elasticity $(1-\omega^{(2)}_{i,k})$. Each of these takeaways drive the admissible range and variation of elasticities. Ultimately, we will estimate the supply and aggregation elasticities $\omega^{(1)}_{i,k} \in (-\infty, \infty)$ and $\omega^{(2)}_{i,k} \in (-\infty, \infty)$, that vary by exporter-industry, and the elasticity of substitution $\sigma_{n,k} \in (1, \infty)$, that varies by importer-industry.

Our model demonstrates a number of hurdles associated with applying standard methodologies without targeted model restrictions. Our goals regarding the scope of the estimation (many importers and exporters trading many heterogeneous goods) rules out prominent instrumental variable (IV) strategies such as Khandelwal (2010) and Fajgelbaum et al. (2020). While it is straightforward theoretically to isolate export supply and import demand shifters, uncovering instruments that equivalently isolate each curve for every importer-exporter-product in the world is infeasible.[24] These challenges are magnified as the export supply elasticity ($\omega^{(S)}_{ni,kt}$) is time varying and comprised of combinations of parameters. To be clear, implementing IV while allowing for all of the channels in the model would require instruments that exogenously shift only demand for every importer-exporter-industry-year in order to estimate export supply elasticities. Additionally, one would also need separate instruments that exogenously shift supply for every importer-exporter-product in order to estimate import demand elasticities and disentangle the aggregation elasticity ($\omega^{(2)}_{i,k}$) from demand. Given available data and methodologies, we find IV infeasible for estimating the full model.[25]

where the supply elasticity $\omega^{(1)}_{i,k}$ and aggregation elasticity $\omega^{(2)}_{i,k}$ are as defined by Equations (12) and (14).

[24] The intuition of IV strategies is illustrated by Appendix Figure A.1 in which we consider a shift in import demand without a shift in export supply, and use this thought experiment together with hat algebra to derive the export supply elasticity.

[25] To provide some specific examples, two uses of IV that cannot be feasibly applied to multiple countries and industries come to mind. First, an instrument that is a meaningful object in only one industry. For example, Costinot et al. (2019) construct an instrument based on disease-related variables, a strategy that is only applicable to the industry they study – pharmaceuticals. Second, strategies that depend on the availability of firm-level data. For example, the approach taken by Lashkaripour and Lugovskyy (2021) requires detailed data on firm-level imports by origin country (their method is applied to Colombia). Generalizing these approaches to multiple industries or multiple countries is hindered both by the nature of instrumental variable construction and the availability of detailed data on the global level. Additionally, these examples rely on models that are more restrictive with targeted restrictions (e.g., Lashkaripour and Lugovskyy (2021) do not allow for imperfect factor mobility or external returns to scale) making it unclear whether their instruments are valid for our more flexible model. Finally, Fajgelbaum et al. (2020) argue that exogenous tariff shocks can be used to separately identify supply and demand elasticities. Setting aside concerns regarding the exogeneity of these shocks across all countries and products, the assumption they rely on to facilitate identification is that supply and demand elasticities do not vary across countries, products or time. Restricting variation in elasticities allows variation across products over time in tariffs to identify supply from demand. We are

An alternative to IV in the international trade literature are heteroskedastic supply and demand estimators (e.g., Feenstra (1994), Broda and Weinstein (2006) and Soderbery (2015)). Our model lends some support to this approach. Specifically, we structurally derive an export supply curve similar in nature to their assumed iso-elastic form. However, these methods rely on a restricted version of our model that imposes $\omega^{(S)}_{ni,kt} = \omega^{(S)}_{n,k} \in (0, \infty)$ and an import demand elasticity $\omega^{(D)}_{ni,k} = 1 - \sigma_{n,k} \in (-\infty, 0)$ that both vary by importer-product in order to jointly estimate export supply and import demand. Our results allow us to determine the model components needed to deliver reduced form specifications from the literature. Feenstra (1994) and Broda and Weinstein (2006) explicitly assume supply is upward sloping and demand is not convoluted by supply when using unit values. Combined with how their elasticities vary, they implicitly assume a model where $\omega^{(2)}_{i,k} = 0$, $\lambda_{ni,kt}$ is time invariant, $\sigma_{n,k} = \sigma_k \ \forall \ n$, and $\varepsilon_i = \varepsilon \ \forall \ i$. A similar model can be found on Row (3) of Table 1. In essence, their reduced form model is a restricted version of Armington or Eaton and Kortum (2002) with imperfect labor mobility. Estimating our model will therefore require a more general heteroskedastic estimator.

One key identifying assumption of the existing methodology is that export supply and import demand error terms ($\varphi_{ni,kt}$ and $\rho_{ni,kt}$) are independent over time. We also rely on this identification assumption. However, and in contrast to the literature, we disentangle these compound error terms to their elementary components, which we use to lay out the full set of basic assumptions for the estimator in Appendix **1.6**. Among these basic assumptions, consistency of the estimator in particular requires independence between productivity shocks to the exporter ($a_{i,kt}$) and taste shocks in the import market ($b_{ni,kt}$) along with the requirement that the estimator is local in nature.[26]

A second key identifying assumption in the literature is that import demand and export supply elasticities are constant over time and homogeneous across exporters in a particular destination. Our model refutes this assumption, and accordingly we relax it in our estimation. The following will briefly describe the data, then develop a structural heteroskedastic estimator of our model.

3.2 Data

Data availability guides our methodology to some extent. Our procedure will be applied to publicly accessible data on international trade and production. Since production data are not available at the disaggregated product level, we aggregate our data into 16 manufacturing industries based on

interested in estimating the full model and thus find IV for this class of models infeasible on a large scale.

[26]See Appendix **1.6** for details.

the ISIC codes, and one non-manufacturing that aggregates all other industries. We obtain from CEPII-BACI the values of bilateral trade ($X_{ni,kt}$). To calculate trade shares, in addition to bilateral trade flows, we need production data, which we extract from UNIDO. Additionally, we obtain from CEPII-BACI the average unit values of products of shipments in every industry between each pair of export-import pair ($p_{ni,kt}$). The corresponding unit values from CEPII-BACI do not incorporate import tariffs while our estimation requires them to incorporate tariffs. We hence combine these unit values with data on tariffs from MacMap. The resulting sample incorporates the largest 15 countries in terms of GDP and 17 industries over the period of 1995-2017.[27]

3.3 Estimation Procedure

Our challenge is estimating the endogenous system in Equation (26) with an unbalanced panel of values and quantities across importers and exporters. We first convert supply and demand into market shares. This aligns the data with the theoretical model and alleviates potential measurement error in recorded trade flows (c.f., Feenstra (1994)). Let $\pi_{ni,kt}$ denote the within-industry share of expenditure by n on exporter i. Additionally, supply and demand fixed effects υ and δ are unobservable in the data so we will use first- and reference-differencing to eliminate them, which yields,

$$\begin{aligned}\Delta^j \ln \pi_{ni,kt} &= \Delta(\omega^{(S)}_{ni,kt} \ln p_{ni,kt}) - \Delta(\omega^{(S)}_{nj,kt} \ln p_{nj,kt}) + \Delta^j \varphi_{ni,kt} \\ \Delta^j \ln \pi_{ni,kt} &= \omega^{(D)}_{ni,k} \Delta \ln p_{ni,kt} - \omega^{(D)}_{nj,k} \Delta \ln p_{nj,kt} + \Delta^j \rho_{ni,kt},\end{aligned} \tag{27}$$

where Δ denotes the first difference and superscript j denotes the reference difference.[28] Disparities between this system and the standard from the literature (e.g., Feenstra (1994)/Broda and Weinstein (2006)) emerge. Notice, export supply elasticities are first differenced as they vary over time with import shares. Time variation in export supply elasticities results from export penetration ($\lambda_{ni,k}$) in the model affecting the slope of export supply. Explicitly, exporters divide excess supply to trade partners around the world. As such, export supply elasticities to a given destination are shaped by domestic production and total exports to all other destinations. Each of these characteristics may vary over time, which poses a problem for heteroskedastic identification in general. The following will show how to overcome the limitations of the standard estimators.

Under our assumptions resulting in independence of the export supply and import demand

[27] See Tables A.1 and A.2 for the list of countries and industries.

[28] For instance, $\Delta^j \ln \pi_{ni,kt} \equiv (\ln \pi_{ni,kt} - \ln \pi_{ni,kt-1}) - (\ln \pi_{nj,kt} - \ln \pi_{nj,kt-1})$ where j is the reference origin.

errors, we can multiply the preceding equations together to begin constructing the estimator. The resulting system is:

$$
\begin{aligned}
(\Delta^j \ln \pi_{ni,kt})^2 = {} & \Delta\left((\omega^{(D)}_{ni,k} + \omega^{(S)}_{ni,kt}) \ln p_{ni,kt}\right) \Delta^j \ln \pi_{ni,kt} - \omega^{(D)}_{ni,k} \Delta \ln p_{ni,kt} \Delta(\omega^{(S)}_{ni,kt} \ln p_{ni,kt}) \\
& - \Delta\left((\omega^{(D)}_{nj,k} + \omega^{(S)}_{nj,kt}) \ln p_{nj,kt}\right) \Delta^j \ln \pi_{ni,kt} + \omega^{(D)}_{nj,k} \Delta \ln p_{nj,kt} \Delta(\omega^{(S)}_{nj,kt} \ln p_{nj,kt}) \\
& + \omega^{(D)}_{ni,k} \Delta \ln p_{ni,kt} \Delta(\omega^{(S)}_{nj,kt} \ln p_{nj,kt}) - \omega^{(D)}_{nj,k} \Delta \ln p_{nj,kt} \Delta(\omega^{(S)}_{ni,kt} \ln p_{ni,kt}) + \Delta^j \varphi_{ni,kt} \Delta^j \rho_{ni,kt}.
\end{aligned}
\tag{28}
$$

To briefly contrast with the literature, if we were to assume demand and supply elasticities were homogenous and constant such that $\omega^{(D)}_{ni,k} = \sigma_{n,k}$ and $\omega^{(S)}_{ni,kt} = \omega^{(S)}_{n,k}\ \forall\ i, t$, Equation (28) would reduce precisely to the estimator developed by Feenstra (1994). Since homogeneous import demand and export supply elasticities are not supported by the model, Feenstra (1994)'s identification strategy breaks down. Soderbery (2018) discusses this possibility (with no theoretical basis) in the context of *constant* heterogeneous export supply elasticities (i.e., $\omega^{(S)}_{ni,kt} = \omega^{(S)}_{ni,k}\ \forall\ t$), and develops a heteroskedastic estimator that leverages contact of exporters in multiple markets. We will borrow much of the intuition developed by Soderbery (2018) to construct our estimator, but note our additional identification hurdle will be addressing time variation in the export supply elasticities.

At this point, a brief discussion of these heteroskedastic market estimators is warranted. In the absence of believable instruments, estimating supply and demand suffers from well-known simultaneity bias. Equation (28) highlights these issues – every proposed regressor is endogenous. Feenstra (1994)'s innovation is an extension of Leamer (1981). They demonstrate that while a regression such as Equation (28) is endogenous in levels, it is exogenous under the assumption that $\mathbb{E}[\Delta^j \varphi_{ni,kt}, \Delta^j \rho_{ni,kt}] = 0$ after averaging over time. The proposed averaging in essence converts the system into a regression of market share variances on price and market share variances and covariances.[29] Feenstra (1994) demonstrated this mapping yields consistent estimates of import demand and export supply using only a time series from a single importer provided the elasticities do not vary across exporters or over time. Our modeling demonstrates that market elasticities are heterogenous across importer-exporter-industry triplets and vary over time.

Soderbery (2018)'s estimator is intuitively the same as Feenstra (1994)'s, but shows how to identify elasticities that vary bilaterally. Essentially, the process for identifying more degrees of heterogeneity in elasticity estimates requires introducing another market for each exporter-industry pair, (i, k). Equation (28) describes the import market n across origins (i, k). Under heterogeneity,

[29] Soderbery (2015) calls this procedure a mapping of "Leamer (1981) hyperbolae" into data.

we additionally require an equation that specifies the sales share of exporter i across destinations (n, k). This market describes export penetration ratios, $\lambda_{ni,kt}$ (i.e., within-industry share of sales by exporter i destined for n). The construction is similar to Equation (28), except our reference differencing will subtract a reference destination m.[30] Notice, supply and demand error terms in the export market are comprised of the same productivity and taste shifters as the import market. Multiplying supply and demand across destinations now yields:

$$\begin{aligned}(\Delta^m \ln \lambda_{ni,kt})^2 = {} & \Delta\left((\omega^{(D)}_{ni,k} + \omega^{(S)}_{ni,kt}) \ln p_{ni,kt}\right) \Delta^m \ln \lambda_{ni,kt} - \omega^{(D)}_{ni,k} \Delta \ln p_{ni,kt} \Delta(\omega^{(S)}_{ni,kt} \ln p_{ni,kt}) \\ & - \Delta\left((\omega^{(D)}_{mi,k} + \omega^{(S)}_{mi,kt}) \ln p_{mi,kt}\right) \Delta^m \ln \lambda_{ni,kt} + \omega^{(D)}_{mi,k} \Delta \ln p_{mi,kt} \Delta(\omega^{(S)}_{mi,kt} \ln p_{mi,kt}) \\ & + \omega^{(D)}_{ni,k} \Delta \ln p_{ni,kt} \Delta(\omega^{(S)}_{mi,kt} \ln p_{mi,kt}) - \omega^{(D)}_{mi,k} \Delta \ln p_{mi,kt} \Delta(\omega^{(S)}_{ni,kt} \ln p_{ni,kt}) + \Delta^m \varphi_{ni,kt} \Delta^m \rho_{ni,kt}.\end{aligned} \tag{29}$$

Provided export supply elasticities are constant over time, jointly estimating Equations (28) and (29) can identify import demand and export supply elasticities. However, export supply elasticities internalize exports to all destinations, which is embodied by export penetration weights ($\lambda_{ni,kt}$) underlying the export supply elasticity ($\omega^{(S)}_{ni,kt}$). Rather than attempting to estimate export elasticities as written, we unbundle the preceding in order to estimate the demand, supply, and aggregation elasticities in Equation (18). This creates additional identification challenges, as we are now requiring the estimator to identify three elasticities; $\sigma_{n,k}$, $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$. However, the elasticities to be estimated are no longer time varying provided we have data on export penetration.

Treating export penetration as data coalesces the estimator. Since $\lambda_{ni,kt}$ is comprised of the same (endogenous) price and value variables as the regressors in Equations (28) and (29), the intuition of heteroskedastic identification is unchanged. Namely, we are effectively weighting the hyperbolae by export penetration ratios. Additionally, this weighting facilitates separately identifying $\omega^{(1)}_{i,k}$ from $\omega^{(2)}_{i,k}$. Simultaneously estimating Equations (28) and (29) after averaging each over time yields estimates of the sub-elasticities $\sigma_{n,k}$, $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$ that are consistent provided supply and demand shocks are independent and hyperbolae across origins and destinations are not asymptotically proportional.[31] The estimator thus leverages the structure of the underlying model to bound the variation and ranges of the elasticity estimates. Additionally, identification comes from jointly estimating the import and export markets and utilizing export penetration data along with the model's constraints.[32]

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[30] For instance, $\Delta^m \ln \lambda_{ni,kt} \equiv (\ln \lambda_{ni,kt} - \ln \lambda_{ni,kt-1}) - (\ln \lambda_{mi,kt} - \ln \lambda_{mi,kt-1})$ where m is the reference destination.

[31] Put more simply, the Leamer (1981) and Feenstra (1994) methodology whereby variances and covariances of prices and quantities can be used to consistently estimate supply and demand, as long as supply and demand shocks are heteroskedastic across exporters, is still the basis of the estimator.

[32] In addition to the equilibrium relationships of our model, we take into account a constraint for uniqueness. It is well-known

3.4 Estimates of the Sufficient Elasticities

We first present our estimates of the supply ($\omega^{(1)}_{n,k}$) and aggregation ($1-\omega^{(2)}_{n,k}$) elasticities. Then we report our demand elasticity estimates ($\sigma_{n,k}$). We also use these three elasticities to construct and present export supply elasticities ($\omega^{(S)}_{ni,kt}$).

Table 2 reports the mean, median, and standard deviation of $\omega^{(1)}_{n,k}$ and $1-\omega^{(2)}_{n,k}$ across industries for a subset of countries. Our estimates of the supply elasticity ($\omega^{(1)}_{n,k}$) lie between 1.315 and 2.666 with an average of 2.131. These estimates are similar to those in the empirical literature that generates finite supply elasticities through labor mobility frictions between industries or occupations while assuming no scale economies (c.f., Hsieh et al. (2019), Burstein et al. (2019), and Galle et al. (2021)). Despite using different estimation methods and data, these studies report comparable estimates of supply elasticities ranging from 1.2 to 2.8 depending on the application. What makes our estimates unique is the considerable variation presented across and within countries and industries.

Table 2: Supply and Aggregation Elasticity Estimates by Country

	Supply Elasticity $\left(\omega^{(1)}_{i,k}\right)$			Aggregation Elasticity $\left(1-\omega^{(2)}_{i,k}\right)$		
Country	Mean	Median	SD	Mean	Median	SD
Canada	2.108	2.265	0.325	−0.119	−0.156	0.310
China	2.276	2.292	0.162	0.030	−0.176	0.417
Germany	2.232	2.379	0.420	−0.147	−0.172	0.108
India	2.236	2.281	0.230	−0.150	−0.166	0.096
Japan	2.085	2.253	0.268	−0.167	−0.160	0.323
UK	2.282	2.296	0.365	−0.186	−0.173	0.093
USA	2.247	2.290	0.246	−0.209	−0.166	0.109

Notes: Mean is the average, Median is the median and SD is the standard deviation estimate across all industries within the country.

Ninety nine percent of our estimates of the aggregation elasticity lie below zero, with an average of -0.158 and notable heterogeneity across industries and countries. Negative values of $1-\omega^{(2)}_{n,k}$ indicate that the aggregate price index ($P_{ni,k}$) falls more than proportionally with a reduction in disaggregate product prices ($p_{n,ik}$). This property, in turn, is indicative of product differentiation and entry within industries. Since aggregation elasticities are only implicitly defined in comparable studies and often convoluted with other elasticity parameters, a comparison with the literature requires a bit of caution. Specifically, an instructive comparison is possible based on the specialization elasticity in the welfare

that models with external economies of scale may not readily admit a unique equilibrium. Borrowing methods from Kucheryavyy et al. (2021), a necessary condition for the uniqueness of our model is $(1-\sigma_{n,k})(1-\omega^{(2)}_{i,k})/\omega^{(1)}_{i,k} \leq 1$. We thus constrain our estimation to the space of $(\sigma_{n,k}, \omega^{(1)}_{i,k}, \omega^{(2)}_{i,k})$ that satisfies this uniqueness condition. For more details, see Appendix 1.4.

Equation (25). As a reminder, Table 1 spells out the specialization elasticity for a select set of models nested within ours. Table 3 presents our estimates of the specialization elasticity ${}^{\omega^{(2)}_{n,k}-1}/_{\omega^{(1)}_{n,k}}$ and the comparable values as implied by recent estimates of Lashkaripour and Lugovskyy (2021) and Bartelme et al. (2021).

Table 3: Specialization Elasticities by Industry

	Specialization Elasticity $\left(\frac{\omega^{(2)}_{i,k}-1}{\omega^{(1)}_{i,k}}\right)$					
	Estimates Across Countries				Literature	
Industry	Mean	Min	Med	Max	LL	BCDR
Food, Beverages and Tobacco	0.051	0.042	0.051	0.066	0.265	0.220
Textiles	0.110	-0.601	0.155	0.178	0.207	0.120
Wood Products	0.051	0.040	0.053	0.056	0.270	0.130
Paper Products	0.097	-0.448	0.151	0.181	0.397	0.150
Coke/Petroleum Products	0.064	0.042	0.063	0.106	1.758	0.090
Chemicals	0.080	0.071	0.082	0.098	0.212	0.240
Rubber and Plastics	0.160	0.118	0.160	0.173	0.162	0.420
Mineral products	0.066	0.055	0.068	0.072	0.186	0.170
Basic metals	-0.170	-0.449	0.045	0.051	0.189	0.090
Fabricated Metals	0.074	0.068	0.078	0.084	0.189	0.120
Machinery and Equipment	0.068	0.061	0.069	0.073	0.100	0.240
Computers and Electronics	0.182	0.116	0.172	0.210	0.453	0.080
Electrical Machinery	0.075	0.055	0.075	0.082	0.453	0.080
Motor Vehicles and Trailers	0.088	0.054	0.078	0.164	0.133	0.180
Other Transport Equipment	0.118	0.090	0.117	0.172	0.133	0.180
Furniture Manufacturing	0.034	-0.565	0.057	0.176	–	–

Notes: Mean, Min, Med, Max refer to the average, minimum, median and maximum, respectively across all exporters in our sample. LL refers to Lashkaripour and Lugovskyy (2021). BCDR refers to Bartelme et al. (2021).

Comparing our estimates with this literature still requires a number of caveats. Lashkaripour and Lugovskyy (2021) assume perfectly mobile factors and only internal returns to scale in an estimation using firm-level Colombian imports. Bartelme et al. (2021) assume perfectly mobile factors and only external returns to scale. In both cases, the resulting elasticities that map to the specialization elasticity are assumed to be positive and industry-specific (i.e., homogeneous across countries). Generally, both alternative methodologies generate larger estimates than ours. This might be expected as models with perfect labor mobility drive up the combined elasticity. However, a direct comparison is tenuous because, in addition to methodological differences, our data and variation leveraged for estimation are also different. Conditional on those caveats, we attribute the differences that emerge to imperfect labor mobility mitigating the effect of returns to scale on the specialization channel. However, this interaction is limited, as the cumulative effect on specialization is still dominated by economies of scale.

We now turn to reporting our estimates of the demand elasticity ($\sigma_{n,k}$) and the inverse of constructed export supply elasticities ($1/\omega^{(S)}_{ni,kt}$).[33] We report these two elasticities together partly because, as we will show in Section **4.1**, they enter the formula for partial equilibrium pass-through rates of tariffs. Specifically, Table 4 presents the mean and standard deviation of inverse export supply elasticities ($1/\omega^{(S)}_{ni,kt}$) and demand elasticities ($\sigma_{n,k}$) across the largest countries and industries in our data. Table 4 also includes the total trade flows in values and export pentration ratios, which drive the levels of export supply elasticities.

Table 4: Export Supply and Import Demand Elasticity Estimates by Industry and Country

	Total Trade		Inverse Export Supply Elasticity ($1/\omega^{(S)}_{ni,kt}$)		Elasticity of Substitution ($\sigma_{n,k}$)	
	Penetration	\$Trillions	Mean	SD	Mean	SD
Industry						
Textiles	0.336	0.655	0.164	0.064	2.810	0.787
Chemicals	0.226	1.181	0.155	0.057	2.811	1.223
Basic metals	0.167	0.424	0.180	0.048	3.532	2.069
Machinery and Equipment	0.314	1.106	0.132	0.047	3.310	0.591
Computers and Electronics	0.462	2.156	0.137	0.084	2.284	0.617
Motor Vehicles and Trailers	0.191	0.623	0.239	0.115	3.301	1.417
Furniture Manufacturing	0.125	0.411	0.238	0.069	3.107	1.742
Country						
Canada	0.462	0.372	0.177	0.049	3.113	0.549
China	0.155	0.864	0.190	0.061	3.476	1.920
Germany	0.275	0.642	0.200	0.074	3.230	0.529
India	0.077	0.107	0.273	0.049	2.160	0.701
Japan	0.151	0.617	0.238	0.101	3.040	0.790
UK	0.221	0.242	0.191	0.066	4.462	1.999
USA	0.139	0.865	0.198	0.050	3.558	1.852

Notes: All values are averaged across the sample years 1995-2017. Penetration is the total export penetration ratio ($\Sigma_n \lambda_{ni,k}$). Mean refers to the average and SD is the standard deviation. Presented estimates are further weighted by the value of bilateral trade.

Our estimates of demand elasticities ($\sigma_{n,k}$) are the most directly comparable to the literature. Ninety percent of our estimates across all industries and countries fall between 1.63 and 7.64. The range and the variation presented in Table 4 are in line with a broad literature (c.f., Broda and Weinstein (2006), Simonovska and Waugh (2014), Imbs and Mejean (2015), and Soderbery (2018)).

Statistics of the inverse export supply elasticities for each industry across markets, and for each country across industries are also presented in Table 4. Overall, direct evidence regarding export supply elasticities across countries or industries is relatively scant. In turn, heteroskedastic estimates

[33] Recall, we directly estimate ($\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{n,k}$) which we use, together with observed export penetration ratios ($\lambda_{ni,kt}$), to construct export supply elasticities ($\omega^{(S)}_{ni,kt}$) based on Equation (18).

of export supply elasticities vary widely across studies. Broda et al. (2008) estimate inverse export supply elasticities across all goods, with a median between 0.9 and 3 across a sample of fifteen countries, and a corresponding mean of 85. Those estimates do not allow for exporter heterogeneity, time variation, or negative elasticities in export supply. Soderbery (2018) extends the estimator to allow for heterogeneity, but still produces relatively large estimates with an average of 68.55 and median of 0.69 for all countries and products. Generally, heteroskedastic elasticity estimates present with a long right tail and large differences across deciles of the distribution of estimates. Our export supply estimates are considerably more tame than other heteroskedastic estimators, with the inverse of estimates across all industries and countries falling between -0.062 and 0.840 and a value weighted mean and median of 0.172 and 0.047, respectively.[34]

Directly comparing our estimates to other estimates in the literature (heteroskedastic based or otherwise) is difficult for a handful of reasons. First, we estimate export supply elasticities at the aggregate industry level (ISIC) while predecessors estimate it at more disaggregated product levels (HS4 or higher). Second, our export supply elasticities are based in general equilibrium, which takes into account various channels ignored by the literature. For instance, market size (i.e., export penetration ratios) are key in determining the levels of our export supply elasticities. Our estimates tend to produce more elastic export supply curves (i.e., smaller inverse export supply elasticities) than the literature, specifically because export penetration ratios tend to be low on average. However, the variation we observe in Table 4 is indicative of key general equilibrium mechanisms that vary across exporters, importers and industries. Differences between our estimates and the literature are a reflection of different levels of aggregation and the form of export supply across studies. These differences are firmly rooted in the general equilibrium mechanisms we have shown to underlie supply and demand, and will be instrumental in analyzing and quantifying the impact of trade and shocks across countries.

4 Equilibrium Analysis & Applications

Our model and estimates lend themselves to a wide range of applications. The following will focus on three applications in order to highlight the role of microeconomic channels in determining partial and general equilibrium international outcomes: (1) pass-through of recent US tariffs to prices and

[34] Variation in inverse export supply elasticities ($1/\omega^{(S)}_{ni,k}$) arise from differences in not only elasticity parameters ($\omega^{(1)}_{i,k}$, $\omega^{(2)}_{i,k}$, and $\sigma_{n,k}$), but also export penetration ratios ($\lambda_{ni,k}$). Magnitudes of $1/\omega^{(S)}_{ni,k}$ tend to be larger in cases where origin i has a larger sales share in market n within industry k, including cases where a country serves its own market.

allocations, (2) the gains from trade and welfare effects of trade liberalization, and (3) strength of home market effects. We are particularly interested in changes to prices and allocations that drive welfare implications associated with various shocks to economies.

4.1 Impact of Recent US Tariffs

We begin by providing a deeper look into how countries react to particular shocks through factor market reallocations and product market outcomes by studying the recent US-China trade war. This focused application provides useful insight into the microeconomic pinnings of the macroeconomic outcomes driven by specialization. First, we derive tariff pass-through rates and report their magnitudes and variation in partial equilibrium. Second, we examine the general equilibrium implications of recent US tariff policy.

4.1.1 Partial Equilibrium Pass-through Rates of Tariffs to Consumer Prices

The effectiveness of unilateral trade policies crucially depends on the extent to which such policies change international prices. Consider an increase in tariffs imposed by importer n on products of industry k from exporter i.[35] We define the partial equilibrium pass-through rate ($\varrho_{ni,k}$) as the partial derivative of log consumer price index in the importing country with respect to log ad-valorem equivalent tariff:

$$\varrho_{ni,k} \equiv \frac{\partial \ln P_{ni,k}}{\partial \ln(1+t_{ni,k})} \quad = \quad \frac{1}{1+\Big(1/\omega^{(S)}_{ni,k}\Big)\Big(1-\omega^{(2)}_{i,k}\Big)\Big(\sigma_{n,k}-1\Big)\Big(1-\pi_{ni,k}\Big)} \tag{30}$$

The pass-through rate ($\varrho_{ni,k}$) is a function of the inverse export supply elasticity ($1/\omega^{(S)}_{ni,k}$) adjusted by the aggregation elasticity ($1-\omega^{(2)}_{i,k}$), and the demand elasticity ($\sigma_{n,k}$) adjusted by ($1-\pi_{ni,k}$) to capture the effect from size of country n's expenditure share on exporter i.[36]

As a primer to what follows, we subsequently examine recent US tariffs applied against Chinese exports. Applying our estimates to Equation (30), we find pass-through from China to US consumers to be centered around unity with only minor deviations across industries. Column (7) in Table 5

[35] Recall that the price wedge for a transaction from exporter i to importer n in industry k is $\tau_{ni,k} \equiv d_{ni,k}(1+t_{ni,k})$ with $d_{ni,k}$ as iceberg trade cost and $t_{ni,k}$ as tariff.

[36] See Appendix **1.3** for a detailed derivation. Notice, we could replace $(1-\omega^{(2)}_{i,k})(1-\sigma_{n,k})$ by $(\omega^{(D)}_{ni,k})$ according to Equation (15). If $\pi_{ni,k}$ is negligible, then the pass-through rate collapses to a more familiar expression, $\omega^{(S)}_{ni,k}/(\omega^{(S)}_{ni,k}+(-\omega^{(D)}_{ni,k}))$, and in a class of models in which $\omega^{(2)}_{i,k}=0$, that simplifies to $\omega^{(S)}_{ni,k}/(\omega^{(S)}_{ni,k}+(\sigma_{n,k}-1))$.

reports partial equilibrium pass-through rates of recent US tariffs imposed on Chinese goods. Recall, Chinese export supply is relatively elastic on average (Table 4). Our estimates thus imply that US tariffs have virtually no impact on Chinese producer prices in partial equilibrium. Consequently, the burden of recent tariffs lie almost entirely onto US consumers. These results are consistent with recent studies from Fajgelbaum et al. (2020) and Amiti et al. (2019) which found near complete pass-through of US tariffs using reduced form empirics applied to partial equilibrium models of trade.

However, it is important to emphasize that pass-through rates from Equation (30) are partial equilibrium in nature. In general equilibrium, interconnections across markets and interdependencies in trade policy may imply different pass-through rates when importer tariffs are substantial enough to induce broad reallocations by the exporter. For this reason, we next consider the general equilibrium impact of the recent US protectionist policies. We will compare partial and general equilibrium pass-through rates given our estimates and highlight the channels driving their differences.

4.1.2 General Equilibrium Impact of Tariffs

While the channels determining pass-through in partial equilibrium also operate in general equilibrium, the shifts to export supply curves in industries facing tariff changes are accompanied by (potentially costly) reallocations by the exporter. These reallocations lead to additional adjustments by exporters to shipped and delivered prices. In order to decompose the mechanisms of tariff responses, we consider a recent example of extreme and unexpected tariffs applied by the US. Over the course of 2018, the United States increased tariffs on a wide range of its imports from China. We study the general equilibrium implications of these increases in US tariffs on Chinese goods. Column (1) of Table 5 records the changes in ad valorem equivalent tariff rates across industries.[37]

As mentioned before, partial equilibrium pass-through rates of US tariffs on the price index of Chinese goods in the US market are reported in Column (7). Pass-through of US tariffs are generally complete with limited variation across industries. In Columns (8) and (9) we allow for general equilibrium linkages. Column (7) applies tariff changes industry by industry, one at a time. General equilibrium adjustments lower pass-through rates, but only modestly. However this exercise is different than the reality, as tariffs were in fact applied simultaneously across industries by the US. Column (9) thus applies tariffs simultaneously on all industries then reevaluates the model in general

[37] Values are extracted from Fajgelbaum et al. (2020) and applied to only Chinese goods (in case other exporters are also targeted), and to the entire industry (in case a subset of products are targeted within that industry). We hold tariffs elsewhere unchanged and suppose that in our baseline equilibrium there are no tariffs for the sake of clarity.

equilibrium. The resulting pass-through rates range from 51.7% for the Paper industry to 77.0% for the Electronics industry. These pass-through rates are substantially lower than those implied by partial equilibrium rates reported in Column (7).

Table 5: Pass-through Rates onto US Consumers from US Tariffs on Chinese Goods

		Trade Shares		Elasticities			Partial	General Equilibrium	
Industry	Δ Tariff	$\lambda_{ni,k}$	$\pi_{ni,k}$	$1/\omega^{(S)}_{ni,k}$	$1-\omega^{(2)}_{i,k}$	$\sigma_{n,k}$	Equilibrium	Single	Full
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Food	0.10	0.2%	0.7%	0.001	-0.11	3.04	100.0%	98.8%	53.8%
Textile	0.10	8.9%	47.0%	0.044	-0.29	3.20	101.5%	89.9%	53.8%
Wood	0.10	0.9%	3.7%	0.004	-0.13	3.20	100.1%	100.1%	53.6%
Paper	0.10	3.2%	1.4%	0.017	-0.33	3.10	101.2%	101.4%	51.7%
Petroleum	0.10	0.4%	0.2%	0.006	-0.25	3.20	100.3%	100.0%	52.7%
Chemical	0.10	2.8%	2.7%	0.014	-0.18	3.18	100.5%	99.3%	53.4%
Rubber	0.11	9.8%	8.2%	0.059	-0.35	1.96	101.8%	102.5%	56.6%
Mineral	0.14	1.8%	3.6%	0.009	-0.16	3.21	100.3%	100.3%	65.7%
Basic Metal	0.11	1.0%	2.3%	0.005	-0.10	3.09	100.1%	100.1%	57.5%
Fabricated Metal	0.15	3.8%	5.2%	0.017	-0.17	3.20	100.6%	100.6%	68.0%
Machinery	0.10	8.1%	12.3%	0.042	-0.18	2.38	100.9%	100.9%	52.9%
Electronics	0.22	8.4%	30.3%	0.041	-0.35	2.04	101.1%	99.2%	77.0%
Electric Machinery	0.20	3.2%	16.1%	0.019	-0.18	2.79	100.5%	99.6%	74.8%
Vehicle	0.20	1.0%	1.8%	0.005	-0.15	6.89	100.4%	99.2%	75.0%
Other Transp.	0.14	0.4%	1.4%	0.003	-0.20	3.21	100.1%	100.1%	64.8%
Furniture	0.12	22.5%	23.6%	0.112	-0.11	8.61	107.7%	93.9%	65.3%

Notes: Column (1) reports changes in USA statutory tariffs against China. We extract these values from Table 2 in Fajgelbaum et al. (2020) and apply them to USA tariffs on Chinese goods and to the entire industry in case a subset of products within an industry are targeted. Across columns, n = USA, i = China, and k refers to the corresponding industry. Columns (2) and (3) report $\lambda_{ni,k}$ as sales share of China in the US and $\pi_{ni,k}$ as expenditure share of the US from China. Column (4) reports the inverse of export supply elasticity. Columns (5) and (6) report aggregation and demand elasticities. Column (7) presents partial equilibrium pass-through rates according to Equation (30), whereas Columns (8) and (9) present the general equilibrium pass-through rates of US tariffs onto US consumers for tariff increases that are reported in Column (1). Column (8) imposes tariffs on only a single industry at a time, whereas Column (9) reports results when tariffs are simultaneously imposed on all industries.

Differences between partial and general equilibrium pass-through rates arise due to general equilibrium linkages. Specifically, a tariff applied on one industry alters resource allocations and costs across all industries in the exporting country. In this respect, our general equilibrium exercises echo recent theoretical findings. For instance, Costinot et al. (2015) and Beshkar and Lashkaripour (2020) assert that the optimal tariff for the importer is uniform across industries. Additionally, Beshkar and Lashkaripour (2020) demonstrate that optimal tariffs across industries are complementary. These results are obtained in frameworks that have shut down certain mechanisms in comparison to our model (e.g., they impose perfect labor mobility). Nonetheless, they illustrate an important margin of optimal unilateral policy which remains operative in our more general model. Intuitively, an importer can exercise a higher degree of market power by simultaneously imposing tariffs on mulitple industries of an exporting country. That is to say, tariffs ranging across exporter industries do not allow the exporter to reallocate resources in order to escape the distortionary effects of the policies. The differences between Column (8) and (9) thus empirically demonstrate the importance of interconnectedness across industries.

4.2 The Gains from Trade and Trade Liberalization

Our estimates also allow us to quantify the gains from trade as the magnitude of welfare loss generated from a move to autarky. In order to further decompose the mechanisms of the model, we also examine gains from trade liberalization by means of eliminating all tariffs. First, we apply Equation (25) to obtain the gains from trade formula. Since in autarky $\pi^A_{nn,k} = 1$ and $r^A_{n,k} = \beta_{n,k}$, it follows that $\widehat{\pi}_{nn,k} = 1/\pi_{nn,k}$ and $\widehat{r}_{n,k} = \beta_{n,k}/r_{n,k}$. Consistent with the literature, we define the gains from trade as the loss of welfare when a country moves from the observed equilibrium to autarky,

$$GFT_n \equiv \frac{W_n - W^A_n}{W_n} = 1 - \Delta W_n = 1 - \Delta^{TR}_n \Delta^{SP}_n, \tag{31}$$

where the trade channel (ΔTR_n), and the specialization channel (ΔSP_n) are given by,

$$\Delta TR_n = \prod_k \pi_{nn,k}^{\frac{\beta_{n,k}}{\sigma_{nk}-1}} \quad \text{and} \quad \Delta SP_n = \prod_k \left({}^{\beta_{n,k}}/_{r_{n,k}}\right)^{\frac{\beta_{n,k}(\omega^{(2)}_{n,k}-1)}{\omega^{(1)}_{n,k}}}. \tag{32}$$

Given model parameters, (Δ^{TR}_n) is larger if the observed domestic expenditure share π^k_{nn} is smaller. That is to say, more open economies would lose more in a shift to autarky. These are the classic Arkolakis et al. (2012) gains from trade.

The specialization channel (Δ^{SP}_n) comprises forces that can operate with opposing tension. Deviation between the expenditure share ($\beta_{n,k}$) and the revenue share ($r_{n,k}$) in an industry k necessarily implies deviation in at least one other industry in that country. This specialization channel thus captures enhancement and depression of efficiency in allocations of productive resources induced by trade. The contribution of this *divergence ratio* (${}^{\beta_{n,k}}/_{r_{n,k}}$) to welfare is raised to the specialization elasticity, which summarizes the tensions in the model driven by the degree of labor mobility and returns to scale. The aggregate effect of the specialization channel on welfare is then given by,

$$\log \Delta SP_n = \sum_{k \in K} \log \Delta SP_{n,k} \quad \text{where} \quad \log \Delta SP_{n,k} \equiv \frac{\beta_{n,k}(\omega^{(2)}_{n,k}-1)}{\omega^{(1)}_{n,k}} \log\left(\frac{\beta_{n,k}}{r_{n,k}}\right). \tag{33}$$

Accordingly, we refer to $(-\log \Delta SP_{n,k}) \approx 1 - \Delta SP_{n,k}$ as the contribution of industry k to the gains from trade in country n through the specialization channel when controlling for the trade channel.

When $\beta_{n,k} < r_{n,k}$, resources would move to industry k as the country transitions from autarky to the baseline trade equilibrium. If in addition $(\omega^{(2)}_{n,k}-1)/\omega^{(1)}_{n,k} > 0$, the contribution of industry k to welfare is positive as $-\log \Delta SP_{n,k} > 0$. In this case, the country is reallocating resources to the industry exploiting economies of scale. Economies of scale dominate costly reallocations in this example, which boosts gains from trade. Conversely, if $\beta_{n,k} > r_{n,k}$, resources would move out of industry k in the transition from autarky to the baseline. If in addition $(\omega^{(2)}_{n,k}-1)/\omega^{(1)}_{n,k} > 0$, then again the contribution of industry k to welfare is positive. Here, resources are being reallocated away from the industry k where the costs of reallocation exceed the gains from returns to scale, which again boosts the gains from trade through specialization.

The interaction of the forces underlying production and exports are a result of the general flexibility in the supply elasticities ($\omega^{(1)}_{n,k}$ and $\omega^{(2)}_{n,k}$) that are allowed in our framework. For comparison, the model developed by Galle et al. (2021) yields $(\omega^{(2)}_{n,k}-1)/\omega^{(1)}_{n,k} < 0$ (see Table 1), such that the specialization channel always boosts welfare for $\beta_{i,k} > r_{i,k}$. In contrast, Kucheryavyy et al. (2021) and Lashkaripour and Lugovskyy (2021) generate a positive specialization elasticity, such that the specialization channel always reduces welfare for $\beta_{i,k} > r_{i,k}$. In summary, when the specialization elasticity is positive (negative), an industry from which resources are removed necessarily contributes to dampen (boost) gains from trade through the specialization channel.

Applying our estimates and data, Table 6 reports the gains from trade for a handful of countries. Additionally, we decompose the contribution of the trade channel and the specialization channel in determining overall gains from trade across countries. The contribution of specialization channel is rather small reflecting the competing welfare effects of industries that expand with those that shrink. Overall, the gains from trade generated by our model are in line with multi-industry models in the literature (c.f., Costinot and Rodríguez-Clare (2014)).

Table 6: Gains from Trade and Trade Liberalization

	Gains from Trade			Gains from Trade Liberalization		
	Welfare	Trade	Specialization	Welfare	Trade	Specialization
Country	$1-\Delta W$	$1-\Delta TR$	$1-\Delta SP$	$\widehat{W}$	$\widehat{TR}$	$\widehat{SP}$
Canada	8.71%	9.12%	−0.44%	0.52%	0.54%	−0.01%
China	1.61%	1.52%	0.09%	0.21%	0.21%	0.00%
Germany	9.41%	9.58%	−0.18%	0.56%	0.65%	−0.08%
UK	11.90%	12.19%	−0.33%	0.43%	0.47%	−0.04%
India	1.99%	2.07%	−0.08%	0.13%	0.10%	0.03%
Japan	2.07%	2.11%	−0.04%	0.22%	0.25%	−0.03%
USA	2.04%	2.27%	−0.23%	0.20%	0.28%	−0.08%

Note: Panel (A) reports the gains from trade with $1-\Delta W$, $1-\Delta TR$, $1-\Delta SP$ calculated according to Equations (31) and (32). Gains from liberalization reports welfare changes from counterfactual elimination of all international manufacturing tariffs. We obtain $\widehat{W}$, $\widehat{TR}$, and $\widehat{SP}$ by computing equilibrium in changes as described by Equation (25).

Of additional and related interest, we also consider a counterfactual policy that eliminates all tariffs in the manufacturing industries. Our most recent year of data are from 2017, which will serve as our baseline trade equilibrium levels including welfare and tariffs. We compute the equilibrium in changes predicted by our model and estimates described in Section **2.3** in a counterfactual world where tariffs are reduced to zero globally. The resulting gains represent the extent to which welfare in every country reacts to the general equilibrium reallocations induced by global free trade. The final three columns of Table 6 report the gains from trade liberalization.

Gains from liberalization are modest compared to the gains from trade. This result is expected since tariffs themselves are historically low in the baseline and all countries decreasing tariffs simultaneously brings with it countervailing effects. In order to further decompose these effects, we apply Equation (25) to decompose the gains from liberalization into trade and specialization channels. Gains from the specialization channel are not necessarily positive or negative, and their absolute values are smaller than those from the trade channel.

The relative magnitudes of the trade and specialization channels broadly echo the estimates from gains from trade. However, in certain countries the patterns of reallocation differ between the two exercises. For instance, in India the specialization channel negatively impacts the gains from trade but has a modest positive effect on the gains from liberalization. The latter suggests that by reallocating production in response to a global trade liberalization India realizes efficiency gains through returns to scale. In contrast, costly labor reallocations dominate gains from scale economies in the more extreme move from autarky to trade. Specialization in more developed countries (e.g., the UK and US) across both exercises negatively impacts welfare. China is somewhat of an outliers, as this country realizes modest but positive gains from specialization through both trade and liberalization.

4.3 Home Market Effects

In this section, we use our model and estimates to shed light on the strength of scale economies reflected in home market effects. The importance of this mechanism has received significant attention since Linder (1961). Given space, we refer the reader to Head and Mayer (2004) for an overview. Here, we examine the sign and magnitudes of elasticities of exports and imports in every country-industry pair with respect to home demand. For instance, consider China as the country and Electronics as the industry. We ask: "What would be the percentage change to Chinese exports and imports of Electronics if Chinese demand for electronics rose by one percent?" The answer defines elasticities of exports and imports with respect to home demand for the country-industry pair of China-Electronics.

We compute these elasticities as follows. First, we rewrite Cobb-Douglas demand shifters $\beta_{n,k}$ as $\beta_{n,k} = b_{n,k}/(b_{n,1} + ... + b_{n,K})$, where $b_{n,k}$ is home demand for industry k. Let $b'_{n,k}$ denote a new set of home demand parameters, where $b'_{n,k} = b_{n,k} + \Delta$ for $k = j$, and $b'_{n,k} = b_{n,k}$ for $k \neq j$. This process generates a new set of Cobb-Douglas parameters $\beta'_{n,k}$ in which the share of spending on $k = j$ is higher than that of $k \neq j$. Export and import elasticities with respect to home demand for country-industry pair (n, j) are then defined by,

$$\beta^X_{n,j} \equiv \frac{S'_{n,j}/S_{n,j} - 1}{b'_{n,j}/b_{n,j} - 1}, \quad \text{and} \quad \beta^M_{n,j} \equiv \frac{D'_{n,j}/D_{n,j} - 1}{b'_{n,j}/b_{n,j} - 1}. \tag{34}$$

where $S_{n,j} \equiv \sum_{i \neq j} S_{in,j}$ is total exports and $D_{n,j} \equiv \sum_{i \neq n} D_{ni,j}$ is total imports of country n.

The literature distinguishes between weak and strong home market effects, as discussed by Costinot et al. (2019). Weak home market effects present when $\beta^X > 0$, and strong home market effects when $\beta^X > \beta^M$. We conduct $N \times K$ counterfactual exercises in which for every country n and industry j, one at a time, where we numerically compute the new equilibrium for a local change to $b_{n,j}$. Comparing exports and imports in the baseline and new equilibrium allows us to calculate $\beta^X_{n,j}$ and $\beta^M_{n,j}$ for every country-industry pair. We report the full table of our results in Appendix (Tables A.1, A.2), and plot them in Figure 1 to connect with a broad literature studying home market effects.

Several observations stand out. First, across all estimates $\beta^X_{n,j}$ is more likely to be large when $\beta^M_{n,j}$ is small. The reason lies in the forces that affect exports and imports in opposite directions. An increase in exports due to home demand originates from an increase in total supply. Since a sufficient rise of total supply helps satisfy total demand, there will be less demand for foreign goods and less imports.

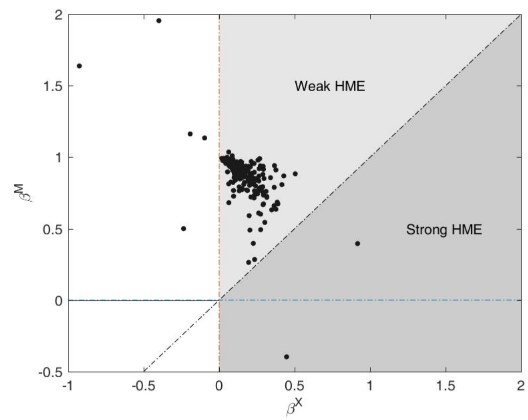

Figure 1: β^X and β^M

Notes: β^X and β^M are elasticities of exports and imports with respect to home demand for every industry-country pair. Weak home market requires $\beta^X > 0$ and strong home market effect requires $\beta^X > \beta^M$.

There is substantial heterogeneity in our estimated elasticities across industries and countries. Despite this heterogeneity, weak home market effects (i.e. cases with $\beta^M > \beta^X > 0$) are a prevalent outcome. In contrast, strong home market effect is a rare outcome given our estimates. The closest comparison to our estimates is with Costinot et al. (2019) who find evidence for strong home market effects in the pharmaceutical industry. Their baseline estimates for the pharmaceutical industry are $\beta^X = 0.93$ and $\beta^M = 0.54$. In our data, the closest we have to pharmaceuticals is the chemicals which includes pharmaceuticals along with several non-pharmaceutical industries. For chemicals in the US, we obtain $\beta^X = 0.14$ and $\beta^M = 0.88$ which support the assertion of weak home market effects in the US chemical industry.

More broadly, we find our results to be in line with reduced form evidence on home market effects, such as Hanson and Xiang (2004) who argue that industries with more differentiated products generate stronger home market effects. According to our estimates, for instance, Computers and Electronics are highly differentiated ($\sigma_{n,k}$ is 2.284 on average) and present weak home market effects in all countries. In contrast, our estimates suggest Food Products are less differentiated ($\sigma_{n,k}$ is 4.039 on average) and do not generate home market effects in a number of countries.

4.4 Channel Estimates

We have shown how to utilize our model and estimates of sufficient elasticities $(\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{n,k})$ across a range of applications. Here we show how to use these estimated sufficient elasticities to uncover the underlying parameters that govern the microeconomic channels of the model. Specifically, we exploit the estimated differences in supply $(\omega^{(1)}_{i,k})$ and aggregation $(\omega^{(2)}_{i,k})$ elasticities across exporters and industries to uncover elasticities that control labor mobility (ε_i), external returns $(\eta_{i,k})$, and internal returns $(\phi_{i,k})$. Doing so requires us to impose additional restrictions as we explain below.

Consider the ratio of $\omega^{(2)}_{i,k}$ to $\omega^{(1)}_{i,k}$,

$$\frac{\omega^{(2)}_{i,k}}{\omega^{(1)}_{i,k}} = \frac{\varepsilon_i - 1}{\varepsilon_i}\frac{1}{\eta_{i,k} - 1}. \tag{35}$$

The above ratio is a nonlinear combination of only two parameters, ε_i and $\eta_{i,k}$. Furthermore, the model bounds the sign and variation of the ratio. Notice the parameter governing the labor supply elasticity $\varepsilon_i > 1$ is exporter specific and does not vary across industries, while the parameter governing internal returns $\eta_{i,k} > 1$ is exporter-industry specific.

Extracting the parameters of the microeconomic channels, however, requires a normalization. We thus impose a proportionality assumption between the elasticity of substitution between national-level varieties and the corresponding elasticity of substitution between products within a country—that governs internal returns. That is, we suppose the elasticity of substitution across products within industry k $(\eta_{i,k})$ is proportional to the substitutability across national varieties of that industry $(\sigma_{i,k})$.[38] Given this normalization, we can jointly uncover ε_i and $\eta_{i,k}$ from the ratio of $\omega^{(2)}_{i,k}/\omega^{(1)}_{i,k}$ by applying nonlinear least squares. Then with ε_i and $\eta_{i,k}$ in hand, we can further back out the parameter that governs internal returns to scale $(\phi_{i,k})$. Table 7 reports our results.

Broadly we find our estimates to be consistent with a cobbling of the literature. Our estimates of labor mobility elasticity (ε_i) are in the range of 1.2 and 2.8 obtained in Hsieh et al. (2019), Burstein et al. (2019), and Galle et al. (2021) for labor allocations between industries or occupations. Our estimates of internal returns to scale $(\eta_{i,k})$ are generally lower than those directly estimated in the literature such as Lashkaripour and Lugovskyy (2021) or implied by markup estimates such as De Loecker et al. (2020), while our our external returns to scale elasticities $(\phi_{i,k})$ are comparable to

[38] Explicitly we nonlinearly estimate ε_i and a proportionality parameter call it κ such that $\eta_{i,k} = \kappa\sigma_{i,k}$ after taking logs of in Equation (35). This delivers the following nonlinear relationship, $\log(\mu_{i,k}) = \log(\frac{\varepsilon_i - 1}{\epsilon_i}) + \log(\frac{1}{\kappa\sigma_{i,k} - 1})$, which can be estimated via nonlinear least squares.

Bartelme et al. (2021) that reports a range between 0.1 and 0.4.

Table 7: Model Parameter Estimates

Country	Labor Mobility (ε_i)	Internal Returns ($\eta_{i,k}$) Mean	Med	SD	External Returns ($\phi_{ni,k}$) Mean	Med	SD
Canada	1.897	1.916	1.953	0.238	0.160	0.184	0.185
China	1.798	2.074	1.952	0.833	0.268	0.276	0.056
Germany	2.020	1.967	1.954	0.229	0.104	0.148	0.114
India	1.658	1.503	1.954	0.304	0.399	0.417	0.116
Japan	1.913	1.884	1.954	0.343	0.210	0.187	0.102
UK	1.784	2.501	1.952	0.867	0.328	0.322	0.146
USA	2.118	2.109	1.950	0.803	0.053	0.068	0.086

Notes: Mean is the average and Med is the median estimate across all goods within the country. SD is the standard deviation.

5 Conclusion

We first developed a general equilibrium model that incorporates key channels from widely used models of international trade. We recast these models as one of supply and demand in product markets through a derivation of export supply from model primitives. Export supply was shown to contain unique information regarding the microeconomic channels underlying general equilibrium models of trade. Specifically, we demonstrated that export supply summarizes the interaction between elasticities that govern scale economies, labor mobility, and demand for products.

Our derivation highlights three elasticities underlying export supply; (1) the elasticity of total supply with respect to product-level prices, (2) the elasticity of the industry level price index with respect to product level prices, and (3) elasticity of demand with respect to price index. We showed the sufficiency of these supply, aggregation, and demand elasticities for quantitative general equilibrium analysis and estimated them by developing a heteroskedastic estimator for international product markets, estimation of which required only publicly available data. We applied our model and estimates primarily to examine the impact of recent US protectionist policies and gains from trade. Throughout the analysis, we highlighted the importance of flexible elasticity parameters and general equilibrium linkages.

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Appendix A Technical Notes

1.1 Equilibrium in Changes —Using wages and labor market clearing

Consider a "policy" as a set of changes to iceberg trade costs $\widehat{d}_{n,ik}$, tariffs $\widehat{t}_{ni,k}$, productivities $\widehat{a}_{i,k}$, and demand shifters $\widehat{\beta}_{n,k}$ and $\widehat{b}_{ni,k}$ for all destinations n, origins i, industries k, and "baseline" values as the vector of national expenditure X_n, deficit-to-income ratio ν_n, employments $L_{n,k}$, revenues $Y_{n,k}$, tariffs $t_{ni,k}$, and trade flows $X_{ni,k}$. Additionally, note that the change to the trade wedge is given by $\widehat{\tau}_{ni,k} = \widehat{d}_{ni,k}(1 + \widehat{t}_{ni,k}t_{ni,k})/(1 + t_{ni,k})$, and

$$L_i \equiv \sum_k L_{i,k}, \qquad \pi_{ni,k} \equiv \frac{X_{ni,k}}{\sum_{\ell \in N} X_{n\ell,k}}, \qquad \alpha_{ni,k} \equiv (\sigma_{nk} - 1)((\eta_{i,k} - 1)^{-1} + \phi_{i,k}),$$

Given the policy and baseline values, a general equilibrium in changes consists of $\widehat{w}_{i,k}$ for all i, k such that Equations A.1-A.6 hold:

$$\widehat{Y}_{i,k} = \widehat{\Phi}_i^{1-\varepsilon_i} \widehat{w}_{i,k}^{\varepsilon_i}, \qquad \text{(Supply)} \tag{A.1}$$

$$\widehat{\Phi}_i = \left[\sum_k \frac{L_{i,k}}{L_i} \widehat{w}_{i,k}^{\varepsilon_i} \right]^{1/\varepsilon_i} \qquad \text{(Income per worker)} \tag{A.2}$$

$$\widehat{X}_n X_n = (1 + \nu_n) \sum_k \widehat{Y}_{n,k} Y_{n,k} + \sum_i \sum_k \frac{\widehat{t}_{ni,k} t_{ni,k}}{1 + \widehat{t}_{ni,k} t_{ni,k}} \widehat{X}_{ni,k} X_{ni,k} \qquad \text{(Total expenditure)} \tag{A.3}$$

$$\widehat{P}_{n,k} = \left[\sum_\ell \pi_{n\ell,k} \widehat{b}_{n\ell,k} \left(\widehat{Y}_{\ell,k}/\widehat{w}_{\ell,k}\right)^{\alpha_{n\ell,k}} \left(\widehat{a}_{\ell,k}\right)^{\sigma_{nk}-1} \left(\widehat{\tau}_{n\ell,k} \widehat{w}_{\ell,k}\right)^{-(\sigma_{nk}-1)} \right]^{\frac{1}{1-\sigma_{nk}}} \qquad \text{(Price index)} \tag{A.4}$$

$$\widehat{X}_{ni,k} = \underbrace{\left(\frac{\widehat{b}_{ni,k} \left(\widehat{Y}_{i,k}/\widehat{w}_{i,k}\right)^{\alpha_{ni,k}} \left(\widehat{a}_{i,k}\right)^{\sigma_{nk}-1} \left(\widehat{\tau}_{ni,k} \widehat{w}_{i,k}\right)^{-(\sigma_{nk}-1)}}{\sum_\ell \pi_{n\ell,k} \widehat{b}_{n\ell,k} \left(\widehat{Y}_{\ell,k}/\widehat{w}_{\ell,k}\right)^{\alpha_{n\ell,k}} \left(\widehat{a}_{\ell,k}\right)^{\sigma_{nk}-1} \left(\widehat{\tau}_{n\ell,k} \widehat{w}_{\ell,k}\right)^{-(\sigma_{nk}-1)}} \right)}_{\widehat{\pi}_{ni,k}} \widehat{\beta}_{n,k} \widehat{X}_n \qquad \text{(Trade flows)} \tag{A.5}$$

$$Y_{i,k} \widehat{Y}_{i,k} = \sum_{n \in N} \frac{1}{1 + \widehat{t}_{ni,k} t_{ni,k}} X_{ni,k} \widehat{X}_{ni,k} \qquad \text{(Market clearing)} \tag{A.6}$$

1.2 Welfare Formula

For the sake of clearer exposition, suppose the only change to exogenous parameters is a shock to iceberg trade costs $\widehat{d}_{ni,k}$. Welfare, or indirect utility, equals $W_n = X_n/P_n$, and its corresponding change is then given by:

$$\widehat{W}_n = \frac{W_n'}{W_n} = \frac{\widehat{\Phi}_n}{\widehat{P}_n}$$

The change to the price index is $\widehat{P}_n = \prod_k \widehat{P}_{nk}$, where $\widehat{P}_{n,k}$ is given by Equation (A.4). Using Equations A.1, A.4, A.5 and considering that $\widehat{E}_{i,k} = \widehat{Y}_{i,k}/\widehat{w}_{i,k}$,

$$\widehat{P}_{n,k} = \widehat{\pi}_{nn,k}^{\frac{1}{\sigma_{nk}-1}} \widehat{E}_{n,k}^{\frac{\alpha_{nn,k}}{1-\sigma_{nk}}} \widehat{w}_{n,k} = \widehat{\pi}_{nn,k}^{\frac{1}{\sigma_{nk}-1}} \left(\widehat{\Phi}_n^{1-\varepsilon_n} \widehat{w}_{n,k}^{\varepsilon_n - 1} \right)^{\frac{\alpha_{nn,k}}{1-\sigma_{nk}}} \widehat{w}_{n,k}$$

Replacing for $\widehat{P}_{n,k}$ from the above expression, and since $\sum_k \beta_{n,k} = 1$,

$$\begin{aligned}\widehat{W}_n &= \frac{\widehat{\Phi}_n}{\prod_k \widehat{\pi}_{nn,k}^{\frac{\beta_{n,k}}{\sigma_{nk}-1}} \left(\widehat{\Phi}_n^{-1}\widehat{w}_{n,k}\right)^{\frac{\beta_{n,k}\alpha_{nn,k}(\varepsilon_n-1)}{1-\sigma_{nk}}} \widehat{w}_{n,k}^{\beta_{n,k}}} \\ &= \prod_k \widehat{\pi}_{nn,k}^{-\frac{\beta_{n,k}}{\sigma_{nk}-1}} \prod_k \left(\widehat{\Phi}_n^{-1}\widehat{w}_{n,k}\right)^{\frac{\beta_{n,k}\alpha_{nn,k}(\varepsilon_n-1)}{\sigma_{nk}-1}} \left(\widehat{\Phi}_n\widehat{w}_{n,k}^{-1}\right)^{\beta_{n,k}}\end{aligned}$$

Given $\widehat{\Phi}_n^{-1}\widehat{w}_{n,k} = \widehat{r}_{n,k}^{1/\varepsilon_n}$, and since $\alpha_{nn,k} \equiv (\sigma_{nk}-1)((\eta_{n,k}-1)^{-1} + \phi_{n,k})$,

$$\widehat{W}_n = \prod_k \widehat{\pi}_{nn,k}^{-\frac{\beta_{n,k}}{\sigma_{nk}-1}} \prod_k \widehat{r}_{n,k}^{\frac{\beta_{n,k}}{\varepsilon_n}\left[-1+(\varepsilon_n-1)\left((\eta_{n,k}-1)^{-1}+\phi_{n,k}\right)\right]}$$

Using Equations 12 and 14 that define $\omega_{i,k}^{(1)}$ and $\omega_{i,k}^{(2)}$, we can express the welfare formula as:

$$\widehat{W}_n = \prod_k \widehat{\pi}_{nn,k}^{-\frac{\beta_{n,k}}{\sigma_{nk}-1}} \prod_k \widehat{r}_{n,k}^{\frac{\beta_{n,k}(\omega_{n,k}^{(2)}-1)}{\omega_{n,k}^{(1)}}}$$

This reproduces Equation (25) in the main text. Given $\widehat{\pi}_{nn,k}$, $\widehat{r}_{n,k}$ and Cobb-Douglas shares $\beta_{n,k}$, sufficient statistics for gains from trade are the trade elasticity $\sigma_{nk}-1$ and specialization elasticity $(\omega_{n,k}^{(2)}-1)/\omega_{n,k}^{(1)}$.

1.2.1 Derivations of Supply and Aggregation Elasticities

Supply Elasticity ($\omega_{i,k}^{(1)}$). Using Equation (2), we write wage $w_{i,k}$ as a function of product-level price at the location of production $p_{ii,k}$,

$$w_{i,k} = p_{ii,k}^{\frac{1}{1-(\varepsilon_i-1)\phi_{i,k}}} \left(a_{i,k}\frac{\eta_{i,k}-1}{\eta_{i,k}}\right)^{\frac{1}{1-(\varepsilon_i-1)\phi_{i,k}}} \left(L_i\Phi_i^{1-\varepsilon_i}e_{i,k}\right)^{\frac{\phi_{i,k}}{1-(\varepsilon_i-1)\phi_{i,k}}} \tag{A.7}$$

Replacing Equation (A.7) into Equation (3) we express total production $Y_{i,k}$ as a function of product-level price at the location of production $p_{ii,k}$,

$$\begin{aligned}Y_{i,k} &= \left(L_i\Phi_i^{1-\varepsilon_i}e_{i,k}\right)w_{i,k}^{\varepsilon_i} \\ &= \left(L_i\Phi_i^{1-\varepsilon_i}e_{i,k}\right)\left[p_{ii,k}^{\frac{1}{1-(\varepsilon_i-1)\phi_{i,k}}} \left(a_{i,k}\frac{\eta_{i,k}-1}{\eta_{i,k}}\right)^{\frac{1}{1-(\varepsilon_i-1)\phi_{i,k}}} \left(L_i\Phi_i^{1-\varepsilon_i}e_{i,k}\right)^{\frac{\phi_{i,k}}{1-(\varepsilon_i-1)\phi_{i,k}}}\right]^{\varepsilon_i} \\ &= \left(L_i\Phi_i^{1-\varepsilon_i}e_{i,k}\right)^{\frac{1+\phi_{i,k}}{1-(\varepsilon_i-1)\phi_{i,k}}} \left(a_{i,k}\frac{\eta_{i,k}-1}{\eta_{i,k}}\right)^{\frac{\varepsilon_i}{1-(\varepsilon_i-1)\phi_{i,k}}} p_{ii,k}^{\frac{\varepsilon_i}{1-(\varepsilon_i-1)\phi_{i,k}}} \\ &= \underbrace{\left(L_ie_{i,k}\right)^{\frac{1+\phi_{i,k}}{\varepsilon_i}\omega_{i,k}^{(1)}} \left(\frac{\eta_{i,k}-1}{\eta_{i,k}}\right)^{\omega_{i,k}^{(1)}} \Phi_i^{1-\omega_{i,k}^{(1)}} a_{i,k}^{\omega_{i,k}^{(1)}}}_{\equiv y_{i,k}} p_{ii,k}^{\omega_{i,k}^{(1)}}\end{aligned} \tag{A.8}$$

which delivers Equation (12),

$$\omega_{i,k}^{(1)} \equiv \frac{\partial \ln Y_{i,k}}{\partial \ln p_{ii,k}} = \frac{\varepsilon_i}{1-(\varepsilon_i-1)\phi_{i,k}}$$

Aggregation Elasticity ($\omega^{(2)}_{i,k}$). To derive the aggregation elasticity, we first express $Y_{i,k}$ as a function of the aggregate price index at the location of exports $P_{ii,k}$. Write the mass of firms $M_{i,k}$ as a function of product-level price $p_{ii,k}$. Then, replace $E_{i,k} = L_i \Phi_i^{1-\varepsilon_i} e_{i,k} w_{i,k}^{\varepsilon_i - 1}$ into $M_{i,k} = E_{i,k}/(\eta_{i,k} F_{i,k})$, and use Equation (A.7) to replace wages by prices,

$$\begin{aligned} M_{i,k} &= \frac{L_i \Phi^{\varepsilon_i - 1} e_{i,k} w_{i,k}^{\varepsilon_i - 1}}{\eta_{i,k} F_{i,k}} \\ &= \frac{L_i \Phi^{\varepsilon_i - 1}}{\eta_{i,k} F_{i,k}} \left[p_{ii,k}^{\frac{1}{1-(\varepsilon_i - 1)\phi_{i,k}}} \left(a_{i,k} \frac{\eta_{i,k} - 1}{\eta_{i,k}} \right)^{\frac{1}{1-(\varepsilon_i - 1)\phi_{i,k}}} \left(L_i \Phi_i^{1-\varepsilon_i} e_{i,k} \right)^{\frac{\phi_{i,k}}{1-(\varepsilon_i - 1)\phi_{i,k}}} \right]^{\varepsilon_i - 1} \\ &= (\eta_{i,k} F_{i,k})^{-1} \left(L_i \Phi_i^{1-\varepsilon_i} e_{i,k} \right)^{\frac{1}{1-(\varepsilon_i - 1)\phi_{i,k}}} \left(a_{i,k} \frac{\eta_{i,k} - 1}{\eta_{i,k}} \right)^{\frac{\varepsilon_i - 1}{1-(\varepsilon_i - 1)\phi_{i,k}}} p_{ii,k}^{\frac{\varepsilon_i - 1}{1-(\varepsilon_i - 1)\phi_{i,k}}} \end{aligned} \tag{A.9}$$

Replacing this relationship into Equation (4),

$$\begin{aligned} P_{ii,k} &= M_{i,k}^{\frac{1}{1-\eta_{i,k}}} p_{ii,k} \\ &= \left[(\eta_{i,k} F_{i,k})^{-1} \left(L_i \Phi_i^{1-\varepsilon_i} e_{i,k} \right)^{\frac{1}{1-(\varepsilon_i - 1)\phi_{i,k}}} \left(a_{i,k} \frac{\eta_{i,k} - 1}{\eta_{i,k}} \right)^{\frac{\varepsilon_i - 1}{1-(\varepsilon_i - 1)\phi_{i,k}}} p_{ii,k}^{\frac{\varepsilon_i - 1}{1-(\varepsilon_i - 1)\phi_{i,k}}} \right]^{\frac{1}{1-\eta_{i,k}}} p_{ii,k} \\ &= (\eta_{i,k} F_{i,k})^{\frac{1}{\eta_{i,k} - 1}} \left(L_i \Phi_i^{1-\varepsilon_i} e_{i,k} \right)^{-\frac{1}{\eta_{i,k} - 1} \frac{1}{1-(\varepsilon_i - 1)\phi_{i,k}}} \left(a_{i,k} \frac{\eta_{i,k} - 1}{\eta_{i,k}} \right)^{-\frac{1}{\eta_{i,k} - 1} \frac{\varepsilon_i - 1}{1-(\varepsilon_i - 1)\phi_{i,k}}} p_{ii,k}^{1 - \frac{1}{\eta_{i,k} - 1} \frac{\varepsilon_i - 1}{1-(\varepsilon_i - 1)\phi_{i,k}}} \\ &= (\eta_{i,k} F_{i,k})^{\frac{1}{\eta_{i,k} - 1}} \left(L_i e_{i,k} \right)^{-\frac{\omega^{(2)}_{i,k}}{\varepsilon_i - 1}} \left(\frac{\eta_{i,k} - 1}{\eta_{i,k}} \right)^{-\omega^{(2)}_{i,k}} \Phi_i^{\omega^{(2)}_{i,k}} a_{i,k}^{-\omega^{(2)}_{i,k}} p_{ii,k}^{1-\omega^{(2)}_{i,k}} \end{aligned} \tag{A.10}$$

which reproduces Equation (14),

$$\frac{\partial \ln P_{ii,k}}{\partial \ln p_{ii,k}} = 1 - \omega^{(2)}_{i,k}, \quad \text{where} \quad \omega^{(2)}_{i,k} = \frac{1}{(\eta_{i,k} - 1)} \frac{(\varepsilon_i - 1)}{1 - (\varepsilon_i - 1)\phi_{i,k}}.$$

1.2.2 Specifying shifters of demand, supply, and aggregation

Recall that demand $D_{ni,k}$, supply $Y_{i,k}$, and variety-level price index $P_i i, k$ can be expressed as functions of product-level price $p_{ii,k}$ in the following way:

$$D_{ni,k} = \delta_{ni,k} p_{ii,k}^{(1-\omega^{(2)}_{i,k})(1-\sigma_{n,k})} \tag{A.11}$$

$$Y_{i,k} = y_{i,k} p_{ii,k}^{\omega^{(1)}_{i,k}} \tag{A.12}$$

$$P_{ii,k} = \Lambda_{i,k} p_{ii,k}^{1-\omega^{(2)}_{i,k}} \tag{A.13}$$

Using the derivations in the previous section, we can obtain the shifters of demand $\delta_{ni,k}$, of supply $y_{i,k}$, and of aggregation $\Lambda_{i,k}$,

$$\delta_{ni,k} \equiv b_{ni,k}\tau_{ni,k}^{1-\sigma_{n,k}} {P_{n,k}}^{-(1-\sigma_{n,k})} \Lambda_{i,k}^{1-\sigma_{n,k}} \beta_{n,k} X_n \tag{A.14}$$

$$\begin{aligned} y_{i,k} \equiv & \left(L_i e_{i,k}\right)^{\omega_{i,k}^{(1)}\left[\frac{1+\phi_{i,k}}{\varepsilon_i}+\frac{\omega_{i,k}^{(2)}}{(1-\omega_{i,k}^{(2)})(\varepsilon_i-1)}\right]} \left(\frac{\eta_{i,k}-1}{\eta_{i,k}}\right)^{\frac{\omega_{i,k}^{(1)}}{\omega_{i,k}^{(2)}}} \left(\eta_{i,k}F_{i,k}\right)^{-\frac{\omega_{i,k}^{(1)}}{(\eta_{i,k}-1)(1-\omega_{i,k}^{(2)})}} \\ & \times \Phi_i^{1-\omega_{i,k}^{(1)}-\frac{\omega_{i,k}^{(1)}\omega_{i,k}^{(2)}}{1-\omega_{i,k}^{(2)}}} \Lambda_{i,k}^{\frac{\omega_{i,k}^{(1)}}{1-\omega_{i,k}^{(2)}}} a_{i,k}^{\omega_{i,k}^{(1)}+\frac{\omega_{i,k}^{(1)}\omega_{i,k}^{(2)}}{1-\omega_{i,k}^{(2)}}} \end{aligned} \tag{A.15}$$

$$\Lambda_{i,k} \equiv \left(\eta_{i,k}F_{i,k}\right)^{\frac{1}{\eta_{i,k}-1}} \left(L_i e_{i,k}\right)^{-\frac{\omega_{i,k}^{(2)}}{\varepsilon_i-1}} \left(\frac{\eta_{i,k}-1}{\eta_{i,k}}\right)^{-\omega_{i,k}^{(2)}} \Phi_i^{\omega_{i,k}^{(2)}} a_{i,k}^{-\omega_{i,k}^{(2)}} \tag{A.16}$$

1.2.3 Alternative Derivation of Export Supply Elasticity Using Exact Hat Algebra

Consider an exogenous increase in demand, $b_{ni,k}$, for exporter i, importer n, and good k. We have defined export supply elasticity as the partial derivative of log exports value with respect to log price. Illustrated by Figure (A.1), the inverse of export supply elasticity is given by

$$(\omega_{ni,k}^{(S)})^{-1} = \tan(\theta) = \frac{\Delta}{d\ln b_{ni,k}} = \frac{d\ln p_{ni,k}}{d\ln X_{ni,k}} \tag{A.17}$$

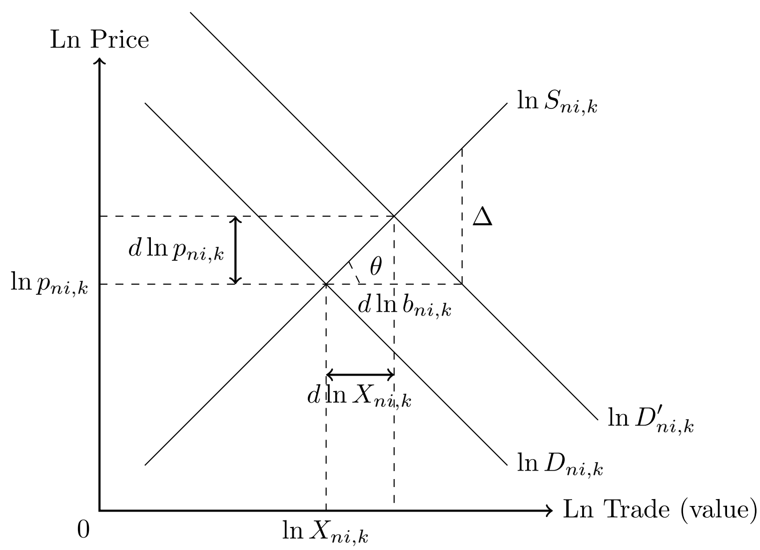

Figure A.1: Market for destination $n-$origin $i-$industry k

Specifically, we derive $\omega_{ni,k}^{(S)}$ by use the exact hat algebra to track responses to a demand shock, $\widehat{b}_{ni,k} > 1$, while all other exogenous parameters remain unchanged: $\widehat{d}_{ni,k} = \widehat{t}_{ni,k} = \widehat{a}_{i,k} = \widehat{\beta}_{n,k} = 1$. Consistent with taking into account only the partial derivatives, we ignore the second order effects of a change in $b_{ni,k}$ on factor rewards and aggregate income.[39] Replacing for $\widehat{Y}_{i,k}$, we can express the numerator of Equation (A.5) in terms of only the demand shock and

[39] This implies that $\widehat{w}_{\ell,k} = 1$ for all $\ell \neq i$, and $\widehat{\Phi}_n = 1$ for all n. Graphically, a change to Φ_n, as income per capita in country n, will make an additional shift to the import demand, which we do not consider as we set $\widehat{\Phi}_n = 1$.

the change to wage:

$$\widehat{b}_{ni,k}\widehat{w}_{i,k}^{\mu_{ni,k}}$$

where

$$\mu_{ni,k} \equiv (\sigma_{n,k}-1)\Big((\varepsilon_i-1)((\eta_{i,k}-1)^{-1}+\phi_{i,k})-1\Big)$$

The change to price index (A.4), in turn, equals:

$$\widehat{P}_{n,k}^{1-\sigma_{n,k}} = (1-\pi_{ni,k}) + \pi_{ni,k}\widehat{b}_{ni,k}\widehat{w}_{i,k}^{\mu_{ni,k}}$$

Replacing the above expressions into Equations (A.4) and (A.5), and setting the second order effects of $dxdy$ at zero for generic dx and dy, we arrive at:

$$\widehat{X}_{ni,k} = \frac{\widehat{b}_{ni,k}\widehat{w}_{i,k}^{\mu_{ni,k}}}{(1-\pi_{ni,k}) + \pi_{ni,k}\widehat{b}_{ni,k}\widehat{w}_{i,k}^{\mu_{ni,k}}}$$

Using $\widehat{x} = 1 + d\ln x$ for a generic variable x,

$$\begin{aligned}
1 + d\ln X_{ni,k} &= \frac{(1+d\ln b_{ni,k})(1+\mu_{ni,k}d\ln w_{i,k})}{(1-\pi_{ni,k}) + \pi_{ni,k}(1+d\ln b_{ni,k})(1+\mu_{ni,k}d\ln w_{i,k})} \\
d\ln X_{ni,k} &= \frac{1+d\ln b_{ni,k}+\mu_{ni,k}d\ln w_{i,k}}{1+\pi_{ni,k}(d\ln b_{ni,k}+\mu_{ni,k}d\ln w_{i,k})} - 1 \\
d\ln X_{ni,k} &= \frac{(1-\pi_{ni,k})(d\ln b_{ni,k}+\mu_{ni,k}d\ln w_{i,k})}{1+\pi_{ni,k}(d\ln b_{ni,k}+\mu_{ni,k}d\ln w_{ni,k})} \qquad \text{(A.18)}
\end{aligned}$$

In addition, using Equations (A.1) and (A.5), we can express the change to exports and outputs as:

$$d\ln X_{mi,k} = \mu_{mi,k}d\ln w_{i,k} \qquad \text{(A.19)}$$

$$d\ln Y_{i,k} = \varepsilon_i d\ln w_{i,k} \qquad \text{(A.20)}$$

Using market clearing Equation (A.6) before and after the change to $b_{ni,k}$,

$$X_{ni,k}d\ln X_{ni,k} + \sum_{m\neq n} X_{mi,k}d\ln X_{mi,k} = Y_{i,k}d\ln Y_{i,k}$$

We now replace (A.18), (A.19), (A.20) into the above equation,

$$X_{ni,k}\left[\frac{(1-\pi_{ni,k})(d\ln b_{ni,k}+\mu_{ni,k}d\ln w_{i,k})}{1+\pi_{ni,k}(d\ln b_{ni,k}+\mu_{ni,k}d\ln w_{i,k})}\right] + \sum_{m\neq n} X_{mi,k}\mu_{mi,k}d\ln w_{i,k} = Y_{i,k}\varepsilon_i d\ln w_{i,k}$$

Rearranging the above equation and ignoring second order effects, the wage response, $d\ln w_{i,k}$, to the demand shock, $d\ln b_{ni,k}$, is given by

$$d\ln w_{i,k} = \frac{1-\pi_{ni,k}}{\varepsilon_i\frac{Y_{i,k}}{X_{ni,k}} - \sum_{m\neq n}\frac{X_{mi,k}}{X_{ni,k}}\mu_{mi,k} - (1-\pi_{ni,k})\mu_{ni,k}} d\ln b_{ni,k} \qquad \text{(A.21)}$$

Replacing $d\ln w_{i,k}$ from (A.21) into (A.18),

$$d\ln X_{ni,k} = (1-\pi_{ni,k})\Big[\frac{\varepsilon_i\frac{Y_{i,k}}{X_{ni,k}} - \sum_{m\neq n}\frac{X_{mi,k}}{X_{ni,k}}\mu_{mi,k}}{\varepsilon_i\frac{Y_{i,k}}{X_{ni,k}} - \sum_{m\neq n}\frac{X_{mi,k}}{X_{ni,k}}\mu_{mi,k} - (1-\pi_{ni,k})\mu_{ni,k}}\Big] d\ln b_{ni,k} \qquad \text{(A.22)}$$

In addition, Equation (2) implies that $d\ln p_{ni,k} = (1-(\varepsilon_i - 1)\phi_{i,k})d\ln w_{i,k}$. Replacing $d\ln w_{i,k}$ from (A.21),

$$d\ln p_{ni,k} = \frac{(1-(\varepsilon_i-1)\phi_{i,k})(1-\pi_{ni,k})}{\varepsilon_i \frac{Y_{i,k}}{X_{ni,k}} - \sum_{m\neq n}\frac{X_{mi,k}}{X_{ni,k}}\mu_{mi,k} - (1-\pi_{ni,k})\mu_{ni,k}} d\ln b_{ni,k} \tag{A.23}$$

Using Equations (A.22)-(A.23), the expression for the export supply elasticity given by by Equation (A.17), and recalling that $\mu_{ni,k} \equiv (\sigma_{n,k}-1)((\varepsilon_i-1)((\eta_{i,k}-1)^{-1}+\phi_{i,k})-1)$, we obtain $\omega^{(S)}_{ni,k}$,

$$\begin{aligned}
\omega^{(S)}_{ni,k} &= \frac{\varepsilon_i \frac{Y_{i,k}}{X_{ni,k}} - \sum_{m\neq n}\frac{X_{mi,k}}{X_{ni,k}}(\sigma_{m,k}-1)\Big((\varepsilon_i-1)((\eta_{i,k}-1)^{-1}+\phi_{i,k})-1\Big)}{1-(\varepsilon_i-1)\phi_{i,k}} \\
&= \frac{1}{\lambda_{ni,k}}\omega^{(1)}_{i,k} - \sum_{m\neq n}\frac{\lambda_{mi,k}}{\lambda_{ni,k}}(1-\sigma_{m,k})(1-\omega^{(2)}_{i,k})
\end{aligned}$$

where $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$ are given by Equations (12) and (14). This alternative approach, hence, delivers the exact same expression as Equation (18) in the main text.

1.3 Tariff Pass-through Rates

Recall that the price wedge between exporter i and importer n in industry k is given by $\tau_{ni,k} = d_{ni,k}(1+t_{ni,k})$, where $d_{ni,k}$ is the iceberg trade cost and $(1+t_{ni,k})$ is ad volarem equivalent tariff. Consider a change to tariff $(1+t_{ni,k})$ as the only change to exogenous variables, meaning that $\widehat{(1+t_{ni,k})} = \widehat{\tau}_{ni,k}$ We seek to derive the change to the price index $P_{ni,k}$,

$$\widehat{P}^{1-\sigma_{n,k}}_{ni,k} = \widehat{E}^{\alpha_{ni,k}}_{i,k}\widehat{\tau}^{1-\sigma_{n,k}}_{ni,k}\widehat{w}^{1-\sigma_{n,k}}_{i,k}$$

where as before,

$$\alpha_{ni,k} \equiv (\sigma_{nk}-1)((\eta_{i,k}-1)^{-1}+\phi_{i,k})$$

Using the above relationships and considering that $\widehat{E}_{ni,k} = \widehat{\Phi}^{1-\varepsilon_i}_i \widehat{w}^{\varepsilon_i - 1}_{i,k}$,

$$d\ln P_{ni,k} = d\ln\tau_{ni,k} + \frac{\mu_{ni,k}}{1-\sigma_{n,k}}d\ln w_{i,k} \tag{A.24}$$

where

$$\mu_{ni,k} \equiv (\sigma_{n,k}-1)\Big((\varepsilon_i-1)((\eta_{i,k}-1)^{-1}+\phi_{i,k})-1\Big)$$

where have ignored the second order effects. Similar to the derivation of Equation (A.21), we calculate $d\ln w_{i,k}$ in response to $d\ln\tau_{ni,k}$,

$$d\ln w_{i,k} = \underbrace{\frac{1-\pi_{ni,k}}{\varepsilon_i\frac{Y_{i,k}}{D_{ni,k}} - \sum_{m\neq n}\frac{D_{mi,k}}{D_{ni,k}}\mu_{mi,k} - (1-\pi_{ni,k})\mu_{ni,k}}}_{\Upsilon_{ni,k}}(1-\sigma_{n,k})d\ln\tau_{ni,k} \tag{A.25}$$

where $\Upsilon_{ni,k}$ summarizes the terms in the denominator. Replacing (A.24) into (A.25),

$$\begin{aligned}
d\ln P_{ni,k} &= \Bigg[1+\Upsilon_{ni,k}\mu_{ni,k}\Bigg]d\ln\tau_{ni,k} \\
&= \frac{\varepsilon_i\frac{Y_{i,k}}{D_{ni,k}} - \sum_{m\neq n}\frac{D_{mi,k}}{D_{ni,k}}\mu_{mi,k}}{\varepsilon_i\frac{Y_{i,k}}{D_{ni,k}} - \sum_{m\neq n}\frac{D_{mi,k}}{D_{ni,k}}\mu_{mi,k} - (1-\pi_{ni,k})\mu_{ni,k}}d\ln\tau_{ni,k}
\end{aligned}$$

Dividing the numerator and denominator by $(1-\omega_{i,k}^{(2)})(1-(\varepsilon_i-1)\phi_{i,k})$, and rearranging terms gives the pass-through rate of tariff onto the consumer price index,

$$
\begin{aligned}
\varrho_{ni,k} \equiv \frac{d\ln P_{ni,k}}{d\ln \tau_{ni,k}} &= \frac{\left[\frac{1}{\lambda_{ni,k}}\frac{\omega_{i,k}^{(1)}}{1-\omega_{i,k}^{(2)}} - \sum_{m\neq n}\frac{\lambda_{mi,k}}{\lambda_{ni,k}}(1-\sigma_{m,k})\right]}{\left[\frac{1}{\lambda_{ni,k}}\frac{\omega_{i,k}^{(1)}}{1-\omega_{i,k}^{(2)}} - \sum_{m\neq n}\frac{\lambda_{mi,k}}{\lambda_{ni,k}}(1-\sigma_{m,k})\right] + (\sigma_{n,k}-1)(1-\pi_{ni,k})} \\
&= \frac{\omega_{ni,k}^{(S)}/(1-\omega_{i,k}^{(2)})}{\omega_{ni,k}^{(S)}/(1-\omega_{i,k}^{(2)}) + (\sigma_{n,k}-1)(1-\pi_{ni,k})} \\
&= \frac{\omega_{ni,k}^{(S)}}{\omega_{ni,k}^{(S)} - \omega_{ni,k}^{(D)}(1-\pi_{ni,k})}
\end{aligned}
$$

where $\omega_{ni,k}^{(D)} \equiv (1-\omega_{i,k}^{(2)})(1-\sigma_{n,k})$ is import demand elasticity given by Equation (15) and $\omega_{ni,k}^{(S)}$ is export supply elasticity given by Equation (18). This reproduces Equation (30) in the main text. For the precise connection, note that $\tau_{ni,k} = d_{ni,k}(1+t_{ni,k})$ and since the iceberg trade cost $d_{ni,k}$ remains unchanged, $d\ln\tau_{ni,k} = d\ln(1+t_{ni,k})$.

1.4 Uniqueness Condition

As we have discussed extensively in Section **2.4**, our model belongs to a more general class of gravity-based models, simpler versions of which have been studied elsewhere. Some of the features in these other models are preserved in the extension to our model. This is particularly the case for the uniqueness condition. Here, we connect our setup to Kucheryavyy et al. (2021) to reproduce their uniqueness condition for the setting of our model.

Using the employment allocation equation, we can write wage per unit of efficiency as:

$$w_{i,k} = L_{i,k}^{1/\varepsilon_i}(L_i e_{i,k})^{-1/\varepsilon_i}\Phi_i$$

Then, using employment equation and $E_{i,k} = L_i\Phi_i^{1-\varepsilon_i}e_{i,k}w_{i,k}^{\varepsilon_i-1}$, we can express the aggregate supply of efficiency units as:

$$E_{i,k} = (L_i e_{i,k})^{1/\varepsilon_i}L_{i,k}^{(\varepsilon_i-1)/\varepsilon_i}$$

To proceed, let $\alpha_{ni,k} \equiv (\sigma_{n,k}-1)\Big((\eta_{i,k}-1)^{-1}+\phi_{i,k}\Big)$. Combining the two above equations yields the following:

$$
\begin{aligned}
E_{i,k}^{\alpha_{ni,k}}w_{i,k}^{1-\sigma_{n,k}} &= (L_i e_{i,k})^{(\alpha_{ni,k}+\sigma_{n,k}-1)/\varepsilon_i}\Phi_i^{1-\sigma_{n,k}}L_{i,k}^{(\varepsilon_i-1)\alpha_{ni,k}/\varepsilon_i+(1-\sigma_{n,k})/\varepsilon_i} \\
&= \bar{\gamma}_i\Phi_i^{1-\sigma_{n,k}}L_{i,k}^{(1-\sigma_{n,k})(1-\omega_{i,k}^{(2)})/\omega_{i,k}^{(1)}},
\end{aligned}
$$

where $\bar{\gamma}_i \equiv (L_i e_{i,k})^{(\alpha_{ni,k}+\sigma_{n,k}-1)/\varepsilon_i}\Phi_i^{1-\sigma_{n,k}}$. Plugging the above expression into the trade share equation,

$$
\begin{aligned}
\pi_{ni,k} &= \frac{h_{ni,k}E_{i,k}^{\alpha_{ni,k}}(\tau_{ni,k}w_{i,k})^{1-\sigma_{n,k}}}{\sum_\ell h_{n\ell,k}E_{\ell,k}^{\alpha_{n\ell,k}}(\tau_{n\ell,k}w_{\ell,k})^{1-\sigma_{n,k}}} \\
& \frac{h_{ni,k}L_{i,k}^{(1-\sigma_{n,k})(1-\omega_{i,k}^{(2)})/\omega_{i,k}^{(1)}}(\tau_{ni,k}\Phi_i)^{1-\sigma_{n,k}}}{\sum_\ell h_{n\ell,k}L_{\ell,k}^{(1-\sigma_{n,k})(1-\omega_{\ell,k}^{(2)})/\omega_{\ell,k}^{(1)}}(\tau_{n\ell,k}\Phi_\ell)^{1-\sigma_{n,k}}}
\end{aligned}
\tag{A.26}
$$

where $h_{ni,k} \equiv b_{ni,k}(\eta_{i,k}F_{i,k})^{-\frac{\sigma_{n,k}-1}{\eta_{i,k}-1}}\left(\frac{\eta_{i,k}}{\eta_{i,k}-1}\right)^{1-\sigma_{n,k}}a_{i,k}^{\sigma_{n,k}-1}$ is a composite exogenous shifter. Equation (A.26) connects our model to Equation (6) in Kucheryavyy et al. (2021) by noting that

$$\alpha_{ni,k}^{KLR} = (1 - \sigma_{n,k})(1 - \omega_{i,k}^{(2)})/\omega_{i,k}^{(1)}, \quad w_i^{KLR} = \Phi_i, \quad \epsilon_{n,k}^{KLR} = \sigma_{n,k} - 1.$$

This mapping then translates their key uniqueness condition to the following inequality:

$$(1 - \sigma_{n,k})(1 - \omega_{i,k}^{(2)})/\omega_{i,k}^{(1)} \leq 1.$$

Note that this inequality is a necessary condition for uniqueness, whereas its violation is sufficient for multiplicity. For a detailed discussion, we refer the reader to Propositions 1–5 in Kucheryavyy et al. (2021).

1.5 Numerical Algorithm for Solving the Model

1.5.1 Solving for prices based on market clearing in product markets

We solve the equilibrium in changes in terms of prices that clear product markets, described by the set of equations 19-24, using the following numerical algorithm. For some i' and k', we choose product (i', k') as the numeraire.

1. Guess $\widehat{p}_{ii,k}$ for all i, k (with $\widehat{p}_{i'i',k'} = 1$).
2. Compute $\widehat{Y}_{i,k}$ and $\widehat{\Phi}_i$ according to the following loop:
   (a) Guess $\widehat{\Phi}_i$;
   (b) Compute $\widehat{Y}_{i,k}$ using Equation (19);
   (c) Update $\widehat{\Phi}_i$ using Equation (20),
   $$\widehat{\Phi}_i^{new} = \frac{1}{L_i \Phi_i} \sum_{k \in K} Y_{i,k} \widehat{Y}_{i,k}$$
   Stop if $|\widehat{\Phi}_i^{new} - \widehat{\Phi}_i| \leq 10^{-12}$ for all i. Otherwise, update $\widehat{\Phi}_i = \widehat{\Phi}_i^{new}$ and go to Step 2(b).
3. Compute $\widehat{X}_n$ using Equation (21).
4. Compute $\widehat{P}_{ni,k}$ and $\widehat{X}_{ni,k}$ using equations (22) and (23).
5. Compute $\widehat{Y}_{i,k}$ based on market clearing condition (24), then $\widehat{\Phi}_i$ according to Equation (20).
6. Update prices $\widehat{p}_{ii,k}$ according to Equation (19),
   $$\widehat{p}_{ii,k}^{new} = \left(\frac{\widehat{Y}_{i,k}}{\widehat{a}_{i,k}^{\omega_{i,k}^{(1)}} \widehat{\Phi}_i^{1-\omega_{i,k}^{(1)}}} \right)^{1/\omega_{i,k}^{(1)}}$$
   Normalize all price changes relative to the numeraire. This implies $\widehat{p}_{i'i',k'} = 1$ which guarantees our choice of numeraire. Stop if $|\widehat{p}_{ii,k}^{new} - \widehat{p}_{ii,k}| \leq 10^{-9}$ for all i, k. Otherwise, update prices $\widehat{p}_{ii,k} = \widehat{p}_{ii,k}^{new}$ and go to Step 2.

1.5.2 Solving for wages based on market clearing in labor markets

We solve the equilibrium in changes in terms of wages that clear labor markets, described by the set of equations A.1-A.6, using the following numerical algorithm. We choose labor in some reference industry k'−country i' as numeraire.

1. Guess $\widehat{w}_{i,k}$ for all i, k. (with $\widehat{w}_{i',k'} = 1$).
2. Compute $\widehat{\Phi}_i$ and $\widehat{Y}_{i,k}$ using Equations (A.1) and (A.2).

3. Compute $\widehat{P}_{n,k}$ and $\widehat{X}_{ni,k}$ using equations (A.4), (A.5).
4. Update $\widehat{Y}_{i,k}$ based on the market clearing condition (A.6).
5. Update $\widehat{w}_{i,k}$ according to Equation (A.2),

$$\widehat{w}_{i,k}^{new} = \left(\widehat{\Phi}_i^{\varepsilon_i - 1}\widehat{Y}_{i,k}\right)^{1/\varepsilon_i}$$

   Normalize all wage changes relative to the numeraire $\widehat{w}_{i_0,k_0} = 1$. This implies $\widehat{w}_{i',k'} = 1$ which guarantees our choice of numeraire. Stop if $|\widehat{w}_{i,k}^{new} - \widehat{w}_{i,k}| \leq 10^{-9}$ for all i, k. Otherwise, update wages $\widehat{w}_{i,k} = \widehat{w}_{i,k}^{new}$ and go to Step 2.

1.6 Supplementary material for the estimation

In this section, we show how to log-linearize import demand and export supply functions around exogenous variables and endogenous prices. This further clarifies how we derive from our model the estimable equations which we bring to data. We take advantage of our derivations also to spell out the assumptions underlying our estimation.

Recall import demand $D_{ni,k}$ and export supply $S_{ni,k}$ functions:

$$D_{ni,k} = \delta_{ni,k} p_{ii,k}^{(1-\omega_{i,k}^{(2)})(1-\sigma_{n,k})} \tag{A.27}$$

$$S_{ni,k} = y_{i,k} p_{ii,k}^{\omega_{i,k}^{(1)}} - \sum_{m \neq n} \delta_{mi,k} p_{ii,k}^{(1-\omega_{i,k}^{(2)})(1-\sigma_{m,k})} \tag{A.28}$$

where $\delta_{ni,k}$ and $y_{i,k}$ combine corresponding non-price shifters as shown in Section **1.2.2** of the Appendix. In reference to the components that constitute these shifters, and for the sake of illustration, and for the sake of exposition, we suppose that the supply shifter that changes over time is the productivity shifter $a_{i,k}$ (that is, we normalize $e_{i,k} = 1$ and $F_{i,k} = 1$ with the understanding that we could incorporate employment shifters $e_{i,k}$ and entry costs $F_{i,k}$), and the demand shifter that changes over time is $b_{ni,k}$ (that is, we normalize $\tau_{nik} = 1$ with the understanding that we could incorporate trade cost $\tau_{ni,k}$).

We now write import demand $D_{ni,k}$ and export supply $S_{ni,k}$ in log-linear terms, for local changes to endogenous variables e.g., price $p_{ni,k}$, and local changes to exogenous productivity and demand shifters, $a_{ni,k}$ and $b_{ni,k}$. Starting with import demand, and incorporating the time subscript, $D_{ni,k,t}$ can be expressed as a function of time-varying vector $(p_{ni,k,t}, a_{i,k,t}, \Phi_{i,t}, b_{ni,k,t}, P_{n,k,t}, X_{n,t})$. By log-linearizing demand,

$$\begin{aligned} \Delta \ln D_{ni,k,t} &= \omega_{ni,k}^{(D)} \Delta \ln p_{ni,k,t} + \varsigma_{ni,k}^{(a)} \Delta \ln a_{i,k,t} - \varsigma_{ni,k}^{(\Phi)} \Delta \ln \Phi_{i,t} \\ &\quad + \varsigma_{n,k}^{(P)} \Delta \ln P_{n,k,t} + \Delta \ln X_{n,t} + \Delta \ln b_{ni,k,t} \end{aligned} \tag{A.29}$$

$$\text{where} \quad \begin{aligned} \omega_{ni,k}^{(D)} &= (1-\sigma_{n,k})(1-\omega_{i,k}^{(2)}) \\ \varsigma_{ni,k}^{(a)} &= (1-\sigma_{n,k})(-\omega_{i,k}^{(2)}) \\ \varsigma_{ni,k}^{(\Phi)} &= (1-\sigma_{n,k})(-\omega_{i,k}^{(2)}) \\ \varsigma_{n,k}^{(P)} &= -(1-\sigma_{n,k}) \end{aligned}$$

Note that the coefficient of log price in the above import demand equation, $\omega^{(D)}_{ni,k}$, is what we have defined as the import demand elasticity.

We now turn to the log-linearization of export supply. Incorporating the time subscript, we note that $S_{ni,k,t}$ can be expressed as a function of time-varying vector $(p_{ni,k,t}, a_{i,k,t}, \Phi_{i,t}, \{b_{mi,k,t}\}_{m\neq n}, \{P_{m,k,t}\}_{m\neq n}, \{X_{m,t}\}_{m\neq n})$. By log-linearizing supply,

$$\begin{aligned}\Delta \ln S_{ni,k,t} &= \omega^{(S)}_{ni,k,t}\Delta \ln p_{ni,k,t} + \xi^{(a)}_{ni,k,t}\Delta \ln a_{i,k,t} + \xi^{(\Phi)}_{ni,k,t}\Delta \ln \Phi_{i,t} \\ &\quad + \sum_{m\neq n}\left(\xi^{(b)}_{ni,k,t}\Delta \ln b_{mi,k,t} + \xi^{(P)}_{nmi,k,t}\Delta \ln P_{m,k,t} + \xi^{(X)}_{ni,k,t}\Delta \ln X_{m,t}\right) \qquad \text{(A.30)} \\ & \qquad \text{(A.31)}\end{aligned}$$

$$\begin{aligned}\text{where} \qquad \omega^{(S)}_{ni,k,t} &= \frac{1}{\lambda_{ni,kt}}\omega^{(1)}_{i,k} - \sum_{m\neq n}\frac{\lambda_{mi,kt}}{\lambda_{ni,kt}}(1-\sigma_{m,k})(1-\omega^{(2)}_{i,k}) \\ \xi^{(a)}_{ni,k,t} &= \frac{1}{\lambda_{ni,kt}}\omega^{(1)}_{i,k} - \sum_{m\neq n}\frac{\lambda_{mi,kt}}{\lambda_{ni,kt}}(1-\sigma_{m,k})(-\omega^{(2)}_{i,k}) \\ \xi^{(\Phi)}_{ni,k,t} &= \frac{1}{\lambda_{ni,kt}}(1-\omega^{(1)}_{i,k}) - \sum_{m\neq n}\frac{\lambda_{mi,kt}}{\lambda_{ni,kt}}(1-\sigma_{m,k})\omega^{(2)}_{i,k} \\ \xi^{(b)}_{ni,k,t} &= \frac{1-\lambda_{ni,kt}}{\lambda_{ni,kt}} \\ \xi^{(P)}_{nmi,k,t} &= -(1-\sigma_{m,k})\frac{1-\lambda_{ni,kt}}{\lambda_{ni,kt}} \\ \xi^{(X)}_{ni,k,t} &= \frac{1-\lambda_{ni,kt}}{\lambda_{ni,kt}}\end{aligned}$$

Note that, unlike the import demand, the coefficients of local changes to prices and shifters are time-dependent in export supply, and in turn the coefficient of log price in the export supply equation, $\omega^{(S)}_{ni,k,t}$, is what we have defined as the export supply elasticity.

In addition, note that the coefficient of productivity $a_{ni,k}$ and income per capita Φ_i (given by Equation 1), are precisely the same in the log-linearized import demand $\varsigma^{(a)}_{ni,k} = \varsigma^{(\Phi)}_{ni,k}$. The relationship in the log-linearized export supply is $\xi^{(a)}_{ni,k} = -\xi^{(\Phi)}_{ni,k} - \widetilde{\lambda}_{ni,k,t}$ where $\widetilde{\lambda}_{ni,k,t} \equiv 1/\lambda_{ni,k,t}$. Consequently, instead of tracking $\ln a_{i,k}$, we define what we refer to as log adjusted-productivity, $\ln \tilde{a}_{i,k,t} \equiv \ln a_{i,k,t} - \ln \Phi_{i,t}$, and track changes to $\ln \tilde{a}_{i,k,t}$.

We now map the above equations to changes in the residuals of import demand and export supply in relation to the pair of estimable Equations (26) in Section **3**.

The import demand equation, in the second line of (26), maps to Equation (A.29) according to the following over-time change to the import demand residual:

$$\Delta\rho_{ni,kt} \quad = \quad \varsigma^{(a)}_{ni,k}\Delta \ln \tilde{a}_{i,k,t} + \Delta \ln b_{ni,k,t} \qquad \text{(A.32)}$$

To complete the mapping, also note that $\Delta\psi_{ni,k} = 0$ and $\Delta\psi_{n,kt} \equiv \varsigma^{(P)}_{n,k}\Delta \ln P_{n,k,t} + \Delta \ln X_{n,t}$.

Next, we turn to the mapping for the export supply equation, between the first line of Equation (26) in the main text and Equation (A.31) which we outlined above. The importer-exporter-industry fixed effect in Equation (26) disappears by taking differences over time, i.e., $\Delta\upsilon_{ni,k} = 0$. We can extract an importer-industry-year fixed effect from Equation (A.31) using the following relationship:

$$\xi^{(b)}_{ni,k,t} \sum_{m \neq n} \left((\sigma_{m,k} - 1)\Delta \ln P_{m,k,t} + \Delta \ln X_{m,t} \right) = \Delta\upsilon_{n,k,t} + \epsilon_{ni,kt} \tag{A.33}$$

The summation term in the above equation by structure varies only along the dimension of (n, k, t). Therefore, $\epsilon_{ni,kt}$ is defined as the deviation around this summation term—reflecting that the coefficient $\xi^{(b)}_{ni,k,t}$ may vary also across origins. Putting together, the over-time change to the residual in the export supply equation can be expressed as:

$$\Delta\varphi_{ni,kt} = \xi^{(a)}_{ni,k,t} \Delta \ln \tilde{a}_{i,k,t} + \widetilde{\lambda}_{ni,k,t} \Delta \ln \Phi_{i,t} + \xi^{(b)}_{ni,k,t} \sum_{m \neq n} \Delta \ln b_{mi,k,t} + \epsilon_{ni,kt} \tag{A.34}$$

Having derived the residuals of import demand and export supply equations, $\Delta\rho_{ni,kt}$ according to (A.32) and $\Delta\varphi_{ni,kt}$ according to (A.34), we now turn to required conditions for the identification assumption that residuals of import demand and export supply are independent from each other other over time.

We focus on the set of our estimable equations as described by the pair of import demand and export supply equations (27).[40] Recall that our estimation of Equation (27) is carried out importer by importer. That is, for the estimation that uses data on importer n, we fix importer n and exploit variations across exporters. As such, we convert all variables to changes over time relative to an origin reference. This means that for a generic variable $x_{ni,k,t}$, we consider $\Delta^j \ln x_{ni,kt} \equiv (\ln x_{ni,kt} - \ln x_{ni,kt-1}) - (\ln x_{nj,kt} - \ln x_{nj,kt-1})$ where j is an origin reference. By converting variables relative to origin reference j, $\Delta^j \psi_{n,k,t} = 0$ in the import demand and $\Delta^j \upsilon_{n,k,t} = 0$ in the export supply. Specifically, our identification assumption—which has been also used across the literature on heteroskedastic estimators–requires that $\mathbb{E}[\Delta^j \rho_{ni,kt} \Delta^j \varphi_{ni,kt}] = 0$. Below, we discuss the basic conditions that can lead to this independence assumption. Consider the following:

1. Productivity shocks in exporting country and demand shocks in importing country, denoted as relative to a reference country, are independent over time, $\mathbb{E}[\Delta^j \ln \tilde{a}_{i,k,t} \Delta^j \ln b_{ni,k,t}] = 0$.

2. Demand shocks across importing countries, denoted as relative to a reference country, are independent over time, $\mathbb{E}[\Delta^j \ln b_{mi,k,t} \Delta^j \ln b_{ni,k,t}] = 0$, for $m \neq n$.

3. Demand shocks in a single industry of importing country and income per capita in exporting country, denoted as relative to a reference country, are independent over time, $\mathbb{E}[\Delta^j \ln \Phi_{i,t} \Delta^j \ln b_{ni,k,t}] = 0$.

4. The error term from deviations in the importer-industry-time fixed effect of the change to export supply, $\epsilon_{ni,kt}$, and the change to the import demand residual, $\rho_{ni,kt}$, denoted as relative to a reference country, are independent over time $\mathbb{E}[\Delta^j \epsilon_{ni,kt} \Delta^j \rho_{ni,kt}]$.

5. Demand shocks in importing countries and productivity shocks in exporting countries, denoted in log terms and relative to a reference country, evolve over time independently from their initial levels, $[\ln(b_{nik,t}/b_{njk,t})\Delta^j \ln b_{ni,k,t}] = [\ln(a_{ik,t}/a_{jk,t})\Delta^j \ln a_{i,k,t}] = 0$ and $[\ln(a_{ik,t}/a_{jk,t})\Delta^j \ln b_{ni,k,t}] = [\ln(b_{nik,t}/b_{njk,t})\Delta^j \ln a_{i,k,t}] = 0$.

[40] A similar discussion can be applied equivalently to the set of expressions that constitute Equation 29.

We take a moment to explain these assumptions. A particular case regarding Assumption (1) is where an exporting country i experiences a labor productivity growth in industry k that equals the growth in income per capita there. In this case, $\Delta \ln \tilde{a}_{i,k,t} = \Delta \ln(a_{i,k,t}/\Phi_{i,t}) = 0$, and so, $\Delta^j \ln \tilde{a}_{i,k,t} = 0$, which then implies that Assumption (1) is automatically satisfied. Over a sufficiently long period, this statement is sensible in expectation. Moving to Assumption (2), we simply require that exogenous changes to demand across countries do not systematically depend on each other once they are considered across origins within an industry. Notice that, we are controlling for importer-exporter-industry fixed effects in our specification (to be canceled out by differencing over time). So, we control for the overall correlations in demand between countries, and here require that their changes do not exhibit further systematic pattern over a sufficiently long period of time. Turning to Assumption (3), as long as the product space is adequately disaggregated, then it is sensible to suppose that the effect of a taste shock from only one importing country in only one industry on the income per capita of the exporting country is negligible. Lastly, Assumption (4) is required for completeness, because the coefficient of demand shifters in the log-linearized export supply function may also vary by exporter. Assumption (5) requires that shocks to the model in each year remain to be exogenous with respect to baseline equilibrium values of that year. This guarantees that for a generic variable x_t in year t, for example, if Assumption (1) holds, then $\mathbb{E}[x_t \Delta^j \ln \tilde{a}_{i,k,t} \Delta^j \ln b_{ni,k,t}] = 0$.

Next, putting together the above assumptions with the changes to residuals of log import demand and log export supply, we have:

$$\begin{aligned}
\mathbb{E}[\Delta^j \rho_{ni,k,t} \Delta^j \varphi_{ni,k,t}] = \quad & \underbrace{\mathbb{E}[\varsigma^{(b)}_{ni,k} \xi^{(a)}_{ni,k,t} (\Delta^j \ln a_{i,k,t})(\Delta^j \ln b_{ni,k,t})]}_{=0 \text{ (Assumptions 1 \& 5)}} + \underbrace{\mathbb{E}[\varsigma^{(b)}_{ni,k} \xi^{(\Phi)}_{ni,k,t} (\Delta^j \ln \Phi_{i,t})(\Delta^j \ln b_{ni,k,t})]}_{=0 \text{ (Assumptions 3 \& 5)}} \\
& \underbrace{\mathbb{E}[\varsigma^{(a)}_{ni,k} \Delta^j \ln a_{i,k,t} \sum_{m \neq n} \xi^{(b)}_{mi,k,t} \Delta^j \ln b_{mi,k,t}]}_{=0 \text{ (Assumptions 1 \& 5)}} + \underbrace{\mathbb{E}[\varsigma^{(b)}_{ni,k} \Delta^j \ln b_{ni,k,t} \sum_{m \neq n} \xi^{(b)}_{mi,k,t} \Delta^j \ln b_{mi,k,t}]}_{=0 \text{ (Assumptions 2 \& 5)}} + \\
& \underbrace{\mathbb{E}[\delta^j_{ni,kt} \Delta^j \rho_{ni,kt}]}_{=0 \text{ (Assumption 4)}} + \mathbb{E}[\varsigma^{(a)}_{ni,k} \xi^{(a)}_{ni,k,t} (\Delta^j \ln \tilde{a}_{i,k,t})^2] + \mathbb{E}[\varsigma^{(a)}_{ni,k} \widetilde{\lambda}_{ni,k,t} (\Delta^j \ln \tilde{a}_{i,k,t})(\Delta^j \ln \Phi_{i,t})]
\end{aligned} \tag{A.35}$$

The resulting expression depends only on the second moment changes to log adjusted-productivity shock and its covariance with change to income per capita in the exporting country. Ultimately, these two terms may constitute a nonzero component remaining in the expectation term. However, this remainder term can be connected to the discussion about the measurement error in Feenstra (1994) and Broda and Weinstein (2006). Specifically, Broda and Weinstein (2006) control for $Z_{ni,k,t} = T^{\frac{3}{2}}_{ni,k} \left(\frac{1}{X_{ni,kt}} + \frac{1}{X_{ni,k,t-1}} \right)^{-\frac{1}{2}}$ as a right-hand side variable in their final estimable equation, where T is the duration of the trade relationship for ni, k. We also follow this approach. Thus we require that the remainder term is proportional to $\mathbb{E}[Z_{ni,k,t}]$.

Appendix B Additional Results

2.1 Import and Export Elasticities w.r.t. Home Demand

Table A.1: Export elasticity of home demand

	Food	Textile	Wood	Paper	Petr	Chem	Rubber	Mineral	B Metal	F Metal	Mach	Elect	E Mach	Vehicle	Other T	Furniture
AUS	0.10	0.27	0.12	0.38	0.14	0.19	0.22	0.15	0.08	0.14	0.13	0.22	0.19	0.43	0.26	0.37
BRA	0.24	0.30	0.09	0.23	0.20	0.29	0.20	0.19	0.09	0.17	0.13	0.17	0.14	0.05	0.20	0.26
CAN	0.15	0.29	0.09	0.31	0.10	0.10	0.11	0.15	0.04	0.14	0.03	0.18	0.09	0.38	0.23	0.21
CHN	0.20	0.10	0.11	0.28	0.20	0.13	0.15	0.12	0.11	0.12	0.09	0.10	0.13	0.21	0.21	0.09
DEU	0.26	0.21	0.10	0.29	0.09	0.12	0.23	0.15	0.04	0.11	0.08	0.10	0.10	0.13	0.10	0.05
FRA	0.14	0.15	0.11	0.36	0.15	0.09	0.27	0.12	0.05	0.14	0.06	0.13	0.13	0.10	0.09	0.15
GBR	0.23	0.27	0.08	0.29	0.11	0.13	0.27	0.13	0.07	0.12	0.08	0.12	0.09	0.30	0.21	0.21
IDN	-0.40	0.22	0.07	0.26	0.42	0.10	0.22	0.11	0.10	0.13	0.10	0.29	0.22	0.06	0.19	0.16
IND	0.38	0.28	0.12	0.39	0.13	0.23	0.23	0.20	0.12	0.18	0.16	0.25	0.16	0.19	0.24	0.27
ITA	-0.10	0.14	0.09	0.29	0.15	0.10	0.28	0.14	0.08	0.14	0.08	0.11	0.13	0.19	0.22	0.09
JPN	-0.19	0.29	0.14	0.35	0.20	0.15	0.21	0.12	0.11	0.10	0.07	0.08	0.15	0.07	0.27	0.08
KOR	0.03	0.24	0.11	0.32	0.07	0.06	0.07	0.13	0.06	0.09	0.09	0.06	0.13	0.09	0.08	-0.93
MEX	0.13	0.26	0.12	0.29	0.16	0.23	0.14	0.15	0.05	0.17	0.02	0.07	0.02	0.50	0.15	0.23
RUS	0.17	0.92	0.11	0.32	0.08	0.17	0.36	0.07	0.08	0.06	0.16	0.18	0.18	0.26	0.15	0.29
USA	-0.24	0.34	0.10	0.25	0.13	0.14	0.13	0.15	0.07	0.10	0.08	0.13	0.11	0.23	0.16	0.45

Table A.2: Import elasticity of home demand

	Food	Textile	Wood	Paper	Petr	Chem	Rubber	Mineral	B Metal	F Metal	Mach	Elect	E Mach	Vehicle	Other T	Furniture
AUS	0.96	0.94	0.91	0.69	0.88	0.94	0.96	0.86	0.98	0.85	0.95	0.85	0.91	0.87	0.98	0.94
BRA	0.80	0.54	0.91	0.73	0.80	0.67	0.59	0.77	0.91	0.82	0.86	0.87	0.90	1.00	0.84	0.87
CAN	0.86	0.94	0.92	0.76	0.91	0.96	0.95	0.94	0.97	0.87	0.99	0.90	0.96	0.91	0.84	0.97
CHN	0.49	0.95	0.84	0.93	0.26	0.90	0.78	0.87	0.93	0.97	0.82	0.95	0.77	0.93	0.84	0.95
DEU	0.83	0.94	0.91	0.67	0.91	0.94	0.76	0.87	0.96	0.86	0.95	0.96	0.93	0.88	0.95	0.98
FRA	0.94	0.89	0.90	0.79	0.86	0.94	0.78	0.89	0.98	0.85	0.98	0.93	0.87	0.90	0.91	0.96
GBR	0.28	0.92	0.93	0.74	0.93	0.92	0.79	0.89	0.98	0.88	0.96	0.94	0.99	0.85	0.88	0.94
IDN	1.95	0.83	0.94	0.76	0.81	0.77	0.89	0.92	0.73	0.94	0.95	0.88	0.85	1.04	0.90	0.93
IND	0.64	0.49	0.90	0.67	0.87	0.89	0.72	0.93	0.91	0.94	0.89	0.85	0.91	0.83	0.85	0.99
ITA	1.13	0.85	0.92	0.73	0.85	0.95	0.76	0.87	0.94	0.90	0.94	0.93	0.92	0.90	0.81	0.90
JPN	1.16	0.76	0.96	0.63	0.85	0.97	0.72	0.85	0.92	0.86	0.93	0.83	0.86	0.97	0.60	0.95
KOR	0.99	0.83	0.90	0.72	0.95	0.90	0.97	0.94	0.81	0.95	0.92	0.95	0.93	1.01	0.93	1.64
MEX	0.79	0.78	0.94	0.79	0.89	0.85	0.97	0.77	0.98	0.90	0.99	0.97	0.98	0.88	0.89	0.96
RUS	0.93	0.40	0.92	0.72	0.94	0.82	0.66	0.99	0.96	0.68	0.81	0.77	0.86	0.61	0.94	0.92
USA	0.50	0.86	0.92	0.74	0.89	0.88	0.90	0.89	0.96	0.88	0.97	0.95	0.96	0.40	0.86	-0.40