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

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Abstract

We develop a general equilibrium model of international trade that incorporates imperfect factor mobility, product entry, and external returns to scale, into a unified framework. The effects from these microeconomic channels can be summarized by two composite elasticities that govern supply and aggregation. We structurally derive export supply and import demand curves, develop a heteroskedastic estimator, and estimate supply, aggregation, and demand elasticities across international product markets. Employing our estimated model, we evaluate the impact of recent US protectionist policies and highlight the importance of our estimates and general equilibrium effects for tariff passthrough rates and cross-industry employment reallocations.
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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. A long-standing tradition has emphasized general equilibrium analyses when tracing trade shocks through economies and examining consequences of trade policy. Quantification depends on elasticity parameters meant to inform microeconomic channels of adjustment across and within economies. Recent advances in the trade literature have established, in particular, the importance of three such channels: imperfect factor mobility, within-industry product entry, and external returns to scale of industries. Nonetheless, the elasticity parameters that discipline these channels have been estimated and analyzed in isolation. We embed these three microeconomic channels in a unified framework in order to jointly estimate their governing elasticity parameters and to perform counterfactual general equilibrium analyses.

In this paper, we take 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. Instead, we recast the problem into one of supply and demand in product markets which facilitates taking trade theories to data on international prices and quantities. Specifically, we derive model-consistent export supply which we use together with import demand to characterize the general equilibrium. We then develop a model consistent heteroskedastic estimation procedure, and employ the model with estimated elasticities to provide new insight into the recent US tariffs against China. Our estimates suggest 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 partly absorbs some of the tariff effects, lowering the average passthrough to 82.5%. In addition, we illustrate the relative importance of the three above-mentioned microeconomic channels by decomposing changes to passthrough rates and employment reallocations across industries to the contribution from each of those channels.

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, product entry, and external returns to scale) in order to perform counterfactual analyses. Under this reformulation, these three individual-level sets of elasticities collapse into two sets of composite supply-side elasticities that summarize how microeconomic channels interact to move general equilibrium in response to policy shocks. One of these composites is the elasticity of each industry's aggregate output to the average price of products in 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 framework, which in turn nests many commonly-used models of trade. Our estimation, in turn, is designed to estimate these sufficient elasticities.

Focusing on product markets allows us to take advantage of data on international trade quantities and unit values 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 1995-2016. We discuss the merits of three potential estimation strategies: Structural microeconomic estimation, instrumental variables approaches that isolate components of the system, and heteroskedastic supply and demand techniques to simultaneously estimate the system. Given our data and the structure of the model we opt to develop a heteroskedastic supply and demand estimator.

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, lack a model-consistent general equilibrium export supply curve, leading to a gap between the welfare analysis in this empirical literature and general equilibrium applications. We address this gap by embedding general equilibrium export supply elasticities into our estimation. Our estimator hinges upon a few assumptions, mainly requiring the independence of export supply and import demand shocks, along with model-based constraints to ensure well-defined counterfactual analyses. Under these assumptions, our estimator delivers consistent estimates of the sufficient set of elasticity parameters for counterfactual analysis (i.e., demand, supply, and aggregation elasticities) that vary across both countries and industries.

Equipped with our estimates of supply, aggregation, and demand elasticities, we provide a focused application through an analysis of the recent US tariffs against China. We find Chinese industries to be particularly resilient to tariffs from the US when evaluated based on partial equilibrium analysis—i.e., complete passthrough of tariffs to imported prices. 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 complete passthrough onto imported prices in the US, 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 an exporting country attempts to reallocate away from targeted industries. Our general equilibrium analysis highlights this mechanism and provides interesting contrast to the partial equilibrium results. In general equilibrium, passthrough 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 US tariffs targeting all Chinese manufacturing industries, the passthrough falls to 82.5% on average across industries.

To be specific, when tariffs are applied simultaneously across all industries, general equilibrium tariff complementarities effectively increase importer market power. Crucially, complementarities rely on the underlying parameters governing the costs of factor reallocation in the exporting country. 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. We confirm this intuition by showing that the average wages in China relative to the US falls monotonically as the coverage of US tariffs incrementally expands to include a higher number of Chinese manufacturing industries. We further demonstrate the patterns of labor reallocations across industries within both countries, highlighting that the employment change across industries were negatively correlated with pre-shock measures of comparative advantage.

Lastly, we conduct a decomposition exercise based on counterfactual changes in response to US tariffs that emerge from shutting down the microeconomics channels of our full model. We find that tuning off labor mobility and within-industry product entry are more important than external scale economies in restricting employment reallocations and lowering passthrough rates onto the prices of Chinese exported goods to the US.

The rest of the paper is organized as follows. We subsequently discuss related literature and our position therein in greater detail before developing the theoretical model. Section 2 presents the model. There we derive export supply 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 paper contributes to several areas of the literature. First, our study 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 jointly accounting for labor mobility frictions, product entry, and external returns to scale into an international setting. Each of these mechanisms have only received independent consideration in the literature, e.g., see Galle et al. (2023) for labor mobility frictions, Lashkaripour and Lugovskyy (2023) for increasing returns to scale which arise from product entry and love-of-variety a la Krugman (1980), in addition to Basu and Fernald (1997), Antweiler and Trefler (2002), Costinot et al. (2019), Bartelme et al. (2021) that examine the economies of scale under various modeling assumptions. We examine and estimate the *combined* operation of the three above-mentioned 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 international 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) to estimate gains from product variety and trade. 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 (2023) exploit information in demand residuals provided that they are on average stable over time. Our derivations, in turn, allow us to characterize similarities and differences between the export supply curves 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, trade policy, or passthrough rates that have been traditionally approached within a partial equilibrium setting in this literature, and a framework that embeds a rich set of endogenous responses from the supply side into general equilibrium analysis.

Lastly, our paper is related to a vast empirical literature on the impact of trade policy, as surveyed by Caliendo and Parro (2022). 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. Several alternative approaches estimate trade elasticities using cross-sectional or time-series variations in trade flows, tariffs, or prices, e.g., Hillberry and Hummels (2012), Simonovska and Waugh (2014), and Caliendo and Parro (2015). In contrast to these methods, we structurally derive supply and demand elasticities which vary both 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 for disaggregated industries by each country. In particular, allowing for disaggregation in the product space and heterogeneity in export supply elasticities could be important for the analysis of trade policy, as discussed in Fajgelbaum and Khandelwal (2022). In turn, we underscore the importance of heterogeneity in our estimates for the response to trade policy in Section 4.

2 Theory

This section presents a general equilibrium model of trade that incorporates imperfect labor mobility, firm entry à la Krugman, and external returns to scale. We characterize sufficient statistics to conduct general equilibrium policy analysis, and derive import demand and export supply elasticities at the origin-destination-industry level which we estimate in Section 3.

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 industry-level composite goods, $C_{n,k}$, with $\beta_{n,k}$ as given expenditure share on industry k. The composite $C_{n,k}$ is a CES aggregator of varieties that are differentiated by origin:

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

where $C_{ni,k}$ denotes consumption quantity of origin variety i. The "Armington" elasticity of substitution between country-level varieties within industry k in market n is denoted by $\sigma_{n,k}$, and $b_{ni,k}$ corresponds to importer-exporter-industry demand shifters. Let $\ell \in \Omega_{ni,k}$ index firms (or equivalently, products) from origin country $i-$industry k that sell to market n. The composite $C_{ni,k}$ is a CES aggregation across shipped quantities of products ℓ from origin $i-$industry k to market n,

$$C_{ni,k} = \left[\int_{\ell \in \Omega_{ni,k}} b_{ni,k}(\ell)^{\frac{1}{\eta_{i,k}}} C_{ni,k}(\ell)^{\frac{\eta_{i,k}-1}{\eta_{i,k}}} \mathrm{d}\ell \right]^{\frac{\eta_{i,k}}{\eta_{i,k}-1}},$$

where the "love of variety" parameter, $\eta_{i,k}$, corresponds to the elasticity of substitution between products in industry k in country i.

Labor Supply across Industries. We consider a Roy-Fréchet-type specification in which workers supply their labor efficiency units to industries. The labor supply shares are given by:

$$\frac{L_{i,k}}{L_i} = e_{i,k} w_{i,k}^{\varepsilon_i} \Phi_i^{-\varepsilon_i} \quad \text{where} \quad \Phi_i \equiv \left[\sum_{k \in K} e_{i,k} w_{i,k}^{\varepsilon_i} \right]^{1/\varepsilon_i}, \tag{1}$$

where $w_{i,k}$ is wage per unit of efficiency in country $i-$industry k and $e_{i,k}$ is a labor supply shifter. The elasticity of labor mobility across industries with respect to wage equals ε_i, and aggregate supply of efficiency equals $E_{i,k} = L_i \Phi_i^{1-\varepsilon_i} e_{i,k} w_{i,k}^{\varepsilon_i - 1}$. In one extreme, as $\varepsilon_i \to 1$, our framework collapses to a specific factor model in which efficiency units employed in each industry is inelastically given. In the other extreme, as $\varepsilon_i \to \infty$, the model collapses to one with perfect labor mobility. 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.

Free Entry, Love of Variety, and External Returns to Scale. Total units of efficiency required to produce $q_{ni,k}(\ell)$ units of product $\ell \in \Omega_{ni,k}$ of variety (i,k) to be delivered at market n equal $(d_{ni,k} q_{ni,k}(\ell)/A_{i,k} + f_{ni,k})$, where $d_{ni,k} \geq 1$ is the standard iceberg trade cost and $f_{ni,k}$

is the fixed cost of entry.[1] 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. This channel brings about "external economies of scale".

The mass of firms/products in country $i-$industry k, denoted by $M_{i,k} \equiv | \cup_{n \in N} \Omega_{ni,k}|$, is pinned down by the free entry condition, which sets $M_{i,k} = E_{i,k}/(\eta_{i,k} F_{i,k})$ where $F_{i,k} = \Sigma_{n \in N} f_{ni,k}$ aggregates fixed costs of entry. An industry with a higher degree of product differentiation (i.e., lower $\eta_{i,k}$) provides a greater number of products ($M_{i,k}$). In their entry decisions, firms do not internalize the entire benefit of new varieties they introduce to the market. Consequently, free entry and love-of-variety give rise to another source of increasing returns, which we refer to as the "entry" channel.

International trade is subject to import tariffs, $t_{ni,k}$, and iceberg trade costs, $d_{ni,k}$. 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, and compete under monopolistic competition, they charge the same price to each destination, such that product-level prices inclusive of trade wedges ($p_{ni,k}$) are:

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

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

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,[2]

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

Lastly, the value of gross output of industry k in country i, $Y_{i,k}$, and its revenue share, $r_{i,k}$, are:

$$Y_{i,k} = L_i \Phi_i^{1-\varepsilon_i} e_{i,k} w_{i,k}^{\varepsilon_i} \qquad \text{and} \qquad r_{i,k} \equiv \tfrac{Y_{i,k}}{\sum_k Y_{i,k}} = e_{i,k} w_{i,k}^{\varepsilon_i} \Phi_i^{-\varepsilon_i}. \tag{3}$$

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

Price Indices and Trade Shares. The price indices associated with consumption aggregates $C_{ni,k}$, $C_{n,k}$, and C_n – at the level of variety, industry, and country – are:

$$P_{ni,k} = \left[\int_{\ell \in \Omega_{ni,k}} b_{ni,k}(\ell) p_{ni,k}(\ell)^{\eta_{i,k}-1} \mathrm{d}\ell\right]^{\frac{1}{\eta_{i,k}-1}} = M_{i,k}^{\frac{1}{1-\eta_{i,k}}} \tau_{ni,k} p_{ii,k}, \tag{4}$$

$$P_{n,k} = \left[\sum_{i \in N} b_{ni,k} P_{ni,k}^{1-\sigma_{n,k}}\right]^{\frac{1}{1-\sigma_{n,k}}} \tag{5}$$

$$P_n = \prod_{k \in K} P_{n,k}^{\beta_{n,k}}. \tag{6}$$

[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, external returns to scale mediate the passthrough of wages onto product-level prices.

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

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

General Equilibrium: Recasting to Product Markets. Our model is designed to be estimated using data on prices and quantities in international product markets. To do so, we recast our model to one of supply and demand in product markets (rather than factors of production). 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 (in our terminology, imports and exports also include domestic purchases in case of $n = i$). 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 and tariff revenues,

$$X_n = L_n\Phi_n + \sum_{i,k} t_{ni,k}D_{ni,k}, \tag{10}$$

which delivers $C_n = X_n/P_n$ as the index of national welfare. 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,

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

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 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, $Y_{i,k} = L_i \Phi_i^{1-\varepsilon_i} e_{i,k} w_{i,k}^{\varepsilon_i}$. Replacing wage $w_{i,k}$ by its corresponding product price $p_{ii,k}$ from Equation (2), total supply 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.[3] The *supply elasticity* is denoted by $\omega_{i,k}^{(1)}$ as the elasticity of industry-level output $Y_{i,k}$ with respect to the average product-level

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

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 Equations (4), (5) and (7), we can express the demand schedule 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*. The aggregation elasticity is defined formally as:

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

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

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

Total supply less exports to all other destinations defines export supply to a destination. Conceptually, export supply is excess supply destined for a foreign market. Following this definition, we can express export supply, $S_{ni,k}$, as:

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

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 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*.[4] 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,

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

We can now express the export supply elasticity as a function of export penetration and elasticity parameters of demand, supply, and aggregation, $(\sigma_{n,k}, \omega_{i,k}^{(1)}, \omega_{i,k}^{(2)})$,

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

Export supply elasticities are endogenous objects rather than a given parameter, as they depend 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 they become 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.[5]

Controlling for export penetration $(\lambda_{ni,k})$, the export supply elasticity $(\omega_{ni,k}^{(S)})$ thus contains information about changes to (i) total industry-level supply $Y_{i,k}$, whose response is controlled by the supply elasticity $\omega_{i,k}^{(1)}$ weighted by the inverse of export penetration, and (ii) 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

[4] 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*.

[5] 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.

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 purchases from that industry.

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 focus on estimating 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 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 General Equilibrium Analysis

We characterize the set of data and parameters required to perform counterfactual policy analysis and discuss several properties of our framework.

Sufficient Statistics. 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 $\mathscr{B} = \left\{X_n, Y_{n,k}, t_{ni,k}, X_{ni,k}\right\}$. 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 $\widehat{\tau}_{ni,k} = \widehat{d}_{ni,k}(1+\widehat{t}_{ni,k} t_{ni,k})/(1+t_{ni,k})$. 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:

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

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

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

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

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

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

Provided that baseline values $\mathscr{B}$ are observed and Equations (19)–(24) have a solution, the set of supply, aggregation and demand elasticities $\{\omega_{i,k}^{(1)}, \omega_{i,k}^{(2)}, \sigma_{n,k}\}$ 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 $\omega_{i,k}^{(1)}$ and $\omega_{i,k}^{(2)}$ are known, one does not require estimates of the microeconomic elasticities governing labor mobility (ε_i), external economies of scale ($\phi_{i,k}$), and love-of-variety ($\eta_{i,k}$) to perform counterfactuals.

Numerical Solution, Alternative Approaches, and Uniqueness. We compute the equilibrium in changes using a numerical algorithm that iterates over prices $\widehat{p}_{ii,k}$ to solve for the system of Equations (19)–(24). Alternatively, the equilibrium in changes can be characterized as a function of wages, $\{\widehat{w}_{i,k}\}$. The sufficient statistics in this factor-market approach are baseline values $\mathscr{B}^w$ that are the same as the ones for the product-market approach, $\mathscr{B}$; and parameters $\mathscr{P}^w = \{\gamma_{i,k}, \varepsilon_i, \sigma_{n,k}\}$ where $\gamma_{i,k} \equiv [\phi_{i,k} + (\eta_{i,k} - 1)^{-1}]$ summarizes the combined effects that determine the strength of scale economies.[6,7]

Uniqueness in the class of models that we consider intuitively requires that forces for concentration of production such as scale economies are not too strong relative to forces for dispersion such as consumers' love of variety and imperfections in labor mobility. However, to our knowledge, none of the existing studies that formalizes this insight can characterize the precise parameter space that guarantees uniqueness in our framework. Nonetheless, we will be careful along two fronts. First, we note that the inequality, $(\sigma_{n,k}-1)(\omega^{(2)}_{i,k}-1)/\omega^{(1)}_{i,k} \leq 1$, serves as a *necessary* condition for uniqueness whose violation is sufficient for multiplicity of equilibria.[8] We will accordingly constrain our estimation to the parameter space where this inequality holds. Second, for our quantitative analysis in Section 4, we check that our algorithm converges to the same outcome from different initial guesses; and, that the equilibrium outcome moves on a continuous path when the trade policy is implemented in a sequence of steps.

Welfare. Finally, a key metric for counterfactual analysis is the effect on welfare. The change to welfare for each country n can be expressed as a function of supply and demand elasticities:

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

Here, the change to domestic expenditure share $\widehat{\pi}_{nn,k}$ and revenue share $\widehat{r}_{n,k}$ can be generically

[6] See Appendix 1.1 for the the characterization of equilibrium as a function of wages.

[7] Our numerical algorithms are detailed in Appendix 1.6. Specifically, given $(\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{n,k})$, we solve for prices, $\widehat{p}_{,ii,k}$ using Equations (19)–(24). Alternatively, given $\{\gamma_{i,k}, \varepsilon_i, \sigma_{n,k}\}$ we solve for wages, $\widehat{w}_{i,k}$, using Equations (A.1)–(A.6) in the appendix. We confirm that, when $\{\gamma_{i,k}, \varepsilon_i, \sigma_{n,k}\}$ map to $(\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{n,k})$, the two methods produce exactly the same equilibrium variables.

[8] This follows from theoretical results in Kucheryavyy et al. (2023) and a mapping between our model to theirs. See Appendix Section 1.4.

obtained from the solution to Equations (19)–(24). 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 plays a key role in governing resource reallocations and the subsequent impact on welfare.

2.4 Discussion: Across Model Comparisons

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

We briefly discuss here the listed models in the table. 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).[9] In those models, there is no product entry, and the aggregation elasticity $(1 - \omega^{(2)}_{i,k})$ is necessarily unity. However, this class of models can allow for a flexible range of supply elasticities $(\omega^{(1)}_{i,k})$ through the interaction between parameters governing factor mobility (ε_i) and external returns to scale (ϕ_{ik}). Total

[9] This is the case, as discussed in Kucheryavyy et al. (2023), insofar as the equilibrium employment in each sector is positive, which is the focus in the literature and the case we consider throughout our analysis.

supply is more elastic (flatter) the greater are external returns to scale or when workers are more mobile across industries. Specifically, for a given price change there is a nonlinear change to wage, which induces changes to (employment and) output:

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

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, $\omega_{i,k}^{(1)}$.

Next, consider a class of multi-sector Krugman (1980) models that allow for an endogenous mass $M_{i,k}$ of product varieties within each country-industry pair. The relationship between the aggregate price index and the product-level price can be spelled out using the 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 $(\partial \ln M_{i,k}/\partial \ln p_{ii,k})$ and $(\partial \ln P_{ii,k}/\partial \ln M_{i,k}|p_{ii,k})$ together, the aggregation elasticity $(1-\omega_{i,k}^{(2)})$ summarizes the relationship between the marginal cost at the product level and the aggregate price index that disciplines the demand behavior.

The key to a non-unity aggregation elasticity (i.e., $(1-\omega_{i,k}^{(2)}) \neq 1$) is a finite within-industry elasticity of substitution, $\eta_{i,k}$. In that case, $(\partial \ln P_{ii,k}/\partial \ln M_{i,k}|p_{ii,k})$ takes a finite negative value, reflecting the well-studied margin of gains from product variety. An increase in the mass of varieties within an exporter-industry pair lowers the associated price index faced by consumers as consumers value a greater set of varieties. This relationship is governed by the degree of differentiation among product varieties within exporter-industry pairs captured by $1/(\eta_{i,k}-1)$.

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, which delivers ${}^{\omega^{(2)}_{n,k}-1}/_{\omega^{(1)}_{n,k}} = {}^{-1}/_{\varepsilon_n} < 0$. Here, controlling for the trade channel, the industry to which more resources will be allocated in response to a shock decreases welfare through adjustment costs of reallocation. Convoluting the adjustment cost channel are economies of scale. Consider the case where the adjustment cost channel is shut down by assuming $\varepsilon_n \to \infty$ as in Row (7). Then, ${}^{\omega^{(2)}_{n,k}-1}/_{\omega^{(1)}_{n,k}} = \frac{1}{\eta_{n,k}-1} + \phi_{n,k} > 0$. In this case, resources allocated to an industry positively contribute to welfare through scale economies[10]

Since our model nests a wide range of 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 individual microeconomic parameters $\{\varepsilon_i, \phi_{i,k}, \eta_{i,k}, \sigma_{i,k}\}$ we aim at estimating supply, aggregation, and demand elasticities $\{\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{i,k}\}$, that in turn serve as sufficient elasticities to conduct policy analysis.

[10]Since the welfare effects from different industries may partly offset each other, the overall contribution of the specialization channel must be understood only as the sum of the effects from all industries, which in logs equals $\sum_k \frac{\omega^{(2)}_{n,k}-1}{\omega^{(1)}_{n,k}} \beta_{n,k} \log \widehat{r}_{n,k}$.

3 Estimation

This section utilizes data to estimate demand, supply, and aggregation elasticities. We describe our data, present our estimation procedure, and discuss our estimation results.

3.1 Data

Our sample incorporates the largest 50 countries (in terms of GDP) and 17 industries (16 manufacturing industries plus one non-manufacturing that aggregates all other industries) over the period of 1995-2016.[11] Our empirical strategy is designed to exploit available data on international trade and production. We obtain from CEPII-BACI values of bilateral trade, $X_{ni,k,t}(\ell)$, and their corresponding unit values, $p_{ni,k,t}(\ell)$, at the HS 6-digit level of products $\ell \in \Omega_{ni,k,t}$ for each importer $n-$exporter $i-$industry $k-$year t. For most of the estimation and quantitative purposes in our paper, we aggregate our trade data to the level of 2-digit ISIC industries and merge them with our production data which are obtained from INDSTAT-UNIDO (that are only available at the 2-digit ISIC level).[12] The resulting merged data map to the values of production, $Y_{i,k,t}$, and trade, $X_{ni,k,t}$ (by way of accounting, including domestic purchases, $X_{ii,k,t}$). In addition, the average of unit values $p_{ni,k,t}(\ell)$ within an importer $n-$exporter $i-$industry $k-$year t in the data correspond to product-level prices, $p_{ni,k,t}$, in our framework.[13] Finally, note that our price data are originally recorded as free-

[11] See Appendix Table A.1 and A.2 for the list of industries and countries in our sample. We relegate a detailed description of our data construction to Appendix B and here briefly explain sources of our data and their mapping to our model variables. Moreover, note that for our quantitative analyses in Section 4, we keep the largest 13 countries in terms of GDP and aggregate the other countries into five broadly-defined geographic regions.

[12] Since sources of trade and production data are different, values of total exports, $\Sigma_{n\neq i} X_{ni,k,t}$, are not always guaranteed to be smaller than values of production, $Y_{i,k,t}$. To avoid such cases, we make adjustments to our production data as described in detail in Appendix B .

[13] Two points come in order. First, we do not have data on prices of domestic transactions, $p_{ii,k,t}$, but that does not impose a limitation on our estimation since we can run the estimation over the data on international markets.

on-board. We apply tariff data from MacMap to make these prices tariff-inclusive.

3.2 Estimating Import Demand and Export Supply: An Overview

International product markets are determined by export supply and import demand. For the trade flow from exporter i to importer n in industry k at year t, our model yields these components locally in logs:

$$\ln S_{ni,k,t} = \left(\tfrac{1}{\lambda_{ni,k,t}}\omega^{(1)}_{i,k} - \sum_{m\neq n} \tfrac{\lambda_{mi,k,t}}{\lambda_{ni,k,t}}(1-\omega^{(2)}_{i,k})(1-\sigma_{m,k})\right)\ln p_{ni,k,t} + \varphi_{ni,k,t} \qquad \text{(Export Supply)}$$

$$\ln D_{ni,k,t} = (1-\omega^{(2)}_{i,k})(1-\sigma_{n,k})\ln p_{ni,kt} + \rho_{ni,k,t} \qquad \text{(Import Demand)},$$

where $S_{ni,k,t}$ is the value of exports from i to n, $D_{ni,k,t}$ is the value of imports by n from i, and $p_{ni,k,t}$ is the average product-level price. Additionally, supply and demand contain importer-exporter-industry-year shifters $\varphi_{ni,kt}$ and $\rho_{ni,kt}$. That is, $\varphi_{ni,k,t}$ is comprised of unobserved shocks, such as exporter productivity, which shift export supply, and $\rho_{ni,kt}$ is comprised of import demand shocks.[14]

The preceding system is simultaneously determined and clearly endogenous as we observe trade flows ($X_{ni,k,t}$) at equilibrium (i.e., $X_{ni,k,t} = S_{ni,k,t} = D_{ni,k,t}$). Three options from the literature for estimation stand out to us: Structural microeconomic estimation, instrumental variables approaches that isolate components of the system, and/or heteroskedastic supply and demand techniques to simultaneously estimate the system.

First, consider approaches from the literature that entail a structural estimation of

Second, CEPII-BACI reports all prices in units of weight, or weight-equivalent, allowing for comparing or averaging unit values.

[14] We refer the reader to Appendix for the structural derivation of the supply and demand shocks $\phi_{ni,kt}$ and $\rho_{ni,kt}$.

individual microeconomic elasticities by assuming that other mechanisms are not operative in the model. For instance, consider the supply elasticity, $\omega_{i,k}^{(1)} = \varepsilon_{i,k}/(1-(\varepsilon_{i,k}-1)\phi_{i,k})$. Estimates of external returns to scale that assume perfect labor mobility ($\varepsilon_i \to \infty$) would then map to $\omega_{i,k}^{(1)} = -1/\phi_{i,k}$ and estimates of labor mobility that assume away external returns ($\phi_{i,k} = 0$) would map to $\omega_{i,k}^{(1)} = \varepsilon_{i,k}$.[15] Here, each structural estimation from the literature imposes a particular knife-edge case accompanied by a sign restriction on the supply elasticity. Given these restrictions, we depart from this approach and aim for one other that can be used to estimate the composite supply elasticity, $\omega_{i,k}^{(1)}$, in the presence of both mechanisms.

Next, consider IV approaches to estimate elasticities of supply and demand. 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 supply. Additionally, one would also need separate instruments that exogenously shift supply for every importer-exporter-industry in order to estimate demand.[16] The task of uncovering such instruments for every importer-exporter-industry-year globally seems too ambitious to be feasible in the full model. In other words, in addition to our point about the identification assumptions that restrict the model structure, generalizing current IV approaches from the literature to multiple industries or multiple countries is hindered both by the nature of instrumental variable construction and the availability of detailed data on

[15]Considering scale economies, Bartelme et al. (2021) use variation in countries population and demand to instrument for sectoral size to identify scale elasticities. In a similar vein, an earlier study by Antweiler and Trefler (2002) use international trade and factor market data to estimate parameters governing returns to scale. As for labor frictions, Hsieh et al. (2019), Burstein et al. (2019), and Galle et al. (2023) employ different data on labor market outcomes to identify a labor mobility elasticity between industries or occupations.

[16]The intuition of IV strategies can be seen in 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.

the global level. For instance, the strategy in Costinot et al. (2019), which relies on disease-related variables to estimate export supply, is only applicable to the industry they study (i.e., pharmaceuticals). As another example, consider Fajgelbaum et al. (2020) who use variation in US tariffs at the onset of US trade war with China. This approach is applicable to other countries and other episodes of tariff policy changes only if tariff changes in the period of the study are sufficiently large and plausibly exogenous across importers, exporters, and products year by year.

Given our interest in estimating the full model with minimum restrictions we opt for the last option, which is to develop a heteroskedastic estimator of industry-level demand and supply in international markets. Our model lends support to popular applications in the literature (e.g., Feenstra (1994), Broda and Weinstein (2006) and Soderbery (2015)). Specifically, we have structurally derived an export supply curve similar in nature to their assumed iso-elastic form. However, these methods from the literature rely on a restricted version of our model. For one, they impose a time-invariant upward sloping export supply elasticity that is homogenous across exporters, $\omega^{(S)}_{ni,kt} = \omega^{(S)}_{n,k} \in (0, \infty)$, and import demand elasticities that are given by $\omega^{(D)}_{ni,k} = 1 - \sigma_{n,k} \in (-\infty, 0)$.[17] Additionally, off-the-shelf methods only allow elasticities to vary across importer-industry pairs.

To be more specific, our formulation allows us to determine the model components needed to deliver reduced form specifications from the literature. Feenstra (1994) and Broda and Weinstein (2006) explicitly assume export supply is upward sloping and import demand is not convoluted by aggregation elasticities. Combined with how their elasticities vary, they implicitly assume a model with restricted entry (i.e., $\omega^{(2)}_{i,k} = 0$), constant trade shares

[17]Explicitly, this literature assumes reduced form export supply curves of the form: $\ln p_{ni,kt} = \xi_{ni,kt} + (1/\omega^{(S)}_{n,k}) \ln S_{ni,kt}$.

(i.e., $\lambda_{ni,kt}$ is time invariant), homogeneous elasticities of substitution across countries (i.e., $\sigma_{n,k} = \sigma_k \;\forall\; n$), and homogenous labor immobility (i.e., $\varepsilon_i = \varepsilon \;\forall\; i$).[18] In essence, their reduced-form model is a restricted version of Armington (1969) or Eaton and Kortum (2002) with imperfect labor mobility. Estimating our full model, therefore, requires a more general heteroskedastic estimator that allows for cross country heterogeneity and broader general equilibrium effects, which we develop subsequently.

3.3 Estimation Procedure

Our challenge is estimating the endogenous system of supply and demand 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. Moreover, to save on notation, we substitute in the export supply and import demand elasticities, $\omega^{(S)}_{ni,kt}$ and $\omega^{(D)}_{ni,k}$, with the understanding that they depend on the sufficient elasticity parameters, $(\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{n,k})$, and international sales shares, $\lambda_{ni,k}$.[19] Additionally, supply and demand fixed effects (e.g., the industry level price index $P_{n,k,t}$) are unobservable in the data so we will use first- and

[18] A similar model can be found on Row (3) of Table 1.

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

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

$$\omega^{(D)}_{ni,k} \equiv \frac{\partial \ln D_{ni,kt}}{\partial \ln p_{ni,kt}} = (1-\sigma_{n,k})(1-\omega^{(2)}_{i,k}),$$

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

reference-differencing to eliminate them, which yields,

$$\Delta^j \ln \pi_{ni,kt} = \Delta(\omega^{(S)}_{ni,kt} \ln p_{ni,kt}) - \Delta(\omega^{(S)}_{nj,kt} \ln p_{nj,kt}) + \Delta^j \varphi_{ni,kt}$$
$$\Delta^j \ln \pi_{ni,kt} = \omega^{(D)}_{ni,k} \Delta \ln p_{ni,kt} - \omega^{(D)}_{nj,k} \Delta \ln p_{nj,kt} + \Delta^j \rho_{ni,kt}, \tag{26}$$

where Δ denotes the first difference and superscript j denotes the reference difference.[20] Here we adopt the ubiquitous assumption of supply and demand shock independence from Feenstra (1994). Specifically, we assume $\mathbb{E}[\Delta^j \varphi_{ni,kt} \Delta^j \rho_{ni,kt}] = 0$. Then multiplying the error terms, $\Delta^j \varphi_{ni,kt}$ and $\Delta^j \rho_{ni,kt}$, from the preceding equations results in the following expression for the intersection of supply and demand:

$$\begin{aligned} \Delta^j \varphi_{ni,kt} \Delta^j \rho_{ni,kt} = (\Delta^j \ln \pi_{ni,kt})^2 - \Big[\; & \Delta \left((\omega^{(D)}_{ni,k} + \omega^{(S)}_{ni,kt}) \ln p_{ni,kt} \right) \Delta^j \ln \pi_{ni,kt} - \omega^{(D)}_{ni,k} \Delta \ln p_{ni,kt} \Delta(\omega^{(S)}_{ni,kt} \ln p_{ni,kt}) \\ & - \Delta \left((\omega^{(D)}_{nj,k} + \omega^{(S)}_{nj,kt}) \ln p_{nj,kt} \right) \Delta^j \ln \pi_{ni,kt} + \omega^{(D)}_{nj,k} \Delta \ln p_{nj,kt} \Delta(\omega^{(S)}_{nj,kt} \ln p_{nj,kt}) \\ & + \omega^{(D)}_{ni,k} \Delta \ln p_{ni,kt} \Delta(\omega^{(S)}_{nj,kt} \ln p_{nj,kt}) - \omega^{(D)}_{nj,k} \Delta \ln p_{nj,kt} \Delta(\omega^{(S)}_{ni,kt} \ln p_{ni,kt}) \Big]. \end{aligned} \tag{27}$$

To fix ideas, Equation (27) is derived similar to Feenstra (1994) estimating equation under our more general assumptions. To reiterate, 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, the preceding reduces precisely to the estimator developed by Feenstra (1994).

Intuitively, Equation (27) relies on variation in import penetration ratios (i.e., within-industry share of expenditure by importer n originated from i) across origins (i, k) for each import market n. We additionally employ an equation that leverages variation in export

[20] 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.

penetration ratios, $\lambda_{ni,kt}$ (i.e., within-industry share of sales by exporter i destined for n) across destinations (n, k) for each exporter i.[21] The construction is similar to the preceding, except our reference differencing will subtract a reference destination m.[22] Multiplying export supply and import demand shocks across destinations now yields:

$$\begin{aligned}\Delta^m \varphi_{ni,kt} \Delta^m \rho_{ni,kt} = (\Delta^m \ln \lambda_{ni,kt})^2 - \Big[&\Delta\left((\omega^{(D)}_{ni,k} + \omega^{(S)}_{ni,kt}) \ln p_{ni,kt}\right) \Delta^m \ln \lambda_{ni,kt} - \omega^{(D)}_{ni,k} \Delta \ln p_{ni,kt} \Delta(\omega^{(S)}_{ni,kt} \ln p_{ni,kt}) \\ &- \Delta\left((\omega^{(D)}_{mi,k} + \omega^{(S)}_{mi,kt}) \ln p_{mi,kt}\right) \Delta^m \ln \lambda_{ni,kt} + \omega^{(D)}_{mi,k} \Delta \ln p_{mi,kt} \Delta(\omega^{(S)}_{mi,kt} \ln p_{mi,kt}) \\ &+ \omega^{(D)}_{ni,k} \Delta \ln p_{ni,kt} \Delta(\omega^{(S)}_{mi,kt} \ln p_{mi,kt}) - \omega^{(D)}_{mi,k} \Delta \ln p_{mi,kt} \Delta(\omega^{(S)}_{ni,kt} \ln p_{ni,kt})\Big].\end{aligned} \tag{28}$$

In Equations (27) and (28), the observables are prices and import/export penetration ratios, $\{p_{ni,kt}, \pi_{ni,kt}, \lambda_{ni,kt}\}$, for each importer n, exporter $i \neq n$, industry k, and year t. Notice, export penetration ratios $(\lambda_{ni,kt})$ enter the equations visibly in Equation (28) but also in the expression for export supply elasticities $(\omega^{(S)}_{ni,kt})$. Rather than attempting to estimate export supply elasticity as written, we unbundle it to estimate its time-invariant sub-elasticities according to Equation (18). Under the identification assumptions which we spell out below, we jointly estimate Equations (27) and (28) via a nonlinear seemingly unrelated regression industry by industry.

We proceed by employing the main identification assumption from Feenstra (1994) which requires export supply and import demand shocks to be independent, namely:

[21] Here, in constructing our second set of equations, we are following Soderbery (2018) who discusses this possibility (with no theoretical basis) in the context of time-invariant but 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. Soderbery (2018)'s estimator is intuitively the same as Feenstra (1994)'s, but shows how to identify elasticities that vary bilaterally.

[22] 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.

Assumption 1 *Independent export supply and import demand shocks:* $\mathbb{E}[\Delta^j \varphi_{ni,kt} \Delta^j \rho_{ni,kt}] = 0$ *and* $\mathbb{E}[\Delta^m \varphi_{ni,kt} \Delta^m \rho_{ni,kt}] = 0$.

Assumption 1 is fundamental to heteroskedastic estimators of supply and demand as far back as Leamer (1981)'s partial identification method. In principle, it means that our estimator is tasked with minimizing the distance between the quadratic term, $(\Delta^j \ln \pi_{ni,kt})^2$, and the expression in brackets in Equation (27), simultaneously with the distance between the quadratic term, $(\Delta^m \ln \lambda_{ni,kt})^2$, and the corresponding expression in brackets in Equation (28). To implement this task, we follow Feenstra (1994)'s approach and average Equations (27) and (28) over time. Hence, the estimating equations can be understood as nonlinear regressions of market share variances on share and unit value covariances and variances. The following assumption is required for these second moment regressions to be identified.

Assumption 2 *Heteroskedasticity in supply and demand shocks. For each industry k there are at least two importers n and three exporters i facing heteroskedastic supply and demand shocks such that* $\frac{Var[\Delta^j \varphi_{ni,kt}] + Var[\Delta^j \varphi_{nm,kt}]}{Var[\Delta^m \varphi_{mi,kt}] + Var[\Delta^m \varphi_{mn,kt}]} \neq \frac{Var[\Delta^j \rho_{ni,kt}] + Var[\Delta^j \rho_{nm,kt}]}{Var[\Delta^m \rho_{mi,kt}] + Var[\Delta^m \rho_{mn,kt}]}$.

Assumption 2 is necessary to separately identify supply from demand elasticities. Assumption 1, that the shocks are orthogonal, defines a rectangular hyperbola in the demand-supply elasticity space for each industry. Assumption 2 provides supply and demand shocks across exporters are heteroskedastic, and ensures variances and covariances of shares and prices form hyperbolae that are not asymptotically identical. Intersections of these hyperbola can then be used to pin down point estimates of supply and demand elasticities.[23]

[23] Soderbery (2015) provides visual representation of these Leamer (1981) hyperbola along with how Feenstra (1994) fit in context. Recently, Grant and Soderbery (2022) demonstrate another way to visualize Feenstra (1994) mapping of these hyperbola to data and discuss statistical testing of the underlying assumptions of the statistical model.

We are now at a point where we can explain the mechanics of parameter identification in our estimation. To begin, suppose that, hypothetically, we were to estimate export supply elasticities ($\omega^{(S)}_{ni,k}$) and import demand elasticities ($\omega^{(D)}_{ni,k}$).[24] Holding an industry fixed, with N importers and I exporters, this would amount to $(I) \times (N-1)$ supply and $(I-1) \times (N)$ demand elasticities (as we exclude $i \neq n$). Since our estimator averages Equations (27) and (28) over time and difference with respect to a reference importer and exporter, we are afforded $(N) \times (I-1)$ importer and $(I) \times (N-1)$ exporter equations of second moments for each industry. As such, the system is exactly identified and cannot accomodate time varying elasticities.

Now, consider our actual estimation in which we aim at pinning down a more parsimonious set of parameters $\{\omega^{(1)}_{i,k}, \omega^{(2)}_{i,k}, \sigma_{n,k}\}$ using export penetration data in order to control for time varying export supply. Recall, this set of parameters comprise the sufficient elasticities for quantitative general equilibrium analyses. Here, for each industry, there are $(2I + N)$ parameters and as before $(I) \times (N-1) + (I-1) \times (N)$ equations. In comparison to the above case, we aim at estimating a lower number of parameters, and so, we are provided by relatively more variation in order for our estimator to identify the parameters. However, by deconstructing the import demand elasticity ($\omega^{(D)}_{ni,k}$) into its sub-components, namely $(1-\sigma_{n,k})$ and $(1-\omega^{(2)}_{i,k})$, we introduce a separate identification hurdle. Specifically, the upper-tier demand parameter $\sigma_{n,k}$ is always attached to the aggregation parameter $\omega^{(2)}_{i,k}$, which can be seen in Equations (15) and (17).

We thus introduce another system of equations to estimate in two steps $\sigma_{n,k}$. In the first step, we construct model-consistent price indices ($P_{ni,kt}$) by estimating lower-tier demand

[24]This specification (implausibly) assumes export supply elasticities do not vary over time.

elasticities within each origin-industry ($\eta_{i,k}$) following Redding and Weinstein (2023)'s reverse weighting procedure. This procedure requires data recording expenditure shares $s_{ni,k,t}(\ell)$ and prices $p_{ni,k,t}(\ell)$ for product varieties within each industry-exporter, corresponding to our 6-digit HS-level observations.[25] For any two years $t-1$ and t, let $\Omega^*_{ni,k} = \Omega_{ni,k,t-1} \cap \Omega_{ni,k,t}$ be the common set of product varieties, and let $s^*_{ni,k,t-1}(\ell)$ and $s^*_{ni,k,t}(\ell)$ be the corresponding expenditure shares in the common set at $t-1$ and t. In addition, define the log mean of within-exporter-industry demand shifters $\{b_{ni,k,t}(\ell)\}_{\ell \in \Omega^*_{ni,k}}$ as $\ln \bar{b}_{ni,k,t} = (1/|\Omega^*_{ni,k}|)\Sigma_{\ell \in \Omega^*_{ni,k}} \ln b_{ni,k,t}(\ell)$, where $|\Omega^*_{ni,k}|$ is the number of varieties in the common set. The main identification assumption in this procedure requires the log mean of demand shifters to remain unchanged over time, namely $\ln \bar{b}_{ni,k,t-1} = \ln \bar{b}_{ni,k,t}$. With the estimates of $\eta_{i,k}$, we recover demand shifters $b_{ni,k,t}(\ell)$ and combine them with observed prices $p_{ni,k,t}(\ell)$ to construct model-consistent price indices, $P_{ni,k,t}$, according to Equation (4).[26]

In the second step, we estimate $\sigma_{n,k}$ using the system of export supply and import demand as functions of model-consistent price index, $P_{ni,k,t}$, characterized by the following elasticities:

$$
\begin{aligned}
\widetilde{\omega}^{(S)}_{ni,kt} &\equiv \frac{\partial \ln S_{ni,kt}}{\partial \ln P_{ni,kt}} = \frac{1}{\lambda_{ni,kt}} \frac{\omega^{(1)}_{i,k}}{1-\omega^{(2)}_{i,k}} - \sum_{m \neq n} \frac{\lambda_{mi,kt}}{\lambda_{ni,kt}} (1-\sigma_{m,k}) \\
\widetilde{\omega}^{(D)}_{ni,k} &\equiv \frac{\partial \ln D_{ni,kt}}{\partial \ln P_{ni,kt}} = (1-\sigma_{n,k}). \qquad (29)
\end{aligned}
$$

The elasticities $(\widetilde{\omega}^{(S)}_{ni,kt}, \widetilde{\omega}^{(D)}_{ni,k})$ are the counterpart of $(\omega^{(S)}_{ni,kt}, \omega^{(D)}_{ni,k})$ for the case in which supply

[25] Specifically, with $X_{ni,k,t}(\ell)$ as expenditure on product $\ell \in \Omega_{ni,k,t}$, $s_{ni,k,t}(\ell) = X_{ni,k,t}(\ell)/(\Sigma_{\ell \in \Omega_{ni,k,t}} X_{ni,k,t}(\ell))$

[26] We provide a detailed, step-by-step description of this procedure in Appendix C. In addition to $\ln \bar{b}_{ni,k,t-1} = \ln \bar{b}_{ni,k,t}$, the reverse weighting estimation relies on two other similar identification assumptions that impose demand stability over time. These three assumptions are similar in the sense that they impose demand stability over time. They are, however, different in how they aggregate product-level demand shifters to an aggregate index of demand shifter which is meant to remain unchanged over time. See Appendix C for the precise statements.

and demand are expressed as functions of the aggregate price index, $P_{ni,k}$, instead of within-industry average product-level price, $p_{ni,k}$.[27] We now implement the same procedure that led us to Equations (27) and (28) by replacing product-level prices ($p_{ni,kt}$) with their corresponding aggregate price indices ($P_{ni,kt}$) and the elasticities ($\omega^{(S)}_{ni,kt}, \omega^{(D)}_{ni,k}$) with their counterparts ($\widetilde{\omega}^{(S)}_{ni,kt}, \widetilde{\omega}^{(D)}_{ni,k}$). Here, the identification assumptions are the same as Assumptions 1 and 2, with the only difference that the residual demand and supply shifters are replaced with the corresponding shifters in relation to the aggregate price index. From this step, the higher-tier substitution elasticity ($\sigma_{n,k}$) will be consistently estimated, as ($\sigma_{n,k}$) is no longer attached to ($\omega^{(2)}_{i,k}$). Note that here we cannot separately identify $\omega^{(1)}_{i,k}$ from $\omega^{(2)}_{i,k}$. However, given the estimates of $\sigma_{n,k}$, we can jointly estimate Equations (27) and (28) in order to identify $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$ for each country-industry pair. Assumption 3 summarizes:

Assumption 3 *Consistent demand elasticities. (i) Estimates of $\eta_{i,k}$, whose identification requires the stability of demand shocks over time as required by the reverse-weighting estimation, are consistent allowing construction of price indices, $P_{ni,kt}$. (ii) The counterparts of Assumptions 1 and 2 expressed in terms of supply and demand residuals in relation to the price indices, $P_{ni,kt}$, hold to estimate $\sigma_{n,k}$.*

In sum, we first estimate ($\sigma_{n,k}$) using Assumption 3, then we invoke Assumptions 1 and 2 to estimate supply and aggregation elasticities ($\omega^{(1)}_{i,k}$, $\omega^{(2)}_{i,k}$).[28] In this respect, our estimation routine can be thought of as a two-stage procedure.[29]

[27] That is, by construction $\widetilde{\omega}^{(S)}_{ni,kt} = \omega^{(S)}_{ni,kt} \times (1-\omega^{(2)}_{i,k})$ and $\widetilde{\omega}^{(D)}_{ni,k} = \omega^{(D)}_{ni,k} \times (1-\omega^{(2)}_{i,k})$, recalling that the aggregation elasticity is: $(1-\omega^{(2)}_{i,k}) = \partial \ln P_{ni,kt} / \partial \ln p_{ni,kt}$.

[28] Note, the estimation of lower-tier substitution elasticities ($\eta_{i,k}$) is only an intermediate step in our way of estimating upper-tier substitution elasticities, ($\sigma_{n,k}$). We only need ($\sigma_{n,k}$, $\omega^{(1)}_{i,k}$, $\omega^{(2)}_{i,k}$) for conducting counterfactual policy analyses.

[29] One implication is that if alternative methods of demand estimation together with more detailed data on certain

Finally, we impose model-based constraints on the parameter space in our estimation:

Assumption 4 *Model-based constraints. Constrain estimates of* $\{\omega^1_{i,k}, \omega^2_{i,k}, \sigma_{i,k}\}$ *to ensure:*

i) gross substitution in demand, $(\eta_{i,k} - 1) > 0$ *and* $(\sigma_{n,k} - 1) > 0$*;*

ii) the necessary condition for uniqueness, $(\sigma_{n,k} - 1)(\omega^{(2)}_{i,k} - 1)/\omega^{(1)}_{i,k} \leq 1$*;*

iii) the admissible range of labor mobility and external returns to scale elasticities, $\varepsilon_{i,k} \geq 1$ *and* $\phi_{i,k} \geq 0$*, which can be equivalently (and, in practice) expressed as:* $1 \leq \Big[1 - (\eta_{i,k} - 1)\left(\omega^{(2)}_{i,k}/\omega^{(1)}_{i,k}\right)\Big]^{-1} \leq \omega^{(1)}_{i,k}$.

We underscore that Assumption 4 is not necessary for the estimation routine, but it is computationally useful and ensures the counterfactual analyses to follow are well defined. That is to say, practitioners could apply or remove these restrictions as they see fit. We have chosen the weakest set of constraints to limit the range of estimates for well-behaved counterfactual analysis, giving particular credence to the uniqueness condition, while still allowing for all the microeconomic channels of our full model to be operative.

3.4 Estimates of the Sufficient Elasticities

We now turn to reporting our estimates of the full model, beginning with demand. Table 2 presents the mean and standard deviation of our demand elasticities ($\eta_{n,k}$ and $\sigma_{n,k}$) across a sleceted set of countries and industries in our data. We also include penetration ratios and the total value of trade in 2016 for context. The sample averages for $\eta_{n,k}$ and $\sigma_{n,k}$ are 2.64 and 3.09, respectively. Overall, the range and the variation of our demand elasticities

industries or countries are provided to obtain alternative estimates of $\sigma_{n,k}$, then one can start from the second stage of our estimation to identify supply-side elasticities of $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$. For example, one could extend the reverse weight estimator with additional assumptions to estimate $\sigma_{n,k}$, then apply our second step to uncover $\omega^{(1)}_{i,k}$ and $\omega^{(2)}_{i,k}$. We prefer our two step method as our assumptions and intuition flow together.

presented in Table 2 are broadly in line with a lengthy literature, providing consideration for differences in aggregation and methodologies (c.f., Broda and Weinstein (2006), Simonovska and Waugh (2014), Imbs and Mejean (2015), and Soderbery (2018)).

Next we report our supply elasticity estimates. Table 3 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 lie between 1.04 and 7.98 with median estimate of 2.79. These estimates are similar to comparable estimates in an 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. (2023)). 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.

All of our aggregation elasticity estimates lie below zero, with a median estimate of -0.34 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 caution. Alternatively, an instructive comparison is based on the specialization elasticity from Equation (25).

Table 4 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 (2023) and

Bartelme et al. (2021)—the specialization elasticity collapses to $(1/\eta_k - 1)$ in the former and ϕ_k in the latter. Specifically, Lashkaripour and Lugovskyy (2023) assume perfectly mobile factors and returns to scale, driven by firm entry and love-of-variety a la Krugman (1980), in an estimation using firm-level Colombian imports. In their quantitative model, 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 industry-specific and uniform across countries. Both of these studies estimate larger specialization elasticities than ours. However, despite differences in methodology and data used for estimation, our findings are consistent with those of the two studies regarding the direction of the effect. Imperfect labor mobility mitigates the effect of returns to scale on the specialization channel. This interaction appears to be limited in our estimates, as the cumulative effect on specialization is still dominated by economies of scale in our estimates—i.e., the sign of the specialization elasticity is positive when scale economies dominate frictions in labor mobility, as evident from Table 1.

Overall, the specialization elasticity governs the degree to which industries reallocate resources in response to shocks. On average, primary products (e.g., Petroleum and Basic Metals) face the lowest specialization elasticities, suggesting relatively weak returns to scale making reallocations toward these industries more costly. Conversely, processed products (e.g., Electrical Machinery and Textiles) face the highest specialization elasticities, suggesting stronger returns to scale. Section 4.3 explores these mechanisms in more detail through counterfactual exercises.

4 Quantitative Analysis: Impact of Recent US Tariffs

We employ our model, at the estimated values of sufficient elasticities (demand $\sigma_{i,k}$, supply $\omega^{(1)}_{i,k}$, and aggregation $\omega^{(2)}_{n,k}$), to study the consequences of recent US protectionist trade policies. Our baseline equilibrium uses country-industry-level data described in Section **3.1**, and for each counterfactual, we solve the system of equations (19)-(24). Following Ossa (2016), we set national trade deficits to zero and treat the resulting equilibrium under the balance of trade as our baseline equilibrium.[30]

As a primer to what follows, we shape our discussion around a few key considerations in evaluating the impact of US tariff policy. First, we examine the general equilibrium implications of US tariffs on Chinese goods and contrast the resulting passthrough rates onto US prices to their partial equilibrium counterparts. Second, once the model is in general equilibrium, we examine how the coverage of tariffs (i.e., how many and which industries are targeted simultaneously) matters in shaping passthrough rates. Third, we decompose the contribution from each microeconomic mechanism in our model to employment reallocations and passthrough.

4.1 Partial Equilibrium passthrough Rates

Evaluating 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 prod-

[30]Note that like all general equilibrium studies, variables that are denominated in values are determined up to a scale set by the choice of numeraire. We choose to normalize the level of average wage income in the United States, Φ_{USA}, to unity. Hence, equilibrium changes to prices, wages, and values of trade which we report below should be understood as relative to the US average wage income. In particular, tariff passthrough onto prices in the US will readily indicate changes to the purchasing power of American workers (vis-à-vis the exporter and industry in question), and changes to Chinese wages are understood to be relative to the American average wage.

ucts of industry k from exporter i.[31] We define the partial equilibrium passthrough 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 passthrough 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.[32]

It is important to emphasize that passthrough rates from Equation (30) are partial equilibrium in nature. In general equilibrium, interconnections across markets and interdependencies in trade policy may imply different passthrough 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 passthrough rates given our estimates and highlight the channels driving their differences.

4.2 General Equilibrium Impact of Tariffs

While the channels determining passthrough in partial equilibrium also operate in general equilibrium, the shifts to export supply curves in industries facing tariff changes are ac-

[31] 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.

[32] 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 passthrough rate collapses to a more familiar expression, ${}^{\omega^{(S)}_{ni,k}}/_{(\omega^{(S)}_{ni,k}+(-\omega^{(D)}_{ni,k}))}$. In a class of models in which $\omega^{(2)}_{i,k}=0$, passthrough then simplifies to ${}^{\omega^{(S)}_{ni,k}}/_{(\omega^{(S)}_{ni,k}+(\sigma_{n,k}-1))}$.

companied by (potentially costly) reallocations by the exporter. These reallocations lead to additional adjustments by exporters to shipped and delivered prices leading to shifts and rotations in export supply. To examine such equilibrium tariff responses, we consider a recent example of extreme and unexpected tariffs applied by the US. Over the course of 2017-18, 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. To start, Column (1) of Table 5 records observed changes in ad valorem equivalent tariff rates across industries.[33] Columns (2)-(6) present data on trade shares along with our estimates of the supply and demand elasticities entering the partial equilibrium passthrough equation ($\varrho_{ni,k}$).

Column (7) reports partial equilibrium passthrough rates of recent US tariffs imposed on Chinese goods. These values are calculated by applying our estimates to Equation (30). We find passthrough from China to US consumers to be centered around unity with only minor deviations across industries. Column (4) highlights that Chinese export supply to the US is relatively elastic on average. Our estimates thus imply that US tariffs have virtually no impact on Chinese producer prices in partial equilibrium. Consequently, partial equilibrium responses to the tariffs suggest 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 passthrough of US tariffs using reduced form empirics applied to models of trade that abstract away from general equilibrium feedback of tariffs on production costs in exporting countries.

Consider now Columns (8) and (9) of Table 5 where we allow for general equilibrium

[33] 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.

linkages. In Column (8), we apply tariff changes industry by industry, one at a time. General equilibrium adjustments lower passthrough 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) applies tariffs simultaneously on all industries then reevaluates the model in general equilibrium. The resulting passthrough rates range from 76% for Paper to 89% for Electronics. These passthrough rates are significantly lower than those implied by partial equilibrium reported in Column (7), or even general equilibrium for single-industry targets reported in Column (8).

Differences between partial and general equilibrium passthrough rates arise due to general equilibrium effects on production costs in the exporting country. In other words, when such general equilibrium effects are not taken into account, a nearly-flat export supply curve implies a nearly-complete passthrough rate. However, general equilibrium effects can generate incomplete passthrough even when export supply is perfectly elastic. Intuitively, an importer can exercise a higher degree of market power by simultaneously imposing tariffs on multiple industries of an exporting country. That is to say, tariffs applied comprehensively across exporter industries do not allow the exporter to freely reallocate resources to escape the distortionary effects of the policies. Differences between Column (8) and (9) empirically demonstrate the importance of tariff complementarity across industries.[34]

To shed light on this matter, we first show how the coverage of US tariffs on Chinese industries plays a role in shaping passthrough rates onto prices of imported Chinese goods

[34] In this respect, our results are in line with theoretical findings in Costinot et al. (2015) and Beshkar and Lashkaripour (2020) who assert that optimal tariffs in general equilibrium feature complementarity across industries. These results are obtained in Ricardian frameworks where certain mechanisms in comparison to our model (e.g., they impose perfect labor mobility) are shut down. Nonetheless, they illustrate an important margin of optimal unilateral policy which remains operative in our more extended model.

in the US, we run the following exercise. For any given sorting that labels manufacturing industries from #1 to #16, we perform 16 counterfactual exercises in which we compute the GE impact from the US tariffs on Chinese products in (1) only industry #1; (2) only industries #1 and #2; ... and, (16) all Chinese manufacturing industries #1 through #16. That is, we increase the coverage of tariffs by adding target industries one after the other. We do not want our results to depend on how we sort the industries, so we repeat this exercise 100 times, where each repetition randomly sorts the sequence of industries. For each level of coverage, from one to all sixteen industries, we compute the average passthrough rate across the 100 values of passthrough rates that correspond to that level of coverage.

Figure 1 displays the results. The average general equilibrium passthrough rate of US tariffs on Chinese industries decreases monotonically from nearly complete passthrough when the coverage includes only one industry to 82.5% when the coverage includes all manufacturing industries. The solid line in Panel (a) displays the average passthrough rate across the 16×100 counterfactual exercises, while the dashed line displays the 90-10 percentiles. Notably, the timing and order of tariff application also matters for the impact of policy in general equilibrium.

To further explain how a higher coverage of tariffs lowers the passthrough rates, Figure 1 additionally shows the percentage change to Chinese average wage relative to the US average wage (i.e., $\Phi_{\text{China}}/\Phi_{\text{USA}}$ with Φ_i given by Equation (1)). This ratio, which can be thought of as Chinese factoral terms-of-trade vis-à-vis the United States, decreases by 0.1% when US tariffs target only one industry and by 2.0% when US tariffs are comprehensive. In other words, a more comprehensive coverage of US tariffs on Chinese goods implies lower passthrough rates through lowering Chinese factoral terms-of-trade vis-à-vis the US.[35]

To deepen our understanding of the general equilibrium adjustments to policy, we next examine reallocations along the pattern of comparative advantage. US protectionist policy moved the US and China one step further away from a bilateral trade integration. In response to this negative trade shock, workers move in and out of industries within these two economies. We examine the resulting employment changes in relation to each country's (pre-shock) pattern of specialization. Specifically, we employ the revealed comparative advantage index, defined as,

$$\mathrm{RCA}_{i,k} = \frac{\mathrm{Exports}_{i,k}/\mathrm{Manufacturing\ Exports}_{i}}{\mathrm{Global\ Exports}_{k}/\mathrm{Global\ Manufacturing\ Exports}}.$$

This index measures a country's share of exports in an industry relative to the global share of exports in that industry. In the baseline year of 2016, the US had its strongest revealed comparative advantage in Other Transport Equipment, Refined Petroleum, and Chemicals & Pharmaceuticals. In turn, China had comparative advantages most notably in Textiles, Furniture, and Electronics.

The solid black bars in Figure 2, labeled as "(e) Imp Mob+Entry+Ext Econ (Full)," show the change to the counts of employment across industries in China (left panel) and in the US (right panel) in response to US tariffs on Chinese manufacturing for our full model given our estimates. In China, employment falls considerably in Electronics and to a lesser extent in Machinery and Electric Machinery. Employment increases notably in the Basic Metal, Paper, and Other Transport Equipments industries. In the US, employment

[35] Note, as wages fall in China, prices also fall there, leading to only 0.04% decline of welfare in China. In turn, welfare in the US falls by 0.08%.

increases most notably in Non-manufacturing, but also to some extent in the manufacturing of Electronics, whereas it falls in most other manufacturing industries (e.g., Chemicals, Other Transport Equipment, and Vehicle industries).

As shown in Figure 3, the comprehensive increase in US tariff rates leads to a reallocation of employment away from comparative-advantage industries in each of the two economies as the countries decouple. For example, consider Other Transport Equipment industry in which Chinese employment rises and the US employment declines. As the figure implies, in addition to the role of pre-shock pattern of comparative advantage, reallocations are compounded by other general equilibrium forces such as across-industry differences in the strength of scale economies in supply and substitutions in demand. To examine the importance of these microeconomic channels, we now turn to a decomposition exercise through the lens of employment reallocations and passthrough rates.

4.3 Microeconomic Sources of Resource Allocation

This section illustrates the role of key channels in our framework for worker reallocations and passthrough rates of tariffs onto prices. To do so, we consider several models that turn on and off the three microeconomic channels that underpin the workings of our model (namely, external scale economies, within-industry product entry, and labor mobility frictions). For each model, we simulate the general equilibrium effects of the same comprehensive US tariff policy that we examined previously using our full model.

To better understand the model's mechanisms, Figure 2 begins with turning off all three microeconomic channels of our model. In one extreme, the model collapses to one without love-of-variety and entry ($\eta_{i,k} \to \infty$), external economies ($\phi_{i,k} = 0$), or labor mobility

($\varepsilon_i \to 1$),[36] implying $\omega_{i,k}^{(1)} = 1$ and $\omega_{i,k}^{(2)} = 0$. In Figure 2, this model is labeled as "(a) Minimum Mobility+No Entry+No Ext Econ." From here, we implicitly raise ε_i from unity to the country-level mean value of our estimated supply elasticity ($\bar{\omega}_i^{(1)}$), which on average equals 3.13 across countries, while keeping $\omega_{i,k}^{(2)} = 0$. This model is labeled as "(b) Imperfect Mobility +No Entry+No Ext Econ." Next, we let $\varepsilon_i \to \infty$ that corresponds to a standard EK/Armington model with full labor mobility, no entry, and no external economies of scale, which we label as "(c) Perfect Mobility+No Entry+No Ext Econ".

Moving from Models (a)-(c) decomposes the role of labor mobility, all else equal. In China, we see a monotonic increase in the degree of reallocations as we soften, and ulimately remove in (c), labor mobility frictions. Effects in the US are a bit more nuanced. For the most part, labor mobility frictions appear to inhibit reallocations across manufacturing industries leading to allocations biased toward Non-manufacturing. From Model (b) we then consider the role of free entry, which we label "(d) Imp Mob+Entry+No Ext Econ." Specifically, we raise $\omega_{i,k}^{(2)}$ from zero to its implied value at $\omega_{i,k}^{(2)} = (\varepsilon_i - 1)/(\eta_{i,k} - 1)$. We suppose Models (b) and (d) face the same $\omega_{i,k}^{(1)}$, but $\omega_{i,k}^{(2)}$ on average equals 1.21 across countries and industries in Model (d). Allowing for love-of-variety and entry considerably boosts the degree of reallocation in both countries. Industries at the tails are particularly impacted. That is to say, China rapidly reallocates away from their comparative advantage industries (e.g., Electronics), while the US strongly reallocates toward their comparative disadvantage industries that see the greatest distortions in China (e.g., Electronics and Electric Machinery).

Finally, augmenting Model (d) with external economies of scale takes us to our full

[36] Note that as $\varepsilon_i \to 1$ our framework collapses to a specific factor model in terms of efficiency units of workers, not in terms of employment (counts of workers). Since we are considering changes to employment, the case of $\varepsilon_i \to 1$ corresponds to the minimum (and, not zero) degree of labor mobility.

model, labeled as "(e) Imperfect Mobility+Entry+Ext Econ," where $\omega_{i,k}^{(2)}$ takes on our estimated values with an average of 1.35. The strongest cumulative reallocations occur in the full model. Our estimates suggest labor mobility frictions are counteracted by entry and positive external economies of scale. A key pattern that emerges from Figure 2 is that the magnitudes of employment changes (in absolute value) increase as we move from Model (a) to (e). Specifically, the differences across Models (a), (b), and (c) capture the contribution of labor mobility frictions, the difference between Model (d) and (b) indicates the contribution of product entry, and the difference between Model (d) and (e) is accounted for by the contribution of external economies of scale.[37]

To complement Figure 2, Table 6 reports the average supply, aggregation, and specialization elasticity, as well as reallocations and passthrough rates for each model. Here, "Reallocation" is defined as the absolute value of changes to counts of employment across industries in China (reported relative to the Full model), and "Passthrough" is defined as the average passthrough rates of tariffs on China onto prices of Chinese goods in the US.

Moving from Model (a) to (e) in Table 6, we strengthen forces that help workers to move and industries to expand. Across these models, Passthrough and Reallocation tend to increase together. That is to say, when the reallocations are more costly in China, wages are pushed down in order for Chinese industries to remain competitive. This results in lower passthrough rates onto prices of Chinese exports to the US. Moving from Model (a) to (b), Passthrough rises from 76.7% to 79.4% and Reallocation from 49.7% to 67.4%. Next,

[37]It is worth noting that Model (b) is the closest to Feenstra (1994)'s specification once it is put in general equilibrium. Feenstra (1994), however, is a partial equilibrium model that imposes two restrictions on export supply schedules. First, it restricts the export supply elasticity (the slope) to be time-invariant and uniform across exporters. Second, it does not let the export supply schedule shift in response to policy. We have discussed the first restriction in Section 3.2. Below, we discuss the importance of relaxing the second restriction.

allowing for full labor mobility we move to the standard EK/Armington model, in which Passthrough rises from 79.4% to 81.5% and Reallocation from 67.4% to 87.6%. The key takeaway is that labor mobility frictions make reallocations more costly, which leads to lower levels of reallocation and lower passthrough rates.

As we move from Model (b) to Model (d) the product entry margin increases Reallocation from 67.4% to 98.4% and it raises Passthrough from 79.4% to 81.1%. Lastly, as we incorporate external economies of scale, we arrive at our full model. Compared to Model (d), the full model increases Reallocation from 98.4% to 100% (by construction) and Passthrough from 81.1% to 82.5%.[38] Overall, mobility frictions and within-industry product entry appear to have a stronger impact than the external scale economies on reallocations of workers in the exporting country and the passthrough rates to the importing country, but it is important to recognize that these mechanisms interact. Notice that that model (c) Standard EK/Armington replicates 87.6% of the reallocation in the full model, but it generates similar average passthrough rates when compared to the full model (81.5% versus 82.5%). Here, as we relax frictions in labor mobility, reallocation and passthrough would increase, but as we shut down external scale economies and product entry, reallocation and passthrough would decrease. In shaping reallocations and passthrough rates, these two opposite forces largely offset each other. One intuitive way to summarize these effects is through the specialization elasticity. Reallocations, specifically, are most pronounced in models with nonnegative specialization elasticities.[39]

[38]In this exercise, we compare our full model with other models that further restrict reallocations across industries. In principle, one could move to the opposite direction, namely toward models that can deliver higher levels of reallocation relative to the full model. However, we find that exercise infeasible to implement, because by raising labor mobility or scale economies we fall into the parameter space in which there are multiple equilibria.

[39]To make a tighter connection to Tables 1 and 4, we additionally perform our exercise on the quantitative models in Bartelme et al. (2021) and Lashkaripour and Lugovskyy (2023) evaluated at their parameter estimates (including their estimates of trade elasticity). As reported in Table A.3 in the appendix, both models result in a slightly lower

It is worth explaining why different models in Table 6 result in pass-through rates that are quantitatively similar. The increase in US tariffs on China shifts the US import demand schedule downward for Chinese varieties. The post-policy partial equilibrium outcome can be then reached by moving along the export supply schedule. Beyond this partial equilibrium effect, the general equilibrium induces a shift in the export supply schedule. To clarify this mechanism, we can express the change to export supply in response to a perturbation in trade costs,[40]

$$\mathrm{d}\ln S_{ni,k} \;=\; \omega^{(S)}_{ni,k}\mathrm{d}\ln p_{ii,k} \;+\; \omega^{(\Phi)}_{ni,k}\mathrm{d}\ln \Phi_i \;+\; \frac{1-\lambda_{ni,k}}{\lambda_{ni,k}}\sum_{m\neq n}\left[(1-\sigma_k)\,\mathrm{d}\ln P_{m,k} + \mathrm{d}\ln X_{m,k}\right] \quad (31)$$

where $\omega^{(\Phi)}_{ni,k} \equiv \sigma_k(1-\lambda_{ni,k})/\lambda_{ni,k} + \omega^{(S)}_{ni,k} + 1$. The first term on the right-hand side represents the movement along the export supply schedule. The second term represents the change in the average wage of the exporting country, i.e., China, Φ_i, corresponding to the *factoral terms-of-trade* under our choice of numeraire (i.e., $\Phi_n = 1$ for the US as the importing country). The third term collects the response in demand across all destinations except the US as the importing country.

In all the general equilibrium models we consider, the average wage in China relative to the US falls in response to the US tariffs as the tariffs lower global demand for Chinese products. This effect is depicted by Figure 1 for our main model, and by Figure A.4 in the appendix for two of the alternative models (the other models exhibit similar patterns). Noting that $\omega^{(\Phi)}_{ni,k} > 0$, the reduction in Chinese average wage shifts the export supply sched-

Passthrough, with values of Reallocation to be comparable in Lashkaripour and Lugovskyy (2023) and substantially higher in Bartelme et al. (2021) relative to our Full model.

[40] See Appendix **1.5** for derivations. For a clearer exposition, the equation assumes a common trade elasticity across markets, i.e., $\sigma_{n,k} = \sigma_k$ for all n.

ule downward, even if export supply is perfectly elastic as in EK/Armington. Moreover, our quantitative results indicate that the shift in the export supply remains to be downward after considering the demand-driven responses in Equation (31). All things considered, these general equilibrium effects (that shift the export supply schedule downward) are quantitatively more dominant than the partial equilibrium effects (that induce a movement along the export supply schedule). Consequently, the general equilibrium pass-through rates onto prices are similar across the models and are all incomplete even when the export supply schedule is flat.

Lastly, we highlight the importance of heterogeneity in our estimates. To this end, we compare the impact of US tariffs in our full model with one in which we shut down the heterogeneity in the parameter space, namely by setting $\omega_{i,k}^{(1)} = \bar{\omega}^{(1)} = 3.13$, $\omega_{i,k}^{(2)} = \bar{\omega}^{(2)} = 1.35$, and $\sigma_{n,k} = \bar{\sigma} = 2.96$, with "bar" variables indicating the average of each parameter across all countries and industries. As shown by Figure 4, the resulting model imposing homogenous elasticities implies lower levels of worker reallocations across Chinese industries. Specifically, Reallocation in China reduces to 62.1% versus 100% in the full model with heterogenous estimates, and Passthrough falls to 75.6% relative to 82.5% in the full model. That is to say, both the mean and variance of our elasticity estimates play an important role in shaping the responses and distributional effects of trade policy.

5 Summary

We developed a general equilibrium model that embeds three microeconomic mechanisms of external economies of scale, product entry and love-of-variety, and imperfect labor mobility into a model of international trade. Recasting the model to one of supply and demand in product markets, we characterize two composite elasticities, corresponding to supply and aggregation, that in addition to usual demand elasticity are sufficient for performing general equilibrium policy analyses. Additionally, we show how to use these sufficient elasticities together with endogenous international sales shares to form export supply elasticities in general equilibrium. We estimate the sufficient elasticities of our model by developing a heteroskedastic estimator that leverages second moment variation in international prices and quantities. Our estimation relies on identifying assumptions similar to those in the literature which follows Feenstra (1994), but, in contrast to previous work, we derived export supply elasticities in general equilibrium from model primitives. Our estimates indicate that supply curves are upward-sloping implying that frictions in labor mobility dominate the agglomeration forces of scale economies. Moreover, our estimated aggregation elasticities indicate product entry and love-of-variety. Given these estimates and observed international market shares, we find export supply curves to be generally very elastic.

We use our model, with the sufficient elasticity parameter estimates, to evaluate the impact of US tariffs on Chinese goods. We find that passthrough rates are virtually complete in partial equilibrium. However, in general equilibrium passthrough is incomplete, with around twenty percent of a tariff increase absorbed by the average exported Chinese industry. Labor mobility frictions and a lower degree of scale economies and product entry limit the extent of employment reallocations across Chinese industries particularly when the tariffs simultaneously target all the industries.

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Tables and Figures

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

Model	Parameters	$\omega_{i,k}^{(1)}$	$\omega_{i,k}^{(2)}$	$\frac{\omega_{i,k}^{(2)}-1}{\omega_{i,k}^{(1)}}$
(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	$\varepsilon_i > 1$, $\eta_{i,k} = \sigma_{nk} = \bar{\sigma}_k$, $\phi_{i,k} > 0$	$\frac{\varepsilon_i}{1-(\varepsilon_i-1)\phi_{i,k}}$	$\frac{\varepsilon_i-1}{1-(\varepsilon_i-1)\phi_{i,k}}\frac{1}{\bar{\sigma}_k-1}$	$\frac{-1}{\varepsilon_i} + \frac{\varepsilon_i-1}{\varepsilon_i}\left(\frac{1}{\bar{\sigma}_k-1} + \phi_{i,k}\right)$
(10) Full Model	$\varepsilon_i > 1$, $\eta_{i,k} > 1$, $\phi_{i,k} > 0$	$\frac{\varepsilon_i}{1-(\varepsilon_i-1)\phi_{i,k}}$	$\frac{\varepsilon_i-1}{1-(\varepsilon_i-1)\phi_{i,k}}\frac{1}{\eta_{i,k}-1}$	$\frac{-1}{\varepsilon_i} + \frac{\varepsilon_i-1}{\varepsilon_i}\left(\frac{1}{\eta_{i,k}-1} + \phi_{i,k}\right)$

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. (2023). (c) Galle et al. (2023) (d) Lashkaripour and Lugovskyy (2023).

Table 2: Demand Elasticity Estimates by Industry and Country

	Trade Statistics (2016)			Elasticities of Substitution			
	Average Penetration		Value	$\eta_{n,k}$		$\sigma_{n,k}$	
	Export $\lambda_{ni,kt}$	Import $\pi_{ni,kt}$	\$Trillions	Mean	SD	Mean	SD
Industry							
Textiles	0.009	0.011	0.535	2.419	0.362	2.819	0.384
Chemicals	0.008	0.009	1.364	2.539	0.606	4.174	2.103
Basic metals	0.009	0.008	0.634	3.088	0.536	3.468	1.889
Machinery and Equipment	0.008	0.011	0.989	2.108	0.240	2.814	1.518
Computers and Electronics	0.008	0.012	1.407	2.032	0.184	2.505	1.027
Motor Vehicles and Trailers	0.007	0.009	1.204	2.949	0.300	3.463	2.174
Coke/Petroleum Products	0.004	0.004	0.290	5.318	1.953	2.944	1.444
Country							
Canada	0.010	0.003	0.262	2.464	0.491	3.261	1.114
China	0.002	0.065	1.521	2.286	0.639	3.807	2.663
Germany	0.010	0.053	1.068	2.185	0.454	2.465	1.154
India	0.003	0.007	0.144	2.683	1.291	2.727	1.587
Japan	0.003	0.012	0.502	2.323	0.478	3.768	2.288
UK	0.007	0.013	0.292	2.126	0.391	2.577	0.913
USA	0.004	0.033	0.968	2.155	0.421	2.919	1.169

Notes: Mean refers to the average and SD the standard deviation. Statistics are calculated across all countries for the indicated product and all products exported by the indicated country for the sample year 2016. Given the large number of estimates, robust standard errors are available with our published estimates.

Table 3: Supply and Aggregation Elasticity Estimates by Country

	Supply Elasticity $\left(\omega_{i,k}^{(1)}\right)$			Aggregation Elasticity $\left(1-\omega_{i,k}^{(2)}\right)$		
Country	Mean	Median	SD	Mean	Median	SD
Canada	3.450	2.999	1.745	−0.391	−0.346	0.249
China	2.923	2.397	1.775	−0.310	−0.275	0.216
Germany	2.811	2.203	1.687	−0.294	−0.200	0.242
India	2.785	2.581	1.201	−0.319	−0.348	0.226
Japan	2.762	2.336	1.398	−0.324	−0.297	0.215
UK	2.776	2.229	1.505	−0.306	−0.239	0.236
USA	2.997	2.219	1.738	−0.319	−0.281	0.233

Notes: Mean, Median, SD refer to the average, median and standard deviation, respectively across all products exported by the indicated country. Given the large number of estimates, robust standard errors are available with the published estimates.

Table 4: Specialization Elasticities by Industry

Industry	Specialization Elasticity $\left(\frac{\omega_{i,k}^{(2)}-1}{\omega_{i,k}^{(1)}}\right)$					
	Estimates Across Countries				Literature	
	Mean	Min	Med	Max	LL	BCDR
Food, Beverages and Tobacco	0.074	0.013	0.062	0.144	0.265	0.220
Textiles	0.170	0.020	0.193	0.243	0.207	0.120
Wood Products	0.096	0.035	0.102	0.119	0.270	0.130
Paper Products	0.093	0.006	0.094	0.200	0.397	0.150
Coke/Petroleum Products	0.036	0.003	0.038	0.076	1.758	0.090
Chemicals	0.083	0.006	0.096	0.127	0.212	0.240
Rubber and Plastics	0.133	0.013	0.144	0.177	0.162	0.420
Mineral products	0.136	0.008	0.148	0.181	0.186	0.170
Basic metals	0.084	0.015	0.085	0.134	0.189	0.090
Fabricated Metals	0.157	0.016	0.167	0.200	0.189	0.120
Machinery and Equipment	0.132	0.012	0.153	0.181	0.100	0.240
Computers and Electronics	0.128	0.007	0.146	0.237	0.453	0.080
Electrical Machinery	0.144	0.012	0.161	0.192	0.453	0.080
Motor Vehicles and Trailers	0.089	0.049	0.092	0.115	0.133	0.180
Other Transport Equipment	0.108	0.017	0.119	0.142	0.133	0.180
Furniture Manufacturing	0.141	0.024	0.146	0.176	–	–

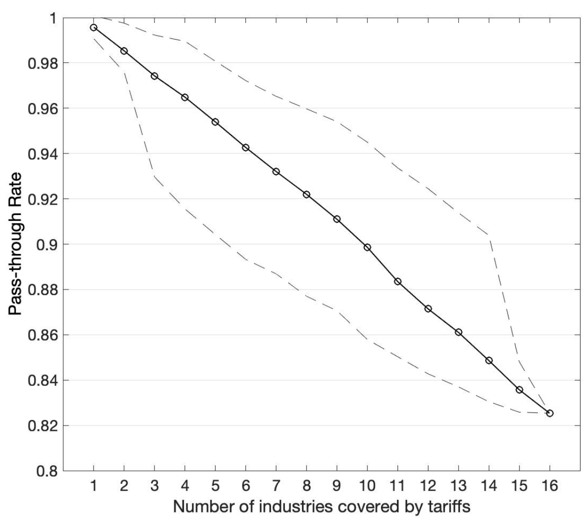
Notes: Mean, Min, Med, Max refer to the average, minimum, median and maximum, respectively across all exporters in our sample. LL refers to Lashkaripour and Lugovskyy (2023). BCDR refers to Bartelme et al. (2021). Specialization elasticity collapses to $1/(\eta - 1)$ in LL and ϕ in BCDR.

Table 5: Passthrough Rates onto US Consumers from US Tariffs on Chinese Goods

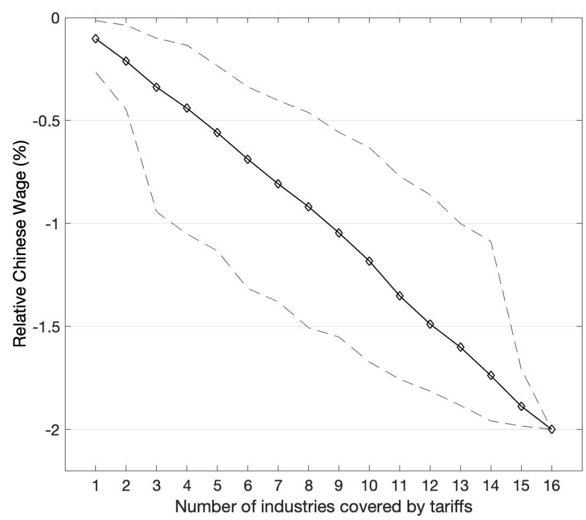
		Trade Shares		Elasticities			Partial	General Equilibrium	
Industry	Δ Tariff	$\lambda_{ni,k}$	$\pi_{ni,k}$	$1/\omega^{(S)}_{ni,k}$	$\omega^{(2)}_{i,k}$	$\sigma_{n,k}$	Equilibrium	Single	Full
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Food	0.10	0.2%	0.4%	0.001	1.26	2.94	100.1%	99.8%	77.9%
Textile	0.10	4.1%	38.6%	0.021	1.24	1.51	100.2%	99.0%	78.1%
Wood	0.10	0.7%	2.2%	0.003	1.29	3.54	100.2%	100.1%	78.1%
Paper	0.11	1.3%	1.2%	0.016	1.82	1.27	100.3%	100.0%	76.1%
Petroleum	0.13	0.1%	0.1%	0.000	1.29	3.06	100.0%	100.0%	82.3%
Chemical	0.12	0.5%	1.6%	0.003	1.02	3.06	100.0%	99.4%	81.3%
Rubber	0.15	2.0%	5.0%	0.010	1.48	2.93	100.9%	100.1%	85.1%
Mineral	0.11	0.3%	2.0%	0.002	1.54	3.18	100.2%	99.9%	79.8%
Basic Metal	0.19	0.1%	1.2%	0.004	1.33	2.80	100.2%	99.9%	86.9%
Fabricated Metal	0.14	1.5%	3.2%	0.015	1.02	2.76	100.0%	99.5%	83.7%
Machinery	0.20	2.0%	7.2%	0.016	1.18	3.13	100.6%	99.1%	88.4%
Electronics	0.21	6.3%	16.8%	0.039	1.19	2.98	101.2%	96.4%	89.3%
Electric Machinery	0.18	1.7%	10.4%	0.014	1.21	2.90	100.5%	99.3%	87.2%
Vehicle	0.15	0.6%	1.1%	0.001	1.61	3.27	100.2%	99.7%	84.6%
Other Transp	0.15	0.3%	0.4%	0.002	1.40	6.32	100.4%	100.1%	83.4%
Furniture	0.10	2.8%	14.1%	0.015	1.09	1.05	100.0%	99.2%	78.1%

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 passthrough rates according to Equation (30), whereas Columns (8) and (9) present the general equilibrium passthrough 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.

Figure 1: General Equilibrium Passthrough Rates and Wage Effects vs. Coverage of Tariff Policy



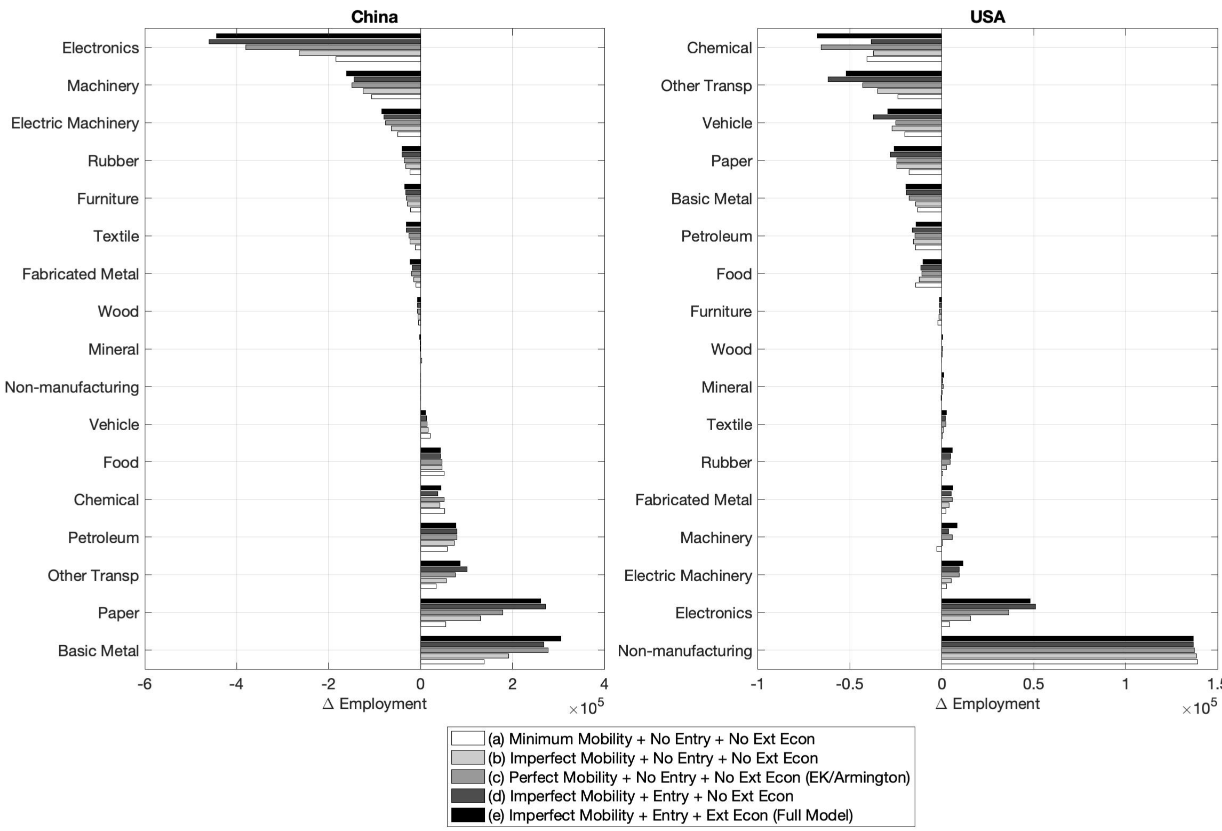
(a) Passthrough Rate



(b) Relative Chinese Wage

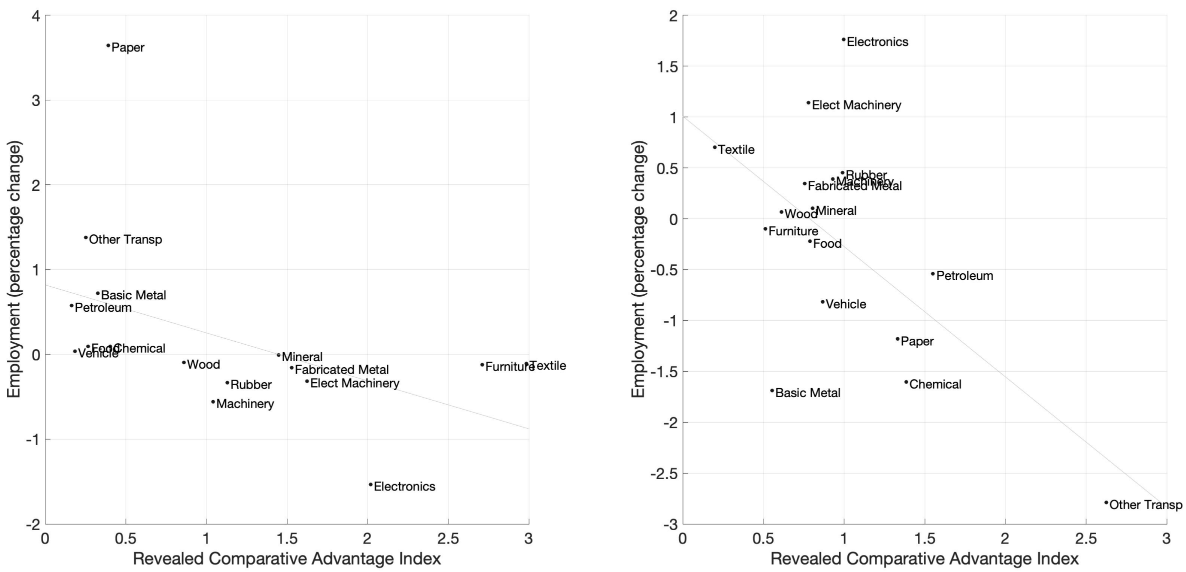
Notes: This figure shows the average passthrough rate of US tariffs onto prices of Chinese goods in the US that are targeted by tariffs (left panel), and percentage change of the average Chinese wage relative to the average US wage (right panel), each as a function of the number of Chinese manufacturing industries that the US tariffs target. Each dot is calculated as an average across a hundred randomly-drawn permutations of industries, with the dashed lines representing the 10th and 90th percentiles of the outcomes.

Figure 2: Reallocation of Employment in China and the US



Notes: This figure shows changes in employment across industries in China (left panel) and the US (right panel) in response to US tariffs imposed on Chinese manufacturing industries.

Figure 3: Employment Reallocations vs. Revealed Comparative Advantage



(a) China (b) USA

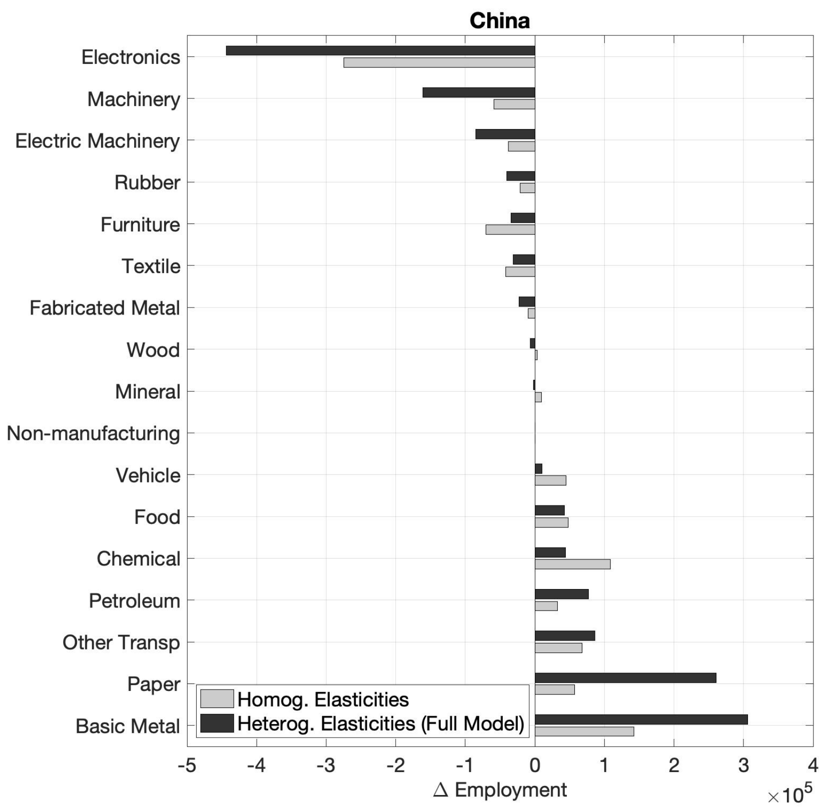
Notes: This figure shows the percentage change to the labor employment across manufacturing industries in China (left panel) and the US (right panel) versus these countries' revealed comparative index, defined as each country's share of exports in an industry relative to the global share of exports in that industry.

Table 6: Reallocations & Passthrough across Models

	Elasticities			GE Effects	
Model Description	Supply $\omega^{(1)}$	Aggregation $\omega^{(2)}$	Specialization $\frac{\omega^{(2)}-1}{\omega^{(1)}}$	Reallocation	Passthrough
Mob Frictions, No Entry, No Ext Econ					
(a) Labor mob: Minimum	1.00	0.00	-1.00	49.7%	76.7%
(b) Labor mob: At Estimated Supply Elast	3.13	0.00	-0.38	67.4%	79.4%
No Mob Frictions, No Entry, No Ext Econ					
(c) Standard EK/Armington	∞	0.00	0.00	87.6%	81.5%
Mob Frictions, Entry, No Ext Econ					
(d) Labor mob: At Estimated Supply Elast	3.13	1.21	0.01	98.4%	81.1%
Mob Frictions, Entry, Ext Econ					
(e) Full Model	3.13	1.35	0.11	100.0%	82.5%

Notes: This table reports, for each model, the general equilibrium effects of a comprehensive US tariff policy on employment reallocations in China and passthrough rates onto prices of Chinese exported goods to the US. Supply, aggregation, and specialization elasticities are reported as their average values for each model. Reallocation is the sum of the absolute value of employment changes in China, reported relative to the Full model. Passthrough is the average passthrough rates onto prices of Chinese exports to the US across all industries.

Figure 4: Heterogenous vs Homogenous Elasticities: Reallocation of Employment in China



Notes: This figure shows changes in employment across industries in China in response to US tariffs in our full model with heterogenous elasticities versus the model with homogenous elasticities.

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Appendix A Technical Notes

1.1 Equilibrium in Changes in terms of Labor Market Clearing

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 $\mathscr{B} = \left\{X_n, Y_{n,k}, t_{ni,k}, X_{ni,k}\right\}$. 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 international expenditure shares are $\pi_{ni,k} \equiv \dfrac{X_{ni,k}}{\sum_{\ell \in N} X_{n\ell,k}}$. In addition, let us define parameters $\gamma_{i,k}$ as follows:

$$\gamma_{i,k} \equiv (\eta_{i,k} - 1)^{-1} + \phi_{i,k}$$

where $\gamma_{i,k}$ can be thought of as the "composite scale elasticity." Given a policy $\mathscr{P}$, baseline values $\mathscr{B}$, and the set of parameters $\{\varepsilon_{i,k},\, \gamma_{i,k},\, \sigma_{n,k}\}$, a general equilibrium in changes consists of $\widehat{w}_{i,k}$ for all i, k such that Equations A.1-A.6 hold:

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

$$\widehat{\Phi}_i = \left[\sum_k \frac{Y_{i,k}}{Y_i} \widehat{Y}_{i,k}\right] \qquad \text{(Income per worker)} \qquad \text{(A.2)}$$

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

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

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

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

1.2 Welfare Formula

For the sake of a clear exposition, suppose the only change to the 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:

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

In addition, let us define parameter $\alpha_{ni,k}$ as:

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

The change to the price index is $\widehat{P}_n = \prod_k \widehat{P}_{nk}^{\beta_{n,k}}$, 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 ($\omega_{i,k}^{(2)}$). 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),

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

which reproduces Equation (14) in the main text:

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

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 $P_{ii,k}$ can be expressed as functions of product-level price $p_{ii,k}$ in the following way:

$$
\begin{aligned}
D_{ni,k} &= \delta_{ni,k} p_{ii,k}^{(1-\omega^{(2)}_{i,k})(1-\sigma_{n,k})} && \text{(A.11)}\\
Y_{i,k} &= y_{i,k} p_{ii,k}^{\omega^{(1)}_{i,k}} && \text{(A.12)}\\
P_{ii,k} &= \Lambda_{i,k} p_{ii,k}^{1-\omega^{(2)}_{i,k}} && \text{(A.13)}
\end{aligned}
$$

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 $\Lambda_{i,k}$,

$$
\begin{aligned}
\delta_{ni,k} &\equiv b_{ni,k} \tau_{ni,k}^{1-\sigma_{n,k}} P_{n,k}{}^{-(1-\sigma_{n,k})} \Lambda_{i,k}^{1-\sigma_{n,k}} \beta_{n,k} X_n && \text{(A.14)}\\
y_{i,k} &\equiv \Big(L_i e_{i,k}\Big)^{\omega^{(1)}_{i,k}\left[\frac{1+\phi_{i,k}}{\varepsilon_i} + \frac{\omega^{(2)}_{i,k}}{(1-\omega^{(2)}_{i,k})(\varepsilon_i - 1)}\right]} \left(\frac{\eta_{i,k}-1}{\eta_{i,k}}\right)^{\frac{\omega^{(1)}_{i,k}}{\omega^{(2)}_{i,k}}} \Big(\eta_{i,k} F_{i,k}\Big)^{-\frac{\omega^{(1)}_{i,k}}{(\eta_{i,k}-1)(1-\omega^{(2)}_{i,k})}} \\
&\quad \times \Phi_i^{1-\omega^{(1)}_{i,k} - \frac{\omega^{(1)}_{i,k}\omega^{(2)}_{i,k}}{1-\omega^{(2)}_{i,k}}} \Lambda_{i,k}^{\frac{\omega^{(1)}_{i,k}}{1-\omega^{(2)}_{i,k}}} a_{i,k}^{\omega^{(1)}_{i,k} + \frac{\omega^{(1)}_{i,k}\omega^{(2)}_{i,k}}{1-\omega^{(2)}_{i,k}}} && \text{(A.15)}\\
\Lambda_{i,k} &\equiv (\eta_{i,k} F_{i,k})^{\frac{1}{\eta_{i,k}-1}} \Big(L_i e_{i,k}\Big)^{-\frac{\omega^{(2)}_{i,k}}{\varepsilon_i - 1}} \left(\frac{\eta_{i,k}-1}{\eta_{i,k}}\right)^{-\omega^{(2)}_{i,k}} \Phi_i^{\omega^{(2)}_{i,k}} a_{i,k}^{-\omega^{(2)}_{i,k}} && \text{(A.16)}
\end{aligned}
$$

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

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

Specifically, we derive $\omega^{(S)}_{ni,k}$ 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.[41] Replacing for $\widehat{Y}_{i,k}$, we can express the numerator of Equation (A.5) in terms of only the demand shock and the change to wage:

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

where

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

[41] 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 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:

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

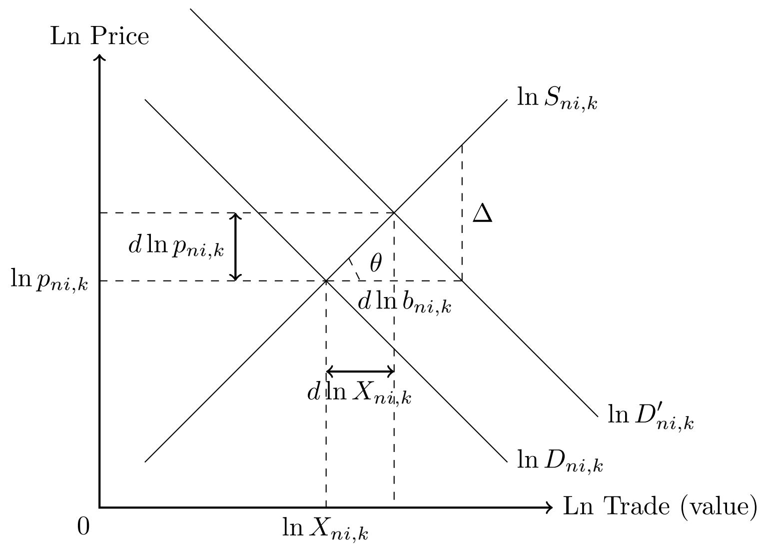


Figure A.1: Market for destination $n-$origin $i-$industry k

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

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

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

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

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

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

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

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

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

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 passthrough 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 $(1-\omega^{(2)}_{i,k})(1-(\varepsilon_i-1)\phi_{i,k})$, and rearranging terms gives the passthrough rate of tariff onto the consumer price index,

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

where $\omega^{(D)}_{ni,k} \equiv (1-\omega^{(2)}_{i,k})(1-\sigma_{n,k})$ is import demand elasticity given by Equation (15) and $\omega^{(S)}_{ni,k}$ 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 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 analytical properties of this class of 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. (2023) to reproduce their (necessary) uniqueness condition in the context 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:

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

where $\bar{c}_i \equiv (L_i e_{i,k})^{(\alpha_{ni,k} + \sigma_{n,k} - 1)/\varepsilon_i} \Phi_i^{1-\sigma_{n,k}}$. 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 (9) in Kucheryavyy et al. (2023) by noting that

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

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

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

We make two comments regarding the above derivations. First, it is understood that we are not the first to establish such a mapping between different trade models in this more general class of models. Moreover, 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 Kucheryavyy et al. (2023).

1.5 GE Effects of Trade Cost Shocks on Export Supply

This section discusses the general equilibrium effects of trade cost shocks on the export supply schedule. Recall that the export supply for the market (importer $n-$exporter $i-$industry k) is given by $S_{ni,k} = Y_{i,k} - \Sigma_{m \neq n} D_{mi,k}$, where $Y_{i,k}$ denotes the industry-level sales of country $i-$industry k, and $D_{mi,k}$ denotes country m's (import) demand for country i's variety in industry k. Using the equations which we derived in Appendix **1.2.2**, let us reproduce import demand $D_{ni,k}$, producer price index $P_{ii,k}$, and industry-level supply $Y_{i,k}$, as:

$$\begin{cases} \ln D_{ni,k} = \ln \Delta_{ni,k} + (1 - \sigma_{n,k}) \ln \tau_{ni,k} + (1 - \sigma_{n,k}) \ln P_{ii,k} \\ \ln P_{ii,k} = \ln \Lambda_{i,k} + \left(1 - \omega_{i,k}^{(2)}\right) \ln p_{ii,k} \\ \ln Y_{i,k} = \ln y_{i,k} + \omega_{i,k}^{(1)} \ln p_{ii,k} \end{cases} \tag{A.27}$$

where the "shifters" $(\Delta_{ni,k},\ y_{i,k},\ \Lambda_{i,k})$ correspond to the following composites,

$$\begin{cases} \Delta_{ni,k} \equiv \ln b_{ni,k} + (\sigma_{n,k}-1)\ln P_{n,k} + \ln\left(\beta_{n,k}X_n\right) \\ \Lambda_{i,k} \equiv \left(\eta_{i,k}F_{i,k}\right)^{\frac{1}{\eta_{i,k}-1}} \Big(L_i e_{i,k}\Big)^{-\frac{\omega_{i,k}^{(2)}}{\varepsilon_i-1}} \left(\dfrac{\eta_{i,k}-1}{\eta_{i,k}}\right)^{-\omega_{i,k}^{(2)}} \Phi_i^{\omega_{i,k}^{(2)}} a_{i,k}^{-\omega_{i,k}^{(2)}} \\ y_{i,k} \equiv \Big(L_i e_{i,k}\Big)^{\frac{1+\phi_{i,k}}{\varepsilon_i}\omega_{i,k}^{(1)}} \left(\dfrac{\eta_{i,k}-1}{\eta_{i,k}}\right)^{\omega_{i,k}^{(1)}} \Phi_i^{1-\omega_{i,k}^{(1)}} a_{i,k}^{\omega_{i,k}^{(1)}} \end{cases} \tag{A.28}$$

Note that, the total supply $Y_{i,k}$ is expressed as a function of the product-level price (net of trade cost), $p_{ii,k}$; and import demand $D_{ni,k}$ can be expressed as a function of $p_{ii,k}$ via its relationship with the producer price index $P_{ii,k}$.

Let us first review the partial equilibrium and general equilibrium responses. According to the first line of Equation (A.27), under the empirically-admissible range of trade elasticities, $(\sigma_{n,k}-1)>0$, an increase in the trade cost, $(\mathrm{d}\ln\tau_{ni,k}>0)$, induces a downward shift in import demand, $\ln D_{ni,k}$. In partial equilibrium, the supply response is limited to moving along the export supply curve. Beyond this partial equilibrium effect, the general equilibrium mechanisms induce not only a movement along, but also a shift in, the export supply schedule. Below, we derive an expression to illustrate this general-equilibrium-induced shift in the export supply.

For a clearer exposition, let us assume that the trade elasticity parameters are common across destinations, i.e., $\sigma_{n,k}=\sigma_k$ for all n. Using Equations (A.27)-(A.28), and taking similar steps as in our derivation of the export supply elasticity, we can express the impact of a local trade cost shock, $\mathrm{d}\ln\tau_{ni,k}$, on export supply as follows:

$$\mathrm{d}\ln S_{ni,k} \;=\; \omega_{ni,k}^{(S)}\mathrm{d}\ln p_{ii,k} \;+\; \omega_{ni,k}^{(\Phi)}\mathrm{d}\ln\Phi_i \;+\; \frac{1-\lambda_{ni,k}}{\lambda_{ni,k}}\sum_{m\neq n}\left[(1-\sigma_k)\ln P_{m,k}+\ln X_{m,k}\right] \tag{A.29}$$

where, recall that Φ_i is the average wage in the exporting country i, and the coefficient, $\omega_{ni,k}^{(\Phi)}$, is given by:

$$\omega_{ni,k}^{(\Phi)} \equiv \left(\frac{1-\lambda_{ni,k}}{\lambda_{ni,k}}\right)\sigma_k + \omega_{ni,k}^{(S)} + 1 \tag{A.30}$$

The first term on the right hand side of Equation (A.29) determines how the equilibrium moves along the export supply curve. The second term represents the factoral terms of trade effects. To see this clearly, with no loss of generality and by choice of the numeraire, let us normalize the average wage in the importing country, Φ_n, to unity. Under this normalization, Φ_i can be interpreted as the wage of the exporting country relative to the importing country, which could be referred to as the exporter's "factoral terms of trade." The third term, in turn, collects the response from demand of all markets except that of the importing country. This includes the response from the domestic market of the exporting country itself and all third country effects.

Consider the factoral terms of trade effect, $\omega_{ni,k}^{(\Phi)}\ln\Phi_i$. Consistent with our quantitative findings in Section **4.2**, consider that the tariff increase from the US (importing country, n) lowers the relative average wage of China (exporting country, i). Moreover, note that, for the empirically relevant values of the parameters and data, $\omega_{ni,k}^{(\Phi)}$ is a positive coefficient.[42] This means that, controlling for the demand-driven term in Equation (A.29), the terms-of-trade effects that materialize due to general equilibrium forces push the export supply curve downward. This downward shift lowers the the prices of exported goods, implying

[42] In particular, $\omega_{ni,k}^{(\Phi)}$ becomes negative only if the export supply elasticity, $\omega_{ni,k}^{(S)}$, is sufficiently negative. Our estimates imply positive export supply elasticities, as shown by Table 5 for the US-China analysis.

a lower pass-through rate onto prices.

1.6 Numerical Algorithm for Solving the Model

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. We choose income per capita in country i_0 as the numeraire.[43]

1. Guess $\widehat{Y}_{i,k}$ for all i and k.
2. Normalize the guess of $\widehat{Y}_{i,k}$ based on the numeraire:
   (a) Use Equation (20) to calculate the change to income per capita in country i_0,

$$\widehat{\Phi}_{i_0}^{\text{num}} = \sum_{k \in K} \left(\frac{Y_{i_0,k}}{Y_{i_0}} \right) \widehat{Y}_{i_0,k}$$

   (b) For all i and k, replace the guess of $\widehat{Y}_{i,k}$ with $\widehat{Y}_{i,k}/\widehat{\Phi}_{i_0}^{\text{num}}$.
3. Compute $\widehat{\Phi}_i$ using Equation (20) (here, it is guaranteed that $\widehat{\Phi}_{i_0} = 1$).
4. Compute $\widehat{p}_{ii,k}$ using the inverse supply schedule, Equation (19),

$$\widehat{p}_{ii,k} = \left(\widehat{a}_{i,k}\right)^{-1} \left(\widehat{Y}_{i,k}\right)^{\frac{1}{\omega_{i,k}^{(1)}}} \left(\widehat{\Phi}_i\right)^{\frac{\omega_{i,k}^{(1)}-1}{\omega_{i,k}^{(1)}}}$$

5. Compute $\widehat{P}_{ni,k}$ and $\widehat{\pi}_{ni,k}$ using equations (22) and (23).
6. Compute $\widehat{X}_{ni,k}$ and $\widehat{X}_n$ using equations (21) and (23).
   (a) Guess $\widehat{X}_n$.
   (b) Calculate $\widehat{X}_{ni,k} = \widehat{X}_n \widehat{\beta}_{n,k} \widehat{\pi}_{ni,k}$.
   (c) Update $\widehat{X}_n$ based on equation (21),

$$\widehat{X}_n^{\text{new}} = \frac{1}{X_n} \left[\sum_k \widehat{Y}_{n,k} Y_{n,k} + \sum_i \sum_k \frac{\widehat{t}_{ni,k} t_{ni,k}}{1 + \widehat{t}_{ni,k} t_{ni,k}} \widehat{X}_{ni,k} X_{ni,k} \right]$$

   Stop if $|\widehat{X}_n^{\text{new}} - \widehat{X}_n| \leq 10^{-16}$ for all n. Otherwise, update $\widehat{X}_n = \widehat{X}_n^{\text{new}}$ and go to Step 6(b).
7. Update $\widehat{Y}_{i,k}$ based on the market clearing condition (24),

$$\widehat{Y}_{i,k}^{\text{new}} = \frac{1}{Y_{i,k}} \left[\sum_{n \in N} \frac{1}{1 + \widehat{t}_{ni,k} t_{ni,k}} X_{ni,k} \widehat{X}_{ni,k} \right]$$

   Stop if $|\widehat{Y}_{i,k}^{\text{new}} - \widehat{Y}_{i,k}| \leq 10^{-14}$ for all (i,k). Otherwise, update $\widehat{Y}_{i,k} = \widehat{Y}_{i,k}^{\text{new}}$ and go to Step 2.

[43] Note, equilibrium in changes in terms of wages can be solved numerically using a similar algorithm that iterates over equations A.1-A.6.

Appendix B Data

Our sample covers annual data on 16 manufacturing industries (plus one non-tradeable non-manufacturing industry) and 50 countries with the largest GDP over the period of 1995-2016.[44]. For our quantitative general equilibrium analyses, we keep the largest 13 countries in terms of GDP and aggregate the other countries into five broadly-defined geographic regions. Tables A.1 and A.2 report, respectively, the list of manufacturing industries and countries/regions.

Data Construction. We obtain bilateral trade data from BACI-CEPII at the level of 6-digit HS products. To calculate trade shares (expenditure shares of each market n across supplying countries i, $\pi_{ni,k}$, and sales shares of each supplying country i across markets, $\lambda_{ni,k}$) we also need data on production (i.e., gross output) which we take from INDSTAT-UNIDO, available at the level of 2-digit ISIC industries. We merge these production data with trade data at the level of 16 manufacturing industries, listed in Table A.1. Below, we explain our data construction procedure.

First, we aggregate trade data from 6-digit HS-level products to our sixteen ISIC manufacturing industries using a crosswalk between the two classifications. Denote the industries by $k = 1, ..., 16$, and let the value of industry-level trade from i to n in industry k at year t be $X_{ni,k,t}$. Note that at this stage, we do not know domestic purchases, $X_{ii,k,t}$. From here, however, we can calculate total imports, $\text{IMP}_{i,k,t} = \Sigma_{n\neq i}X_{in,k,t}$ and total exports, $\text{EXP}_{i,k,t} = \Sigma_{n\neq i}X_{ni,k,t}$. Furthermore, we denote by $Y_{i,k,t}$ the production data from INDSTAT-UNIDO for each country $i-$industry $k-$year t.

Since the source of data on production, $Y_{i,k,t}$, differs from exports, $\text{EXP}_{i,k,t}$, there is no guarantee for values of production to be larger than exports, i.e., no guarantee that $Y_{i,k,t} - \text{EXP}_{i,k,t} > 0$. Inspecting the data, we specifically detect that one source of this issue is that for certain country-industry-year observations, *growth* in production is considerably negative whereas *growth* in exports is positive. In some cases, these sudden divergent paths between growth rates of production and exports lead to the problematic situation in which exports $\text{EXP}_{i,k,t}$ become larger than gross output $Y_{i,k,t}$ (i.e., when exports and production have comparable initial levels and production drops largely whereas exports increase, then in the subsequent year, production is likely to fall below exports).

Our approach in addressing the issues in merging production with trade data is based on two assumptions. First, we take a stance that exports data are more accurately measured than production data. The reason is that international transactions are likely to be measured on a more consistent basis over time and across national borders than the way that output of manufacturing industries are measured across countries and potentially over time in countries whose methods of measurement were subject to changes. As such, wherever trade and production data do no match, we adjust the latter. Second, in adjusting production data, when needed, we primarily focus on growth rates rather than levels. The reason lies in the observation which we highlighted above—that problematic situations frequently come from sudden drops in production relative to exports.

Moving forward, let $Y_{i,t} = \Sigma_k Y_{i,k,t}$ denote country i's total manufacturing gross output, and $\text{EXP}_{i,t} = \Sigma_k \text{EXP}_{i,k,t}$ denote country i's total manufacturing exports. In addition, consider the growth rate of total manufacturing production and exports:

$$g^Y_{i,t} = \frac{Y_{i,t} - Y_{i,t-1}}{Y_{i,t-1}}, \qquad g^X_{i,t} = \frac{\text{EXP}_{i,t} - \text{EXP}_{i,t-1}}{\text{EXP}_{i,t-1}}$$

[44] The availability of reliable gross output data by disaggregated manufacturing industries restricts us in expanding the sample of countries.

Moreover, define growth rates at the level of country-industry-year:

$$g^{Y}_{i,k,t} = \frac{Y_{i,k,t} - Y_{i,k,t-1}}{Y_{i,k,t-1}}, \qquad g^{X}_{i,k,t} = \frac{\text{EXP}_{i,k,t} - \text{EXP}_{i,k,t-1}}{\text{EXP}_{i,k,t-1}}$$

We begin with the year 1995 that is the initial year in our sample. If in country $i-$industry k, gross output is less than exports, i.e., if $Y_{i,k,1995} < \text{EXP}_{i,k,1995}$, then we replace $Y_{i,k,1995}$ by $1.01 \times \text{EXP}_{i,k,1995}$. This modification alters 9% of observations. Since our focus in the paper is on China and the US, we should be extra careful with the statistics of these two countries. At this stage, we only need to adjust the production in "Furniture; other manufacturing" industry in China (and, none in the US). From here, we obtain $\{Y_{i,k,t_0}, \text{EXP}_{i,k,t_0}\}_{i,k}$ for $t_0 = 1995$ such that Y_{i,k,t_0} is always greater than EXP_{i,k,t_0}.

Given the data in year $t-1$ we adjust the growth rate of production data in year t as explained below. This step consists of a loop over $t = 1996, 1997, ..., 2016$. Our procedure will guarantee that at each year t in the loop, data of year $t-1$ is already adjusted to have no problematic cases—meaning that once we come to consider year t, gross output values in $t-1$, $Y_{i,k,t-1}$, are already altered (if needed) to guarantee that they are larger than exports, $\text{EXP}_{i,k,t-1}$.

Specifically, we consider a statistical relationship between *growth rate* of total manufacturing production, $g^{Y}_{i,t}$, and *growth rate* of total manufacturing exports, $g^{X}_{i,t}$. Let this relationship be represented by $\widehat{g}^{Y}_{i,t} = f_{i,t}(g^{X}_{i,t})$ where $\widehat{g}^{Y}_{i,t}$ is the predicted growth in total production as a function of observed growth in total exports, $g^{X}_{i,t}$, across all countries and years.

To do so in a transparent way, we regress $g^{Y}_{i,t}$ against $g^{X}_{i,t}$ based on: $g^{Y}_{i,t} = \delta_t + \beta g^{X}_{i,t} + \epsilon_{i,t}$ where δ_t is a year dummy capturing global trends in trade to GDP ratio and β reflects the extent to which production growth correlates with exports growth. The two growth rates are highly correlated and values of production generically grow less than proportionately relative to exports. Specifically, this regression gives $\hat{\beta} = 0.84$ (S.E. $= 0.04$) with $R^2 = 0.64$. Moving ahead, at each year t, we apply the following two rules:

- (R1) If *(i)* $g^{Y}_{i,k,t} < -b < 0$ where $(-b)$ is a threshold from below on the growth rate of production, and *(ii)* $g^{Y}_{i,k,t} < g^{X}_{i,k,t}$; then replace $g^{Y}_{i,k,t}$ by $g^{Y}_{i,k,t} = \widehat{g}^{Y}_{i,k,t}$
- (R2) After applying (R1), if it is still the case that $Y_{i,k,t} < \text{EXP}_{i,k,t}$, then impose that $g^{Y}_{i,k,t} = g^{X}_{i,k,t}$.

In (R1), b is meant to be a sufficiently large rate of growth, and so, $(-b)$ reflects a sufficiently large drop in production. In practice, we set $(-b) = -0.20$. When in addition to $g^{Y}_{i,k,t} < -b$, we observe in year t that production drops not only in absolute term but also relative to exports, we replace the growth rate of gross output $g^{Y}_{i,k,t}$ by its predicted value $\widehat{g}^{Y}_{i,k,t}$.

Note that the procedure in (R1) does not guarantee that production is larger than exports in year t. That is why we go to (R2) where we check whether $Y_{i,k,t}$ is larger than $\text{EXP}_{i,k,t}$. If not, then we replace the growth rate of gross output with that of exports. Note that the growth rate of exports is larger than the predicted growth rate of gross output, so (R2) alters the data more aggressively compared to (R1). Also note that here it will be guaranteed that $Y_{i,k,t} \geq \text{EXP}_{i,k,t}$, because in year $t-1$ we have already made sure that $Y_{i,k,t-1} \geq \text{EXP}_{i,k,t-1}$ and (R2) imposes that the two grow at the same rate from $t-1$ to t. Finally, in case of a modification, update the value of gross output: $Y_{i,k,t} = (1 + g^{Y}_{i,k,t})Y_{i,k,t-1}$. We run this procedure for each t given the potentially updated values in $t-1$. This stage alters less than 5% of data in the US and China, with the majority in the "Furniture; other manufacturing" industry in China.

Data Description. We describe key variables that emerge from our final sample across countries and manufacturing industries, and we examine some cross-checks between our sample of data and other sources.

In Table A.2, for the manufacturing industry, we report domestic expenditure shares and domestic sales shares, and annualized growth rates of production, exports, and imports for each country at the aggregate level of manufacturing sector.

For instance, the US domestic expenditure share has been on average 76.9% which declined from 81.9% in 1995 to 71.8% in 2016, reflecting the increase in imports of manufacturing to the US relative to its manufacturing production and exports. In contrast, Chinese domestic expenditure share was on average 86.7% which rose from 79.2% in 1995 to 94.2% in 2016, reflecting that in China, manufacturing production and exports rose more sharply than imports.

Moreover, we cross check our data on production, imports, and exports of manufacturing sector to those in WIOD (World Input Output Database). Figure A.2 shows the scatter plot for production between our data and WIOD. Figure A.3 depicts the scatter plot of imports and exports between our data and WIOD. As shown by these figures, our data are close to the WIOD data on production and trade.

Note that we chose not to use WIOD because WIOD does not report unit values. Instead, we have based our trade data on BACI-CEPII that also reports unit values. Moreover, we note that we have unit values only for international trade flows and not for domestic purchases. This does not limit our estimation as it can run over quantities and unit values of international trade excluding transactions of a country with itself. The reason that we additionally need production data is that our estimation also requires data on $\pi_{ni,k}$ (import penetration or expenditure share of each market n across supplying countries i) and $\lambda_{ni,k}$ (export penetration, or sales share of each supplying country i across each market n).

Table A.1: List of Industries

Industry	ISIC Code	Description (Short Name)
1	C10-C12	Food products, beverages and tobacco products (Food)
2	C13-C15	Textiles, wearing apparel and leather products (Textile)
3	C16	Wood and of products of wood and cork (Wood)
4	C17-C18	Paper and paper products; Printing and reproduction of recorded media (Paper)
5	C19	Coke and refined petroleum products (Petroleum)
6	C20-C21	Chemicals and chemical products; pharmaceutical products (Chemical)
7	C22	Rubber and plastic products (Rubber)
8	C23	Other non-metallic mineral products (Mineral)
9	C24	Basic metals (Basic Metal)
10	C25	Fabricated metal products, except machinery and equipment (Fabricated Metal)
11	C28	Machinery and equipment n.e.c. (Machinery)
12	C26	Computer, electronic and optical products (Electronics)
13	C27	Electrical equipment (Electric Machinery)
14	C29	Motor vehicles, trailers and semi-trailers (Vehicle)
15	C30	Other transport equipment (Other Transp.)
16	C31-C32	Furniture; other manufacturing (Furniture)

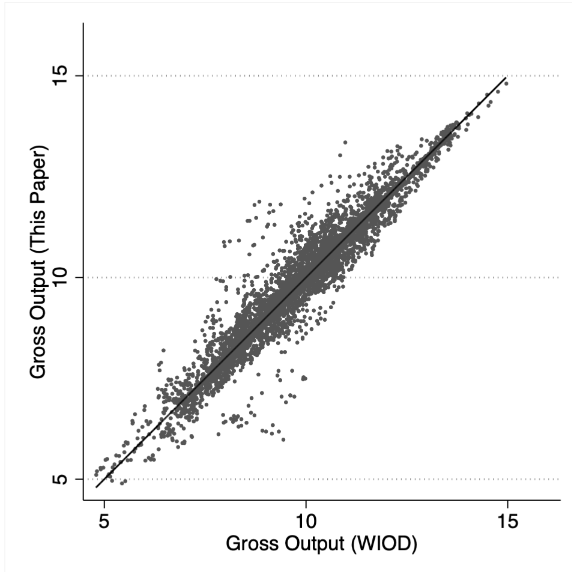
This table reports the list of manufacturing industries in this study.

Table A.2: Summary of Statistics—Countries

	Dom Exp	Dom Sales	Annualized Growth (%)		
	Share	Share	Production	Exports	Imports
Country	(1)	(2)	(3)	(4)	(5)
United States	0.769	0.824	2.4%	3.6%	5.0%
China	0.867	0.777	17.0%	12.0%	10.4%
Japan	0.895	0.838	0.5%	1.8%	2.8%
Germany	0.636	0.575	2.4%	4.5%	4.0%
United Kingdom	0.573	0.652	1.4%	2.4%	4.2%
France	0.703	0.708	3.1%	2.9%	3.4%
India	0.932	0.916	22.8%	9.7%	10.8%
Italy	0.699	0.649	2.3%	3.4%	3.4%
Brazil	0.865	0.874	6.8%	5.5%	4.7%
Canada	0.486	0.505	2.3%	2.5%	4.1%
Russia	0.825	0.836	12.1%	7.1%	7.5%
Australia	0.641	0.767	5.9%	4.2%	5.8%
Mexico	0.519	0.501	8.2%	8.0%	7.9%
RO Asia	0.805	0.804	14.0%	6.7%	6.0%
RO North Europe	0.627	0.614	6.4%	4.2%	4.4%
RO South Europe	0.594	0.620	5.2%	7.6%	6.6%
RO South America	0.808	0.911	37.2%	6.2%	5.1%
Africa	0.806	0.868	11.7%	6.9%	6.0%

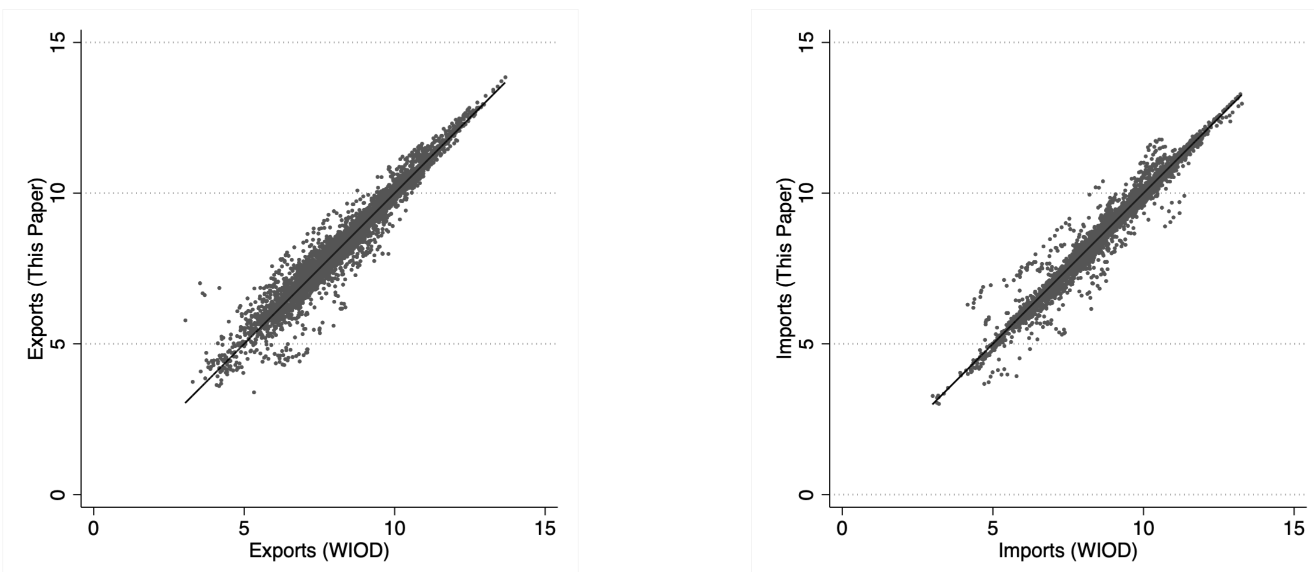
Notes: This table reports the list of countries/regions in our sample. "Dom Exp Share" and "Dom Sales Share" indicate the domestic expenditure share and domestic sales share in the aggregate of the manufacturing, averaged between the first and last year of our sample. Annual growth rates in Production, Exports, and Imports are also for the aggregate of manufacturing reported as the average annualized growth between the first and last year in the sample, 1995 to 2016.

Figure A.2: Crosscheck: Gross Output



Notes: This figure shows production data in our sample compared to WIOD database at the level country-industry pairs for years 1995-2011.

Figure A.3: Crosscheck: Exports and Imports



Notes: This figure shows imports and exports data in our sample compared to WIOD database at the level country-industry pairs for years 1995-2011.

Appendix C Estimation of Lower-tier Demand Elasticities & Construction of Price Indices

In this section, we first provide a detailed description of the estimation of lower-tier demand elasticities ($\eta_{i,k}$) where we follow Redding and Weinstein (2023)' reverse-weighting procedure. We then use our estimates of ($\eta_{i,k}$) to construct CES price indices ($P_{ni,k}$).

Prices and Expenditure Shares. Consider the lower tier of the CES preferences[45] that aggregates across HS6 product varieties $\ell \in \Omega_{ni,k}$ (within the set of 2-digit ISIC industry k from origin i to destination n)

$$C^t_{ni,k} = \Big[\sum_{\ell \in \Omega^t_{ni,k}} b^t_{ni,k}(\ell)^{\frac{1}{\eta_{i,k}}} C^t_{ni,k}(\ell)^{\frac{\eta_{i,k}-1}{\eta_{i,k}}} \Big]^{\frac{\eta_{i,k}}{\eta_{i,k}-1}},$$

where the price of variety (ni,k,ℓ) is $p^t_{ni,k}(\ell)$ which empirically maps to the c.i.f. unit value of the HS6 product variety $\ell \in \Omega^t_{ni,k}$. In turn, $b^t_{ni,k}(\ell)$ corresponds to the demand shifter/taste for this variety. We aim to estimate $\eta_{i,k}$, which is the *origin-industry* specific elasticity of substitution that consumers face when demanding product varieties $\ell \in \Omega^t_{ni,k}$ from origin country $i-$industry k.

The corresponding price indices and expenditure shares are given by:

$$P^t_{ni,k}\left(\{b^t_{ni,k}(\ell)\}, \{p^t_{ni,k}(\ell)\}, \Omega^t_{ni,k}\right) = \left[\sum_{\ell \in \Omega^t_{ni,k}} b^t_{ni,k}(\ell) \left(p^t_{ni,k}(\ell)\right)^{1-\eta_{i,k}} \right]^{\frac{1}{1-\eta_{i,k}}},$$

$$s^t_{ni,k}(\ell) \equiv \frac{X^t_{ni,k}(\ell)}{\sum_{\ell \in \Omega^t_{ni,k}} X^t_{ni,k}(\ell)} = \frac{b^t_{ni,k}(\ell)\left(p^t_{ni,k}(\ell)\right)^{1-\eta_{i,k}}}{\left(P^t_{ni,k}\right)^{1-\eta_{i,k}}},$$

where $X^t_{ni,k}(\ell) \equiv p^t_{ni,k}(\ell) C^t_{ni,k}(\ell)$.

Consider the set of product varieties in two periods 0 and 1, $\Omega^0_{ni,k}$ and $\Omega^1_{ni,k}$ and let $\Omega^*_{ni,k} = \Omega^0_{ni,k} \cap \Omega^1_{ni,k}$ be the common set. For each period, define the price index that aggregates over the common set, denoted by superscript "*"

$$P^{*t}_{ni,k}\left(\{b^t_{ni,k}(\ell)\}, \{p^t_{ni,k}(\ell)\}, \Omega^*_{ni,k}\right) = \left[\sum_{\ell \in \Omega^*_{ni,k}} b^t_{ni,k}(\ell) \left(p^t_{ni,k}(\ell)\right)^{1-\eta_{i,k}} \right]^{\frac{1}{1-\eta_{i,k}}}, \quad t = 0, 1$$

Since the above aggregates over the common set, it differs from the exact price index:

$$P^t_{ni,k} = P_{ni,k}\left(\{b^t_{ni,k}(\ell)\}, \{p^t_{ni,k}(\ell)\}, \Omega^t_{ni,k}\right) = \left[\sum_{\ell \in \Omega^t_{ni,k}} b^t_{ni,k}(\ell) \left(p^t_{ni,k}(\ell)\right)^{1-\eta_{i,k}} \right]^{\frac{1}{1-\eta_{i,k}}}, \quad t = 0, 1$$

[45] In the model presented in the main text, we supposed a continuum of products and used an integral notation. Here, we use a summation and assume that the product space is large enough so that the price of an individual product has no impact on the aggregate price index. We adopt this alternative notation because there is a finite set of products in the data.

Define $\mu^t_{ni,k}$ as the aggregate share of common varieties in total expenditure in period t,

$$\mu^t_{ni,k} \equiv \frac{\sum_{\ell\in\Omega^*_{ni,k}} p^t_{ni,k}(\ell)C^t_{ni,k}(\ell)}{\sum_{\ell\in\Omega^t_{ni,k}} p^t_{ni,k}(\ell)C^t_{ni,k}(\ell)} = \frac{\sum_{\ell\in\Omega^*_{ni,k}} b^t_{ni,k}(\ell)\left(p^t_{ni,k}(\ell)\right)^{1-\eta_{i,k}}}{\sum_{\ell\in\Omega^t_{ni,k}} b^t_{ni,k}(\ell)\left(p^t_{ni,k}(\ell)\right)^{1-\eta_{i,k}}}, \quad t=0,1$$

The change to the exact price index from period 0 to 1 can be expressed as:

$$\frac{P^1_{ni,k}}{P^0_{ni,k}} = \left(\frac{\mu^1_{ni,k}}{\mu^0_{ni,k}}\right)^{\frac{1}{\eta_{i,k}-1}} \times \left(\frac{P^{*1}_{ni,k}}{P^{*0}_{ni,k}}\right)$$

where $\left(\mu^1_{ni,k}/\mu^0_{ni,k}\right)^{\frac{1}{\eta_{i,k}-1}}$ is an adjustment for entry & exit and $\left(P^{*1}_{ni,k}/P^{*0}_{ni,k}\right)$ is the inflation in the common-set. Focusing on this latter term, define expenditure shares corresponding to the purchases in the common set:

$$s^{*t}_{ni,k}(\ell) \equiv \frac{p^t_{ni,k}(\ell)C^t_{ni,k}(\ell)}{\sum_{\ell\in\Omega^*_{ni,k}} p^t_{ni,k}(\ell)C^t_{ni,k}(\ell)} = \frac{b^t_{ni,k}(\ell)\left(p^t_{ni,k}(\ell)\right)^{1-\eta_{i,k}}}{\left(P^{*t}_{ni,k}\right)^{1-\eta_{i,k}}}, \quad \text{for } \ell\in\Omega^*_{ni,k}$$

Using the above expenditure shares and price indexes, we can express the log inflation in the common set as:

$$\ln\left(\frac{P^{*1}_{ni,k}}{P^{*0}_{ni,k}}\right) = \frac{1}{\eta_{i,k}-1}\ln\left(\frac{s^{*1}_{ni,k}(\ell)}{s^{*0}_{ni,k}(\ell)}\right) + \ln\left(\frac{p^1_{ni,k}(\ell)/(b^1_{ni,k}(\ell)^{\frac{1}{1-\eta_{i,k}}})}{p^1_{ni,k}(\ell)/(b^1_{ni,k}(\ell)^{\frac{1}{1-\eta_{i,k}}})}\right)$$

Identification Assumptions. To save on notation, let us drop the (ni,k) subscript with the understanding that all we derive below corresponds to variables within (ni,k). That is, let us equivalently work with:

$$\ln\left(\frac{P^{*1}}{P^{*0}}\right) = \frac{1}{\eta-1}\ln\left(\frac{s^{*1}(\ell)}{s^{*0}(\ell)}\right) + \ln\left(\frac{p^1(\ell)/(b^1(\ell)^{\frac{1}{1-\eta}})}{p^1(\ell)/(b^1(\ell)^{\frac{1}{1-\eta}})}\right) \tag{A.31}$$

which holds for all $\ell\in\Omega^*$.

Next, define "bar" variables as unweighted geometric means. Specifically, for any generic variable x, define $\bar{x}$ as:

$$\bar{x}^t = \prod_{\ell\in\Omega^*} x^t(\ell)^{1/L}$$

where L is the number of product varieties in the common set, $L\equiv|\Omega^*|$.

We now begin to impose assumptions on the structure of demand by supposing that taste parameters are *stable* in the sense that they do not change on average over time:

$$\text{(Identification Assumption 1)} \qquad \bar{b}^1 = \bar{b}^0$$

Applying the definition of bar variables to Equation (A.31), and under (Identification Assumption 1), it follows that:

$$\ln\left(\frac{P^{*1}}{P^{*0}}\right) = \frac{1}{\eta-1}\ln\left(\frac{\bar{s}^{*1}}{\bar{s}^{*0}}\right) + \ln\left(\frac{\bar{p}^1}{\bar{p}^0}\right)$$

This is the first way of calculating the price change in the common set. There are two other ways of obtaining the price change as we follow to explain.

Next, apply the exact hat algebra to the CES price index, P^*, as we move from period 0 to 1:

$$\frac{P^{*1}}{P^{*0}} = \left[\sum_{\ell\in\Omega^*} s^{*0}(\ell)\left(\frac{b^1(\ell)}{b^0(\ell)}\right)\left(\frac{p^1(\ell)}{p^0(\ell)}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

which can be expressed as:

$$\frac{P^{*1}}{P^{*0}} = \Pi_F \times \left[\sum_{\ell\in\Omega^*} s^{*0}(\ell)\left(\frac{p^1(\ell)}{p^0(\ell)}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{A.32}$$

where

$$\Pi_F \equiv \frac{\left[\sum_{\ell\in\Omega^*} s^{*0}(\ell)\left(\frac{b^1(\ell)}{b^0(\ell)}\right)\left(\frac{p^1(\ell)}{p^0(\ell)}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}}{\left[\sum_{\ell\in\Omega^*} s^{*0}(\ell)\left(\frac{p^1(\ell)}{p^0(\ell)}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}}$$

Supposing that the change in the demand shifters of the numerator in the above ratio is inconsequential in the aggregation such that the numerator and denominator remain the same, then we can impose that:

$$\text{(Identification Assumption 2)} \qquad \ln \Pi_F = 0$$

Similarly, we could apply the exact hat algebra to the CES price index, P^*, this time backward, by moving from period 1 to 0:

$$\frac{P^{*0}}{P^{*1}} = \left[\sum_{\ell\in\Omega^*} s^{*1}(\ell)\left(\frac{b^0(\ell)}{b^1(\ell)}\right)\left(\frac{p^0(\ell)}{p^1(\ell)}\right)^{1-\eta_{i,k}}\right]^{\frac{1}{1-\eta_{i,k}}}$$

which can be expressed as:

$$\frac{P^{*0}}{P^{*1}} = \Pi_B \times \left[\sum_{\ell\in\Omega^*} s^{*1}(\ell)\left(\frac{p^0(\ell)}{p^1(\ell)}\right)^{1-\eta_{i,k}}\right]^{\frac{1}{1-\eta_{i,k}}} \tag{A.33}$$

where

$$\Pi_B = \frac{\left[\sum_{\ell\in\Omega^*} s^{*1}(\ell)\left(\frac{b^0(\ell)}{b^1(\ell)}\right)\left(\frac{p^0(\ell)}{p^1(\ell)}\right)^{1-\eta_{i,k}}\right]^{\frac{1}{1-\eta_{i,k}}}}{\left[\sum_{\ell\in\Omega^*} s^{*1}(\ell)\left(\frac{p^0(\ell)}{p^1(\ell)}\right)^{1-\eta_{i,k}}\right]^{\frac{1}{1-\eta_{i,k}}}}$$

Similarly, suppose:

$$\text{(Identification Assumption 3)} \qquad \ln \Pi_B = 0$$

Reverse-Weighting Estimator. Under the Identification Assumptions 1, 2 and 3, we can summarize three ways of calculating the price index of the common set, expressed in logs:

$$\ln\left(\frac{P^{*1}}{P^{*0}}\right) = \frac{1}{\eta-1}\ln\left(\frac{\bar{s}^{*1}}{\bar{s}^{*0}}\right) + \ln\left(\frac{\bar{p}^1}{\bar{p}^0}\right)$$

$$\ln\left(\frac{P^{*1}}{P^{*0}}\right) = \frac{1}{1-\eta}\ln\left[\sum_{\ell\in\Omega^*} s^{*0}(\ell)\left(\frac{p^1(\ell)}{p^0(\ell)}\right)^{1-\eta}\right]$$

$$\ln\left(\frac{P^{*1}}{P^{*0}}\right) = \frac{1}{-(1-\eta)}\ln\left[\sum_{\ell\in\Omega^*} s^{*1}(\ell)\left(\frac{p^1(\ell)}{p^0(\ell)}\right)^{-(1-\eta)}\right]$$

As we use the three above equations to construct two moment conditions, let us also bring back the subscript (ni,k) to the formulas:

$$M^{(1)}_{ni,k}(\eta_{i,k}) = \frac{1}{\eta_{i,k}-1}\ln\left(\frac{\bar{s}^{*1}_{ni,k}}{\bar{s}^{*0}_{ni,k}}\right) + \ln\left(\frac{\bar{p}^1_{ni,k}}{\bar{p}^0_{ni,k}}\right) - \frac{1}{1-\eta_{i,k}}\ln\left[\sum_{\ell\in\Omega^*_{ni,k}} s^{*0}_{ni,k}(\ell)\left(\frac{p^1_{ni,k}(\ell)}{p^0_{ni,k}(\ell)}\right)^{1-\eta_{i,k}}\right]$$

$$M^{(2)}_{ni,k}(\eta_{i,k}) = \frac{1}{\eta_{i,k}-1}\ln\left(\frac{\bar{s}^{*1}_{ni,k}}{\bar{s}^{*0}_{ni,k}}\right) + \ln\left(\frac{\bar{p}^1_{ni,k}}{\bar{p}^0_{ni,k}}\right) - \frac{1}{-(1-\eta_{i,k})}\ln\left[\sum_{\ell\in\Omega^*_{ni,k}} s^{*1}_{ni,k}(\ell)\left(\frac{p^1_{ni,k}(\ell)}{p^0_{ni,k}(\ell)}\right)^{-(1-\eta_{i,k})}\right]$$

For each origin-industry, we stack all the moments with exporter (i,k) across all import markets $n = 1,...,N$, into vector $\mathbf{M}_{i,k}(\eta_{i,k}) = \left\{M^{(1)}_{ni,k}(\eta_{i,k}), M^{(2)}_{ni,k}(\eta_{i,k})\right\}_{n=1}^{N}$. We base our estimation on $\mathbb{E}[\mathbf{M}_{i,k}(\eta_{i,k})] = 0$, and so, the estimate $\hat{\eta}_{i,k}$ achieves:

$$\hat{\eta}_{i,k} = \arg\min_{\eta_{i,k}} \ \mathbf{M}_{i,k}(\eta_{i,k})\mathbf{W}_{i,k}\mathbf{M}^T_{i,k}(\eta_{i,k})$$

where $\mathbf{W}_{i,k}$ is a weighting matrix which we set to the identity matrix.

Constructing Price Indices. Using the expenditure shares of the common set, we can now recover the demand shifters for each variety in the common set, $\ell \in \Omega^*_{ni,k}$,

$$b^t_{ni,k}(\ell) = s^{*t}_{ni,k}(\ell)\left(\frac{p^t_{ni,k}(\ell)}{P^{*t}_{ni,k}}\right)^{\eta_{i,k}-1}$$

From here, we can recover the relative demand shifters in each period, but we cannot pin down their common scale, so let us revisit Identification Assumption 1, and make it a bit stronger by assuming that the average of demand shifters equals one.

$$\text{(Identification Assumption 1')} \qquad \bar{b}^1_{ni,k} = \bar{b}^0_{ni,k} = 1$$

Using the above equation and Identification Assumption 1', we recover demand shifters $b^t_{ni,k}(\ell)$ from the observables and the estimates of $(\eta_{i,k}-1)$,

$$b^t_{ni,k}(\ell) = \frac{s^{*t}_{ni,k}(\ell)\left(p^t_{ni,k}(\ell)\right)^{\eta_{i,k}-1}}{\bar{s}^{*t}_{ni,k}\left(\bar{p}^t_{ni,k}\right)^{\eta_{i,k}-1}}, \quad \text{for } \ell \in \Omega^*_{ni,k}.$$

Plugging $b^t_{ni,k}(\ell)$ into the following equation, we can obtain $P^{*t}_{ni,k}$,

$$P^{*t}_{ni,k}\left(\{b^t_{ni,k}(\ell)\},\{p^t_{ni,k}(\ell)\},\Omega^*_{ni,k}\right)=\left[\sum_{\ell\in\Omega^*_{ni,k}} b^t_{ni,k}(\ell)\left(p^t_{ni,k}(\ell)\right)^{1-\eta_{i,k}}\right]^{\frac{1}{1-\eta_{i,k}}}$$

From here, we calculate the exact price index $P_{ni,k}$ by incorporating the entry/exit adjustment,

$$P^t_{ni,k}=\left(\mu^t_{ni,k}\right)^{\frac{1}{\eta_{i,k}-1}}\times P^{*t}_{ni,k}.$$

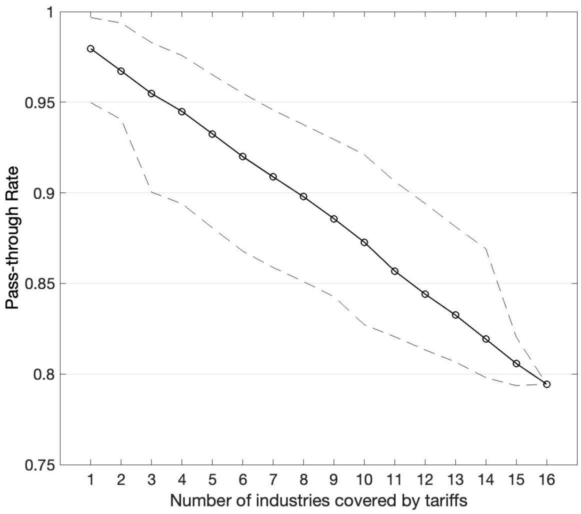
Appendix D Additional Results

Table A.3: Reallocations & Passthrough across Models

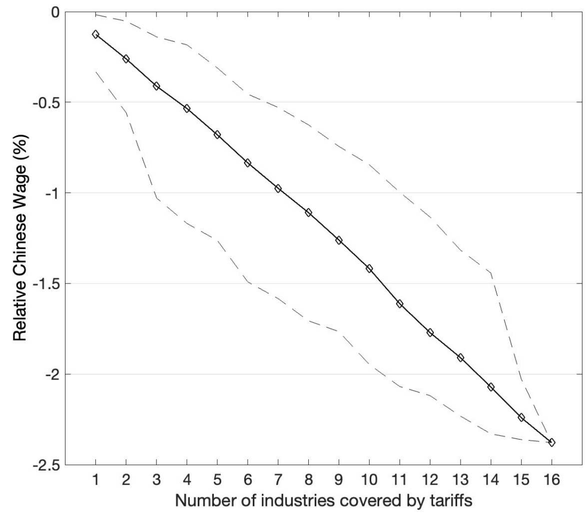
Model Description	Demand σ	Supply $\omega^{(1)}$	Aggregation $\omega^{(2)}$	Specialization $\frac{\omega^{(2)}-1}{\omega^{(1)}}$	Reallocation	Passthrough
	Elasticities				GE Effects	
No Mob Frictions, No Entry, Ext Econ Bartelme et al. (2021)	7.14	-7.20	0.00	0.17	151.27%	81.6%
No Mob Frictions, Entry, No Ext Econ Lashkaripour and Lugovskyy (2023)	4.75	∞	∞	0.33	101.7%	79.9%
Mob Frictions, Entry, Ext Econ Farrokhi-Soderbery (Full Model)	2.96	3.13	1.35	0.11	100.0%	82.5%

Notes: This table reports, for each model, the general equilibrium effects of a comprehensive US tariff policy on employment reallocations in China and passthrough rates onto prices of Chinese exported goods to the US. Supply, aggregation, and specialization elasticities are reported as their average values for each model. Reallocation is the sum of the absolute value of employment changes in China, reported relative to the Full model. Passthrough is the average passthrough rates onto prices of Chinese exports to the US across all industries. The parameters for Bartelme et al. (2021), ϕ and σ, are taken from their Table 1 under Column (IV) and Table B.1 under Column (4)—with $\omega^{(1)}=-1/\phi$ and $\frac{\omega^{(2)}-1}{\omega^{(1)}}=\phi$. The parameters for Lashkaripour and Lugovskyy (2023), η and σ, are taken from their Table 3—with $\frac{\omega^{(2)}-1}{\omega^{(1)}}=\frac{\sigma-1}{\eta-1}$. The reported elasticities are evaluated at their average in each model.

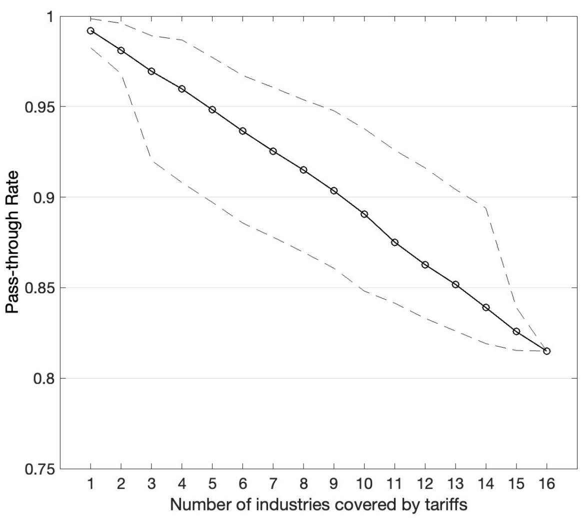
Figure A.4: General Equilibrium Passthrough Rates and Wage Effects vs. Coverage of Tariff Policy in Simpler Models



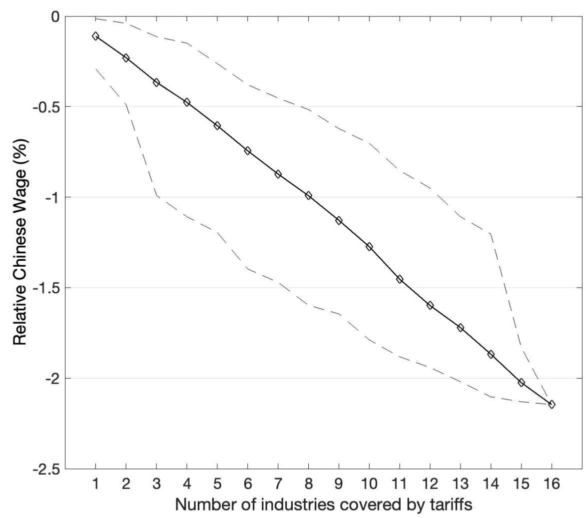
(a) Model (b) – Passthrough Rate



(b) Model (b) – Relative Chinese Wage



(c) Model (c) – Passthrough Rate



(d) Model (c) – Relative Chinese Wage

Notes: Model (b), in the two top panels, corresponds to one in which there is no product entry, no external economies of scale, and the labor mobility is set according to the estimated supply elasticity. Model (c), in the two bottom panels, is the standard EK/Armington model in which there is no product entry, no external economies of scale, with perfect labor mobility. For each model, the figure shows the average passthrough rate of US tariffs onto prices of Chinese goods in the US that are targeted by tariffs (left panel in each row), and percentage change of the average Chinese wage relative to the average US wage (right panel in each row), each as a function of the number of Chinese manufacturing industries that the US tariffs target. Each dot is calculated as an average across a hundred randomly-drawn permutations of industries, with the dashed lines representing the 10th and 90th percentiles of the outcomes.