Processing Trade and Costs of Incomplete Liberalization: The Case of China*

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ABSTRACT:

A major objective of policies promoting processing trade in developing countries is integration with global markets. A central feature of processing regimes is that firms do not have to pay tariffs on imported inputs as long as they are used exclusively in the production of goods for export. These firms are typically restricted from selling output using imported inputs on the domestic market. These restrictions can be viewed as a form of incomplete liberalization due to protectionist motives. Using data from China for 2000-2007 for 109 industries, we study the welfare effects of these measures. Counterfactual experiments imply total welfare losses of 2.2% for China due to the restriction on selling processing output domestically, and even larger loses of 5.7% for labor. Gains from only the tariff exemption for processing firms however are negligible.

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1. Introduction

Economists have long believed that policies encouraging integration into the global economy help expedite economic development. One common lever toward this end is the establishment of export processing zones and the adoption of policies that encourage the setting up of firms to engage in export processing. Radelet and Sachs (1997) argue that such programs have been instrumental in the successful economic development of East and Southeast Asia.

A central feature of processing regimes is that firms do not have to pay tariffs on the import of intermediate goods and capital equipment as long as they are used exclusively in the production of goods for export. This means that these firms are often restricted from selling output using these imported inputs on the domestic market. Processing trade typically co-exists with "ordinary trade" under which firms are required to pay tariffs on imports but are then free to sell the resulting output (or the imported good itself) on the domestic market.[1]

In an environment of high domestic tariffs, processing trade allows low-income countries to better leverage their low labor costs in labor-intensive manufacturing assembly, leading to an increase in labor demand and foreign exchange earnings. At the same time however, the processing regime entails a form of incomplete liberalization: local agents are not able to consume goods produced by export processors or use them as intermediates. Insofar as there are differences between processing and ordinary producers in the varieties they produce, the technology they use, or their productivity or quality levels, there are potential welfare gains that are left unrealized.

Protectionist motives may underlie these restrictions. In the context of a general market liberalization, China has used tariffs and non-tariff barriers to protect domestic firms in key industries. Branstetter and Feenstra (2002) argue that a desire to protect state owned enterprises played an important role in policy with respect to FDI. For example, the location of the first special economic zones in Guangdong and Fujian put them near Hong Kong and Taiwan, outside the state's industrial centers (e.g. Beijing and Shanghai) to "prevent 'contamination' of Chinese heavy

[1] In Mexico, initial restrictions on maquiladoras from selling domestically were gradually relaxed under NAFTA. From a complete prohibition before NAFTA, in 1993, firms were allowed to sell 50% of the previous year's export production on the domestic market, and, in 2001, 70-90%. See Vargas (2001) and Canas and Gilmer (2007).

industry by outside influences" [Branstetter and Feenstra (2002) pg. 339].

Despite the popularity of such regimes, there are relatively few quantitative assessments of the costs and benefits associated with processing.[2] This paper carries out such an analysis by examining the welfare implications associated with China's processing regime for the years 2000-2007. We extend the multi-sector, multi-country, general equilibrium models of the sort developed by Caliendo and Parro (2015), and Levchenko and Zhang (2016) to include both ordinary and processing trade. We allow for multiple factors of production (capital and labor) as well as traded intermediate inputs, which are essential for thinking about the implications of China's trade regime. Through a series of counterfactual exercises, we assess the welfare consequences of two important dimensions of China's processing regime: First, the gains of the tariff exemption enjoyed by processing firms; and second, the potential welfare costs stemming from the restrictions on the sale of processing output in the domestic economy. Ironically, in June of 2020 China's State Council acted to remove these restrictions on processing firms.[3]

A central component of our analysis is the examination of productivity differences between ordinary and processing production, a likely determinant of the costs of restrictions on the processing sector. We obtain estimates of relative productivity for ordinary and processing based on estimates of unit costs derived from gravity regressions, factoring in differences in input prices across the two regimes. In our examination of productivity, we allow for differences between ordinary and processing both within and across industries. Using the multivariate Fréchet distribution as in Ramondo and Rodríguez-Clare (2013), we assume productivity draws for ordinary and processing within an industry are stochastic and imperfectly correlated. This captures our prior

[2]Hamada (1974), Hamilton and Svensson (1982) , Young (1987), Young and Miyagiwa (1987), and Facchini and Willmann (1999) all develop welfare results for duty free zones. Panagariya (1992) studies duty drawbacks in the context of a small open economy. Ianchovichina (2007) builds on Panagariya (1992) to assess the welfare effects of tariff drawbacks for China. Connolly and Yi (2015) offers an assessment of duty drawbacks for South Korea in a full general equilibrium model. Both Ianchovichina (2007) and Connolly and Yi (2015) assume that all exports receive drawbacks and therefore do not explore the endogenous choice of how to organize between ordinary or processing production. In addition, neither paper explores the potential welfare losses when processing firms cannot sell domestically. Madani (1999) and OECD (2007) offer descriptive analysis of processing but do not engage in formal cost-benefit analysis.

[3]http://www.mofcom.gov.cn/article/b/e/202006/20200602976509.shtml (in Chinese) and https://www.chinadaily.com.cn/a/202006/23/WS5ef162bba310834817254ccd.html. Both retrieved August 26th, 2020.

that productivity draws in ordinary and processing production for a given producer are unlikely to be identical, but might still be correlated. This reflects differences in the production activities carried out under ordinary and processing, and heterogeneity across firms in these capabilities. To estimate the degree of correlation, we introduce a new method that combines the insights of Berry (1994) and Caliendo and Parro (2015).[4] Our estimate for this correlation suggests that the idiosyncratic portions of the productivity draws for ordinary and processing production are correlated.[5] However this correlation is far from perfect which implies room for both across- and within-industry comparative advantage gains from allowing processing to sell domestically.

Several findings emerge from our analysis. First, although underlying total factor productivity (TFP) for processing Chinese production is slightly lower on average than ordinary, there are significant differences across industries. In 2000, for example, the TFP premium of processing relative to ordinary production ranges from -26.2% to +18.5%. This heterogeneity suggests that looking at a single premium estimated over all industries as is commonly done may be misleading, and that there are potent comparative-advantage gains from allowing the processing sector to sell domestically.

Second, we find relatively small welfare gains from the duty drawbacks enjoyed by the processing sector. This is consistent with small estimated welfare effects of incremental international trade liberalization in quantitative trade models such as Eaton and Kortum (2002) and Caliendo and Parro (2015), and the fact that processing represents less than 5% of aggregate gross output in

[4]Lind and Ramondo (2018) independently establishes a two-step gravity-based procedure to measure this correlation across countries.

[5] As shown in Manova and Yu (2016), there are many firms that engage in both processing and ordinary production. However, Brandt and Morrow (2017) document that at the six-digit HS product level, only 7.6 percent of all exporting firms exported a given product through multiple forms in 2000; in 2006, this number had fallen to 3.2 percent. Reflecting this, we assume perfect competition and constant returns to scale in output markets. As a result, firms have no role in our baseline model and the organization of production at the goods level, and not the organization of the firm, is our object of interest. In our robustness section, we examine the sensitivity of our results to a model of monopolistic competition, firm heterogeneity, and increasing returns based on Hsieh and Ossa (2016). An obvious extension would be to more formally model the forces at play by extending contemporary models of multi-product firms such as Bernard, Redding and Schott (2010) to multi-industry quantitative settings with input-output linkages. Liu and Ma (2018) offer a general equilibrium model of margins of trade in China building on Melitz (2003). They assume that every firm takes both an ordinary and a processing draw and chooses a single organizational form at the firm level.

China in 2000.[6]

Third, we find large potential welfare gains in the domestic economy from eliminating the restriction on domestic sales for the processing sector. We estimate that real income in 2000 would have been 2.2% higher in a world with no restrictions, and real wages 5.7% higher. The increase in real wages is larger due to smaller gains for owners of capital, and a loss of tariff income as domestic processing sales crowd out imports. Labor gains relative to capital for two reasons: first, processing is generally more labor intensive than ordinary production; and second, the processing sector grows from 13% to 45% of tradable output in the counterfactual.[7]

And fourth, labor bears the costs of completely eliminating the processing regime which includes here China's access to processing technology. Real wages fall 1.6% relative to our benchmark. Real incomes fall much less because of offsetting effects on capital income and tariff revenue. This finding highlights the positive contribution of processing to labor demand and earnings in the economy.

In robustness checks, we find that welfare gains are not limited to those coming through domestic access to consumer goods produced by the processing sector; in fact, a majority are tied to capital goods and intermediate inputs. In the early 2000s, capital goods and intermediates represented nearly 60% of processing exports from China. This finding links our analysis to recent research identifying imported intermediates as an important channel through which liberalization affects welfare [Amiti and Konings (2007), Goldberg, Khandelwal, Pavcnik and Topalova (2010), Caliendo and Parro (2015)].

Large documented barriers to international trade [e.g. Anderson and Van Wincoop (2004)] partially underlie our finding of large gains from eliminating the restriction on domestic sales for processing, relative to the small estimated effect of duty drawbacks. Because domestic sales face substantially lower barriers than imports, endogenous domestic expenditure shares for domestically produced goods are higher. As a result, falling prices for domestically produced goods

[6]Processing represents approximately 10% of manufacturing sales in our data. Manufacturing, on the other hand, is approximately 45% of gross aggregate output [Timmer, Dietzenbacher, Los, Stehrer and Vries (2015)].

[7]This increase in wages relative to the returns to capital resulting from the expansion of a labor-intensive segment of the economy is reminiscent of Stolper-Samuelson effects.

have larger effects on the overall price index.[8] The importance of domestic market liberalization for welfare links our analysis to other papers finding large welfare effects of reducing barriers to domestic trade [Ramondo, Rodríguez-Clare and Saborío-Rodríguez (2016) and Tombe and Zhu (2019)].

This paper contributes to a literature examining the welfare effects of processing regimes. Our analysis on the potential welfare gains associated with duty drawbacks and allowing processing firms to sell domestically is static. There are also dynamic considerations, most notably, the effect of processing on technological development and innovation in the local economy [Bai, Krishna and Ma (2017)]. Processing may have also played an important role in relaxing foreign exchange constraints, thereby facilitating acquisition of new technologies and capital equipment for domestic firms [Branstetter and Lardy (2008)].

Section 2 reviews institutional details related to China's processing regime. Section 3 describes the model that we bring to our question. Section 4 describes the data. Section 5 details how we map the model to the data. Section 6 presents our results including estimates of relative productivity between ordinary and processing and the welfare results of the counterfactual simulations. Section 7 presents alternate specifications based on model parameters and model selection. Section 8 concludes.

2. Context/Institutions

China's processing regime was established in 1979 and provided incentives for the processing of raw materials, parts, and components used for exports [Branstetter and Lardy (2008)]. A major objective of the trade regime was to leverage China's low labor costs to earn foreign exchange while maintaining the protection of domestic industry, especially state owned enterprises (SOEs),

[8] Defever and Riano (2017) explore the welfare effects of special tax treatment for processing firms using a two country-single sector model. In the context of a Melitz (2003) model, they argue that special tax treatment afforded to processing firms discouraged entry by Chinese firms into China's domestic markets, leading to a higher domestic price index.

through tariffs on imports. Because 100% of processing output was exported, and none could be sold domestically, these goals were compatible.

The vast majority of Chinese exports occur through either ordinary or processing trade, which combined represent more than 95 percent of Chinese exports between 2000 and 2007. In the aggregate, the export share of processing increased between 1990 and 2000 to more than half before falling slightly in the early 2000s [Kee and Tang (2016) and Brandt and Morrow (2017)]. Within processing trade, there are two forms: import and assembly and pure assembly, of which the former represents the vast majority.[9] Both forms allow for duty free imports, but are restricted in terms of the ability of firms to sell to the domestic market. Because of these similarities, we combine these two organizational forms into a single form that we refer to as "processing".[10]

Processing is often associated with the assembly of consumer goods such as electronics and textiles. However, on the basis of the Broad Economic Classification (BEC) codes, 32% of China's processing exports in 2000 were intermediate inputs, 25% capital equipment, and 42% were consumer goods.[11] These numbers suggest that restrictions on domestic sales of processing output not only affected the availability of consumer goods, but also critical inputs into manufacturing.

In China, tariffs began to come down in the early 1990s as part of a comprehensive set of external reforms culminating in WTO accession. Between 2000 and 2007, tariffs (unweighted) fell even further from 17.3% in 2000 to 9.1% in 2007. However, the level of these tariffs varied substantially. Output tariffs were on average substantially higher than input tariffs, reflecting the

[9] For a general discussion, see Naughton (1996). For much more detailed discussions of these trade forms, see discussions in Feenstra and Hanson (2005), Branstetter and Lardy (2008), and Fernandes and Tang (2012).

[10] While we combine the two types of processing, important differences remain in terms of tax treatment. Ordinary exporters pay value added taxes (VAT) on intermediate inputs (imported or not). For processing exporters, it is more complicated. Exporters engaged in pure assembly are subject to a "no collection and no refund" policy in which no VAT is collected on imported inputs and there is no refund [see Gourdon, Hering, Monjon and Poncet (2020) pg. 6 and Ferrantino, Liu and Wang (2012) pg. 145]. For import and assembly, there is no VAT applied to imported intermediate inputs [see Ferrantino et al. (2012) pg. 145], but it is subject to the same partial VAT rebate on exports as ordinary exports. Our decision to not model these differences is driven by the following facts. First, the type of processing that receives a full rebate (pure assembly) is a small portion of overall trade. Second, both import and assembly and ordinary exports receive the same rebate rate. Third, although import and assembly does not pay VAT on their imported inputs, ordinary firms are able to receive a credit on VAT paid on these inputs. This leads us to abstract from this policy dimension.

[11] The remaining 1% are "unclassified". These calculations use the WITS HS 1996 to BEC crosswalk.

different treatment of final goods from raw materials, intermediates inputs, and capital imports [Brandt, Biesebroeck, Wang and Zhang (2017)]. Both output and input tariffs declined during this time, with the interquartile range for both declining substantially.[12]

The size of the welfare gains from allowing processing firms to sell domestically depends critically on the productivity differences between the two organizational forms.[13] If there are no differences, then there are no gains from allowing processing to sell domestically aside from tariff treatment differences. A small but developed literature has found that Chinese processing firms are, on average, less productive than ordinary and experienced slightly slower productivity growth than ordinary between 2000 and 2006 [Yu (2015), Table 9, Manova and Yu (2016), and Dai, Maitra and Yu (2016)]. Taken at face value, these findings suggest minimal gains from removing constraints on the processing sector. Several caveats are in order. First, conventional measures of productivity are potentially biased by uncontrolled for differences in input and output prices facing the two sectors. Second, the literature usually ignores differences across industries which can be a source of gains when processing enjoys a comparative advantage in some goods and industries. And third, productivity differences across varieties within an industry can generate *within-industry* gains from comparative advantage. We discuss these issues in more detail in section 6.2.

Ex ante, there are number of reasons why productivity might differ between the two organizational forms, largely related to differences in the tasks carried out, the capabilities required (e.g. quality assurance, logistics and supply chain management, and design), and the prominence of foreign firms. Processing typically entails the labor-intensive assembly of products with high-import content [Koopman, Wang and Wei (2012) and Kee and Tang (2016)]. A foreign partner usually assumes responsibility for product design, management of the supply chain, and logistics. Local firms largely oversee the labor-intensive assembly and ensure quality levels and the timely delivery of output, while keeping final costs down. In contrast, firms involved in ordinary production

[12] See Brandt et al. (2017), Figure 1.

[13] Our baseline model is perfect competition but there may also be gains from new varieties if one considers a model of monopolistic competition. If varieties are imperfectly substitutable, then consumption of newly available processing varieties can serve as a source of welfare gains [e.g. Feenstra (1994)]. We assess these additional gains due to endogenous and imperfectly substitutable varieties in section 7.4.

typically require a broader set of capabilities that span design, local sourcing, manufacturing, and logistics. Differences in firms' abilities to use high quality inputs, design goods, and manage supply chains can lead to measurable differences in productivity between ordinary and processing production. Even more simply, higher levels of multinational activity in processing may allow foreign affiliates to bring different technologies to China.[14]

3. Model

Our quantitative model possesses several important features. First, all prices and quantities are endogenous equilibrium outcomes. Second, rich input-output linkages capture the role of imported intermediate inputs, especially for processing. These same linkages allow for welfare gains from the removal of restrictions to come not just from increased consumption possibilities, but also through access to capital equipment and intermediate inputs. Third, the presence of multiple industries allows us to capture the empirical fact that processing tends to be more prominent in certain industries [Brandt and Morrow (2017)], and that there are differences in the productivity of processing relative to ordinary across industries. Finally, we allow for multiple factors of production, which will help distinguish productivity from differences in factor prices and factor intensity in the determination of unit costs.

We model ordinary and processing trade to reflect their policy treatment: processing production does not face tariffs on imports of intermediate inputs but cannot be sold on China's domestic markets. Ordinary production faces import tariffs but faces no restriction from selling on domestic markets. Consequently, ordinary output can be used in processing production but the reverse is not

[14]Implicit in our analysis will be an assumption that when a potential producer takes its two productivity draws for ordinary and processing, it cannot take the higher of the two and use it in the *other* organizational form. For example, if processing productivity is higher than ordinary, agents cannot keep their processing draw, relinquish duty rebates, obtain domestic market access, and sell through ordinary. Brandt and Morrow (2017) and Defever and Riano (2017) discuss the logistical hurdles firms must navigate when choosing which organizational form in which to operate as well the additional hurdles that must be undertaken to switch from one organizational form to another. These include segregated production facilities for firms' ordinary and processing productivity lines as discussed in Brandt and Morrow (2017). Data from the Chinese State Administration of Tax used by Chen, Liu, Serrato and Xu (2018) show the share of total processing output sold domestically is less than 1% suggesting major logistical costs that prevent processing output from being sold domestically.

allowed. In the rest of the paper, we refer to sales or exports through ordinary and processing as the "organization of production" or the "organization of trade", respectively. We further assume that this distinction holds only for China: all other countries engage only in ordinary trade exclusively.

3.1 Preliminaries

In addition to China, there are N countries indexed by n,i. Because our model is static, we suppress the time subscript for now. As in Levchenko and Zhang (2016), there are J traded and one non-traded sector indexed by j,k. We model China as two additional markets: $o$rdinary (o) and $p$rocessing (p). Notationally, there are $N+2$ "countries", with countries other than China indexed by $n = 1,...,N$, and the $N+1^{th}$ and the $N+2^{nd}$ terms representing ordinary and processing production in China, respectively. In some cases, we use the subscript c for China, for example, when we reference the utility function of its representative consumer or factor prices that are common across the two organizational forms.

Each country possesses exogenous endowments of the primary factors labor L_n and capital K_n. These factors are fully mobile across sectors within a country but are internationally immobile. Factor payments are w_n and r_n, respectively. In China, labor and capital are fully mobile across ordinary and processing, with factor returns w_c and r_c.[15]

Within each industry j, there is a continuum of varieties indexed by ω^j. As in Caliendo and Parro (2015), all trade is in varieties of intermediate inputs. Each variety is sourced from its lowest cost supplier inclusive of tariffs and transport costs. In a given destination location n, these intermediates are either costlessly transformed into (non-traded) consumption goods or used as intermediate inputs for downstream production.

[15]We treat traded machinery and equipment as an intermediate good whose price differs for ordinary and processing production due to differential tariff treatment and because processing imports cannot be sold domestically, which prevents price arbitrage. For this reason, capital K_n is best thought of as comprising the non-traded component of the capital stock.

3.2 *Demand*

Preferences are identical and homothetic across countries with the representative consumer in each country n possessing the following Cobb-Douglas utility function defined over $J+1$ consumption aggregates: $U_n = \Pi_{j=1}^{J+1} \left(C_n^j\right)^{\alpha^j}$ where α^j is a constant expenditure share.

3.3 *Production*

Production of any variety ω^j requires labor, capital, and intermediate inputs. Producers differ in their efficiency of production $z_n^j(\omega^j)$. The Cobb-Douglas production technology of variety ω^j is

$$q_n^j(\omega^j) = z_n^j(\omega^j) \left[l_n^j(\omega^j)\right]^{\gamma_{L,n}^j} \left[k_n^j(\omega^j)\right]^{\gamma_{K,n}^j} \Pi_{k=1}^{J+1} \left[m_n^{kj}(\omega^j)\right]^{\gamma_n^{kj}}$$

where $\gamma_{L,n}^j$, $\gamma_{K,n}^j$, and γ_n^{kj} are Cobb-Douglas input cost shares, and $\gamma_{L,n}^j + \gamma_{K,n}^j + \sum_{k=1}^{J+1} \gamma_n^{kj} = 1$. Input cost shares vary across both industries and countries. $l_n^j(\omega^j)$ and $k_n^j(\omega^j)$ are the labor and capital, respectively, associated with producing variety ω^j in country n, and $m_n^{kj}(\omega^j)$ is the amount of composite good k required. Unit cost is $c_n^j / z_n^j(\omega^j)$ where the cost of an input bundle is

$$c_n^j \equiv \Upsilon_n^j w_n^{\gamma_{L,n}^j} r_n^{\gamma_{K,n}^j} \Pi_{k=1}^{J+1} \left[p_n^k\right]^{\gamma_n^{kj}} \tag{1}$$

and Υ_n^j is an industry-country specific constant.[16] p_n^k is the price of a composite unit of k in country n. As emphasized by Costinot and Rodríguez-Clare (2014) and Caliendo and Parro (2015), the inclusion of intermediate inputs is important for modelling welfare effects.

As in Caliendo and Parro (2015), the composite intermediate in sector j, Q_n^j, is a CES aggregate of industry-specific varieties given by $Q_n^j = \left[\int x_n^j(\omega^j)^{\frac{\sigma^j-1}{\sigma^j}} d\omega^j\right]^{\frac{\sigma^j}{\sigma^j-1}}$ where $x_n^j(\omega^j)$ is the demand for intermediate goods ω^j from the lowest cost supplier. Because this composite is used either for intermediate inputs for downstream production or final goods consumption, market clearing implies $Q_n^j = C_n^j + \sum_{k=1}^{J+1} \int m_n^{jk}(\omega^k) d\omega^k$. An analogous expression holds for ordinary production. For processing, $Q_p^j = \sum_{k=1}^{J} \int m_p^{jk}(\omega^k) d\omega^k$ since all of the composite processing output must be used in the production of processing goods and cannot be used to satisfy final demand.[17]

[16] $\Upsilon_n^j \equiv \left(\gamma_{L,n}^j\right)^{-\gamma_{L,n}^j} \left(\gamma_{K,n}^j\right)^{-\gamma_{K,n}^j} \Pi_{k=1}^{J+1} \left(\gamma_n^{kj}\right)^{-\gamma_n^{kj}}$.

[17] Our model imposes the assumption that the entire non-traded sector is organized through ordinary production.

3.4 *Transport Costs and Pricing*

There are two components of trade costs: ad-valorem tariffs and iceberg international trade costs. The statutory ad-valorem tariff that country n imposes on varieties of good j shipped from i is given by τ^j_{ni}. All exports from China are subject to the same tariff level regardless of their organization such that $\tau^j_{ic} = \tau^j_{io} = \tau^j_{ip}$. We model the iceberg costs as a weakly increasing industry-specific function of distance, $g^j(d_{ni})$, where d_{ni} is the distance between n and i.[18] To allow for asymmetries, we follow Waugh (2010), and introduce multiplicative exporter i-industry j specific iceberg costs t^j_i to allow total iceberg costs between two locations to depend on the direction of shipment. We follow the literature by setting $g^j(d_{nn}) = 1$, and $t^j_n = 1$ for domestic shipments. Combined, the total trade cost of shipping a unit of a variety of j from i to n, κ^j_{ni} takes the following form:

$$\kappa^j_{ni} \equiv (1 + \tau^j_{ni}) g^j(d_{ni}) t^j_i. \tag{2}$$

With perfect competition, the equilibrium price of ω^j in country n, $p^j_n(\omega^j) = \min_i \left\{ \frac{c^j_i \kappa^j_{ni}}{z^j_i(\omega^j)} \right\}$.

3.5 *Productivity Distributions*

Ricardian motives for trade follow Eaton and Kortum (2002). Outside of China, those in country i-industry j draw from Fréchet distributions with location parameters λ^j_i and shape parameters θ^j. Following Eaton and Kortum (2002), we refer to λ^j_i as the *state of technology* to distinguish it from *average underlying productivity* which is given by $\left(\lambda^j_i\right)^{\frac{1}{\theta^j}}$.[19] θ^j captures heterogeneity across varieties in countries' relative efficiencies, and governs comparative advantage within an industry.

For ordinary and processing trade within a Chinese industry, draws between the two organizational forms are not likely to be independent nor taken from a distribution with a single state of technology. Thus, we follow Ramondo and Rodríguez-Clare (2013) by assuming correlated draws $\{z^j_o(\omega^j), z^j_p(\omega^j)\}$ for ordinary and processing production from an industry-specific multivariate

[18] We assume $g^j(d_{ni})$ is symmetric in distance with $g^j(d_{ni}) = g^j(d_{in})$.

[19] This can differ from average observed productivity due to selection as noted by Costinot, Donaldson and Komunjer (2012) and Finicelli, Pagano and Sbracia (2013). Because the triangle inequality does not hold for domestic sales for processing due to the policy restriction, the Costinot et al. (2012) transformation from underlying to observed productivity is invalid. See their online appendix (especially Lemma 3) for details.

Fréchet distribution:

$$F^j(z_o,z_p) = exp\Big\{ - \Big[(\lambda_o^j)^{\frac{1}{1-\nu^j}} z_o^{-\frac{\theta^j}{1-\nu^j}} + (\lambda_p^j)^{\frac{1}{1-\nu^j}} z_p^{-\frac{\theta^j}{1-\nu^j}}\Big]^{1-\nu^j}\Big\} \tag{3}$$

where λ_o^j and λ_p^j reflect states of technology in the two organizational forms, and $\nu^j \in [0,1)$ governs the correlation between z_o and z_p. Analogous to θ^j, ν^j regulates heterogeneity in relative efficiency between ordinary and processing across varieties. It therefore governs *within-industry* comparative advantage across the two organizational forms. As the correlation increases ($\nu^j \to 1$), the draws are more correlated, there is less heterogeneity, and there are smaller gains from being able to buy from both forms of production. As the correlation declines ($\nu^j \to 0$), the opposite holds true. $\nu^j = 0$ corresponds to the case where z_o and z_p are independent.

3.6 *Trade Shares*

We now define equilibrium expenditure shares for each country. Outside of China, the share of total expenditures by (importing) country n in industry j on exports from (exporter) i, or π_{ni}^j, is given by:

$$\pi_{ni}^j = \frac{\lambda_i^j (c_i^j \kappa_{ni}^j)^{-\theta^j}}{\Phi_n^j} \tag{4}$$

where

$$\Phi_n^j \equiv \left[(\lambda_o^j)^{\frac{1}{1-\nu^j}} \left(c_o^j \kappa_{no}^j\right)^{\frac{-\theta^j}{1-\nu^j}} + (\lambda_p^j)^{\frac{1}{1-\nu^j}} \left(c_p^j \kappa_{np}^j\right)^{\frac{-\theta^j}{1-\nu^j}}\right]^{1-\nu^j} + \sum_{i'=1}^{N} \lambda_{i'}^j \left(c_{i'}^j \kappa_{ni'}^j\right)^{-\theta^j}. \tag{5}$$

For China, the expenditure shares for ordinary and processing need to be modified. The share of expenditure on sector j goods in destination n on ordinary production in China is given by:

$$\pi_{no}^j = \frac{(\lambda_o^j)^{\frac{1}{1-\nu^j}} \left(c_o^j \kappa_{no}^j\right)^{-\frac{\theta^j}{1-\nu^j}}}{(\lambda_o^j)^{\frac{1}{1-\nu^j}} \left(c_o^j \kappa_{no}^j\right)^{-\frac{\theta^j}{1-\nu^j}} + (\lambda_p^j)^{\frac{1}{1-\nu^j}} \left(c_p^j \kappa_{np}^j\right)^{-\frac{\theta^j}{1-\nu^j}}} \times \frac{\left[(\lambda_o^j)^{\frac{1}{1-\nu^j}} \left(c_o^j \kappa_{no}^j\right)^{-\frac{\theta^j}{1-\nu^j}} + (\lambda_p^j)^{\frac{1}{1-\nu^j}} \left(c_p^j \kappa_{np}^j\right)^{-\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j}}{\Phi_n^j}. \tag{6}$$

The first term to the right of the equality in equation (6) is the share of ordinary exports in total Chinese exports to destination market n. The second term is the share of country n expenditures going to China as a whole. The share of ordinary is endogenous and increasing in its relative productivity, λ_o^j/λ_p^j, but decreasing in its relative costs, c_o^j/c_p^j, and iceberg trade $\kappa_{no}^j/\kappa_{np}^j$. Similarly, the expenditure share for processing is:

$$\pi_{np}^j = \frac{(\lambda_p^j)^{\frac{1}{1-\nu^j}}\left(c_p^j\kappa_{np}^j\right)^{-\frac{\theta^j}{1-\nu^j}}}{(\lambda_o^j)^{\frac{1}{1-\nu^j}}\left(c_o^j\kappa_{no}^j\right)^{-\frac{\theta^j}{1-\nu^j}}+(\lambda_p^j)^{\frac{1}{1-\nu^j}}\left(c_p^j\kappa_{np}^j\right)^{-\frac{\theta^j}{1-\nu^j}}} \times \frac{\left[(\lambda_o^j)^{\frac{1}{1-\nu^j}}\left(c_o^j\kappa_{no}^j\right)^{-\frac{\theta^j}{1-\nu^j}}+(\lambda_p^j)^{\frac{1}{1-\nu^j}}\left(c_p^j\kappa_{np}^j\right)^{-\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j}}{\Phi_n^j}. \tag{7}$$

Deriving import shares for the processing and ordinary sectors in China is straightforward and obtained by setting $\kappa_{op}^j = \kappa_{pp}^j = \infty \ \forall \ j$. $\kappa_{op}^j = \infty$ imposes the restriction that processing cannot sell to those organized into ordinary production, and $\kappa_{pp}^j = \infty$ imposes the condition that processing cannot sell to itself.[20] This allows us to derive a share of expenditure by processing on country i as $\pi_{pi}^j = \frac{\lambda_i^j(c_i^j\kappa_{pi}^j)^{-\theta^j}}{\Phi_p^j}$, where Φ_p^j is obtained by setting $n = p$ and $\kappa_{pp} = \infty$ in equation (5). The share of expenditures in destination o on goods from source i is given analogously: $\pi_{oi}^j = \frac{\lambda_i^j(c_i^j\kappa_{oi}^j)^{-\theta^j}}{\Phi_o^j}$, where Φ_o^j is given by setting $n = o$ and $\kappa_{op}^j = \infty$ in equation (5). Online Appendix A provides proofs of all expenditure shares.[21] Finally, as in Eaton and Kortum (2002), price distributions are given by:

$$p_n^j = A^j \left[\Phi_n^j\right]^{-\frac{1}{\theta^j}} \tag{8}$$

where $A^j \equiv \left[\Gamma\left(\frac{\theta^j+1-\sigma^j}{\theta^j}\right)\right]^{\frac{1}{1-\sigma^j}}$ and $\Gamma(\cdot)$ is the Gamma function.

[20] We make the assumption that processing production sources from ordinary production but not from itself for two reasons. First, although there are exemptions for selling to other processing producers, the volume of these sales at the industry level is negligible. And second, assuming that all processing output is exported provides a very powerful identifying assumption when breaking industry level output into ordinary and processing output which is required for our empirical strategy in section 5. Based on the matched NBS firm-customs data used in Brandt and Morrow (2017), we find that exporting firms that engage in processing alone (i.e. 100% of the value of customs exports are through processing) obtain on average 93% of their total revenue from exporting and that the median firm obtains all of their revenue from exporting. Aggregating up to the industry level, 97% of total revenue *for these firms* comes from exporting while the median is 96%. Revenue is reported from the NBS data and exports are from the Customs data.

[21] For the non-traded sector, $\pi_{nn}^{J+1} = 1$ and $\pi_{ni}^{J+1} = 0$ if $i \neq n$.

3.7 *Goods Market Clearing*

Total expenditure on industry j for country n can be decomposed as:

$$X_n^j = \alpha^j I_n + \sum_{k=1}^{J+1} \gamma_n^{jk} \left[\sum_{i=1}^{N+2} X_i^k \frac{\pi_{in}^k}{1+\tau_{in}^k} \right]. \tag{9}$$

The first component ($\alpha^j I_n$) reflects final consumption expenditure on the industry j composite good in n while the second term reflects use of j as an input.[22] For ordinary goods in China, the expression is analogous and given by:

$$X_o^j = \alpha^j I_c + \sum_{k=1}^{J+1} \gamma_o^{jk} \left[\sum_{i=1}^{N+2} X_i^k \frac{\pi_{io}^k}{1+\tau_{io}^k} \right]. \tag{10}$$

All processing production must be used as an intermediate input for exports, and cannot be used for either domestic production or as an intermediate input for domestic final sales. This results in the expression:

$$X_p^j = \sum_{k=1}^{J+1} \gamma_p^{jk} \sum_{i=1}^{N} X_i^k \frac{\pi_{ip}^k}{1+\tau_{ip}^k}. \tag{11}$$

Income is defined as $I_n \equiv w_n L_n + r_n K_n + R_n$ where R_n is the value of tariff revenue that is then distributed back to the representative agent: $R_n \equiv \sum_{j=1}^{J} \sum_{i=1}^{N+2} \tau_{ni}^j M_{ni}^j$ where $M_{ni}^j = X_n^j \frac{\pi_{ni}^j}{1+\tau_{ni}^j}$.

3.8 *Balanced Trade and Factor Market Clearing*

We assume that income equals expenditure for all countries including China, implying that a country's income equals its total global expenditures. Total payments to labor in a country equal total world expenditures on output in a given country-industry pair times labor's share, summed across industries. A similar condition holds for capital.[23]

[22]For a given (downstream) industry k-country i pair, the second component, $\gamma_n^{jk} X_i^k \frac{\pi_{in}^k}{1+\tau_{in}^k}$, describes the share of country i expenditures on k that go to country n (exclusive of tariffs), multiplied by the cost share of those industry k sales accruing to (upstream) industry j. Summing over i gives global industry k expenditure to industry j-country n intermediate inputs; then summing over downstream industries k captures total demand for inputs from industry j that are produced in n.

[23]For formal statements of factor market clearing, see Online Appendix A.3. Also, we have confirmed that our quantitative results are robust to the inclusion of exogenous trade imbalances.

3.9 *Equilibrium*

Definition 1 *Given L_n, K_n, λ_n^j, $g^j\,(d_{ni})$, t_n^j, α_n^j, $\gamma_{L,n}^j$, $\gamma_{K,n}^j$, γ_n^{jk}, ν^j, σ^j, and θ^j, an equilibrium under tariff structure $\{\tau_{ni}^j\}$ is a wage vector $\mathbf{w} \in \mathbf{R}_{++}^{\mathbf{N+1}}$, a rental rate vector $\mathbf{r} \in \mathbf{R}_{++}^{\mathbf{N+1}}$, and prices $\{p_n^j\}_{j=1,n=1}^{J+1,N+2}$ that satisfy equations* (1),(4)-(11)*, balanced trade, and factor market clearing for all j,n.*

4. Data

The Data Appendix (Online Appendix B) describes our data in detail, and here we briefly discuss key aspects of it. Based on country availability, our data cover 109 manufacturing sectors, and one non-traded sector for 23 developed and developing countries for the years 2000-2007. Manufacturing industries are at the four-digit ISIC level, with the non-traded sector a composite of services and agriculture. For countries other than China, trade data come from the BACI data base maintained by CEPII (Gaulier and Zignago (2010)).[24] For Chinese exports and imports, transactions data from the Customs Administration of China allow us to distinguish ordinary and processing shipments. To calculate domestic sales by domestic producers at the country-industry level, we use output data from the UN IDSB data base and subtract exports from the same source to obtain domestic shipments. For China, output data are taken from the Annual Survey of Manufacturers carried out by the National Bureau of Statistics.[25] We subtract exports reported by the Customs Administration to obtain domestic sales.[26] All remaining data used in the gravity estimation come from CEPII (distance and contiguity measures) or UN TRAINS (tariff data). For aggregate variables,

[24]These data are aggregated from the HS six-digit level to the four-digit ISIC level.

[25]Unlike INDSTAT, the IDSB contains both export and production data from one source which makes it ideal for calculating domestic shipments. However, it does not contain input data necessitating the need for INDSTAT discussed below. The IDSB data set does not contain data for China, thus our use of the NBS production data.

[26]These data do not distinguish between sales by Chinese firms to ordinary or to processing firms (processing firms do not sell domestically but can source domestically). Online Appendix B.5 shows how we can use the structure of the model to allocate domestic sales into sales to other ordinary producers/consumers and to processing producers. In addition, since the NBS data only cover firms with sales larger than 5 million (RMB) and the trade data are the universe of transactions, we scale up the NBS data by the ratio of manufacturing output in the 2004 census to output in the 2004 NBS annual firm survey for each industry.

total employment, cost of capital, and the (real) capital stock both come from the Penn World Tables 9.0. INDSTAT provides data for national wages.[27]

The cost share of labor $\gamma^j_{L,n}$ is the ratio of wages to total output in the UN INDSTAT data set for manufacturing and WIOD for the non-traded sector. The share of intermediate inputs is given by one minus the total share of value added in output from the same sources. We assume that capital's share of output, $\gamma^j_{K,n}$, is one minus labor's share and the share of intermediate inputs. For China, these statistics are derived from the Annual Survey of Manufacturers.[28] We calculate γ^{jk}_n by starting with the world input-output matrix as published by Timmer et al. (2015). At the NACE level, this provides the shares of intermediate inputs of each input industry. We denote these as $\tilde{\gamma}^{j'k'}$ where $'$ denotes a NACE sector. Using a concordance available from WITS and a proportionality assumption, we calculate ISIC-specific intermediate input shares, $\tilde{\gamma}^{jk}$. Multiplying these by one minus the value added share, we obtain γ^{jk}_n.

5. Mapping Theory onto Empirics

5.1 *Estimates of θ^j and ν.*

As in Simonovska and Waugh (2014), we use $\theta^j = 4 \;\; \forall j$.[29] We now propose an estimation strategy to measure the correlation parameter ν. We initially assume that it is constant across j but let it vary in our robustness exercises. This parameter is important as it governs *within-industry* comparative advantage between ordinary and processing production, and the potential gains from allowing processing to sell domestically. Using the triad strategy of Caliendo and Parro (2015) with equations (4) and (6), we obtain the following expression:

$$\left(\frac{\pi^j_{no}\pi^j_{oh}\pi^j_{hn}}{\pi^j_{nh}\pi^j_{ho}\pi^j_{on}}\right) = \left(\frac{(1+\tau^j_{no})(1+\tau^j_{oh})(1+\tau^j_{hn})}{(1+\tau^j_{nh})(1+\tau^j_{ho})(1+\tau^j_{on})}\right)^{-\theta^j} \left(\frac{s^j_{no}}{s^j_{ho}}\right)^{\nu} \quad (12)$$

[27]The wage is equal to total wage payments in manufacturing divided by total employment.

[28]Online Appendix B.4 describes how we measure the cost shares for ordinary and processing production within an industry.

[29]We also set $\sigma^j = 2 \; \forall j$. We examine the robustness of our results to alternate values of θ^j in section 7.

where the π^j_{ni} are *across-country* market shares, τ^j_{ni} are statutory tariffs, and s^j_{no} are *within* China shares of exports accruing to ordinary exports $s^j_{no} \equiv \frac{\pi^j_{no}}{\pi^j_{no}+\pi^j_{np}}$. When $\nu = 0$, draws between ordinary and processing are uncorrelated, and equation (12) nests the strategy of Caliendo and Parro (2015). Conditional on θ^j, we can use a simple method of moments strategy to estimate ν.

Using the language of discrete choice models [e.g. Berry (1994)], ordinary and processing trade are assumed to reside within a group. As ν goes to one, the correlation of productivity draws across ordinary and processing within this group goes to one, and as ν approaches zero, the within-group correlation goes to zero. A higher value of ν reduces heterogeneity between the two organizational forms, and leads to a stronger relationship between the *within-group* shares on the right hand side and *across-market* ordinary market shares on the left. Our estimation method is analogous to techniques developed in Berry (1994) in which *across-group* market shares are regressed on *within-group* shares to identify within-nest elasticities of substitution in nested-logit models.[30] As in Caliendo and Parro (2015), the use of the triad approach differences out all destination-industry-specific, source-industry-specific, and pair-industry-specific factors which mitigates–though not necessarily eliminates–endogeneity concerns.[31]

Where t indexes years, we pool observations across industries j and the years 2000-2007. We then estimate a log-linear equation based on (12):

$$\ln\left[y^j_{noht} \equiv \left(\frac{\pi^j_{not}\pi^j_{oht}\pi^j_{hnt}}{\pi^j_{nht}\pi^j_{hot}\pi^j_{ont}}\right)\left(\frac{(1+\tau^j_{not})(1+\tau^j_{oht})(1+\tau^j_{hnt})}{(1+\tau^j_{nht})(1+\tau^j_{hot})(1+\tau^j_{ont})}\right)^{\theta^j}\right] = \nu \ln\left(\frac{s^j_{not}}{s^j_{hot}}\right) + \epsilon^j_{noht} \tag{13}$$

[30]See Berry (1994), section 5. Both Eaton and Kortum (2002) and Ramondo and Rodríguez-Clare (2013) state that this parameter is generally not identified. This is true when the researcher does not take a stand on which countries or industries reside in which groups. However, if a researcher is willing to take a stand on the composition of these groups, one can use the procedure here to identify the within-group correlation of productivity draws. Calibration-based approaches to measuring this parameter are found in Arkolakis, Ramondo, Rodríguez-Clare and Yeaple (2018) and Lagakos and Waugh (2013). Independently of this paper, Lind and Ramondo (2018) develop a two-step gravity-based estimator to identify low- and high-correlation industries using aggregate shipments.

[31]For example, all c^j_i, λ^j_i, and Φ^j_i terms are differenced out as are $g^j(d_{ni})$ and t^j_i. Although pair specific terms (e.g. distance) are differenced out, pair-*direction*-specific terms such as tariffs τ^j_{ni} remain.

and ϵ^j_{noht} is a white noise error term which is assumed to be normally distributed.[32] The resulting estimate of ν, $\widehat{\nu}$, is 0.78 with a standard error, clustered by noh triplets, of 0.02. The tight estimate allows us to reject both the null hypotheses that $\nu = 0$ and $\nu = 1$ at conventional levels. We examine the importance of heterogeneity in $\widehat{\nu}$ across industries for our welfare results in section 7.

5.2 *Measuring States of Technology*

We are interested in how differential productivity levels within and across industries affect the potential gains from allowing processing to sell domestically in our counterfactuals. If processing expands the most in industries in which it has relatively higher underlying productivity, this is similar to classic productivity-based comparative advantage and our counterfactual has the intuitive interpretation as measuring Ricardian gains from domestic market liberalization.

To obtain our productivity estimates, we start by following the structural gravity approach of Levchenko and Zhang (2016). First, we estimate a gravity model for each industry and year. The resulting country-industry fixed effects measure differences in unit costs. Using factor prices and cost shares from the data, and intermediate input prices obtained using the structure of the model, we can isolate $\lambda^j_n/\lambda^j_{us}$, $\lambda^j_o/\lambda^j_{us}$, and $\lambda^j_p/\lambda^j_{us}$. Accounting for cost shares and intermediate input prices is crucial as it allows us to take into account that some of China's unit cost advantages might come from low factor prices and/or access to intermediate inputs at favorable prices. It will also take into account the fact that China has low value-added in some sectors (e.g. computers) which

[32]Unlike Caliendo and Parro (2015), we move the term involving θ^j over to the left hand side in our estimation. We do this for data-related reasons. By 2000, when our China customs data begins, much of the variation in tariffs across countries had disappeared as WTO membership for many countries led to MFN tariff rates. This removes valuable variation that was present prior to WTO which is the period of the analysis in Caliendo and Parro (2015). In our data at the exporter-importer-ISIC industry-year level in 2000, 80% of reported tariffs were set at the MFN rate. At the same level, the correlation between average tariffs and MFN tariffs is 0.97; a regression of the average tariff on the MFN tariff delivers a coefficient of 0.97 and a $R^2 = 0.96$. This does not imply that tariff cuts do not matter but rather that the triad approach removes much of the meaningful variation post-WTO. Using additional non-China countries in the triad does not add to our ability to identify ν and so we do not pursue this further. We also note that there is broad agreement that θ lies roughly between 4 and 8 even when estimated in models that nest our approach (e.g. Simonovska and Waugh (2014) which does not include China). However we also examine the robustness of our results to alternate values of θ in section 7. When all tariffs are set at MFN rates, ν is still identified as equation (12) becomes $\left(\frac{\pi^j_{no}\pi^j_{oh}\pi^j_{hn}}{\pi^j_{nh}\pi^j_{ho}\pi^j_{on}}\right) = \left(\frac{s^j_{no}}{s^j_{ho}}\right)^{\nu}$.

means that larger market shares do not translate directly into productivity or quality differences.[33]

5.21 *Measuring $\lambda_n^j/\lambda_{us}^j$ outside of China, and for Ordinary Production*

In what follows, we suppress the year subscript although all estimation occurs at the industry-year level. To recover $\lambda_n^j/\lambda_{us}^j$, start by normalizing equation (4) for a given ni pair by its nn counterpart, and take logs to obtain

$$\ln\left(\frac{\pi_{ni}^j}{\pi_{nn}^j}\right) = \ln\left(\lambda_i^j\left[c_i^j\right]^{-\theta^j}\right) - \ln\left(\lambda_n^j\left[c_n^j\right]^{-\theta^j}\right) - \theta^j \ln\left(\kappa_{ni}^j\right). \qquad (14)$$

The first two terms represent the effect of differences in average unit costs between n and i, and the last term reflects international trade costs. We parameterize these trade costs as $\theta^j \ln\left(\kappa_{ni}^j\right) \equiv \theta^j \ln(1+\tau_{ni}^j) + \sum_{d=1}^{6}\beta_d^j d_{ni,d} + b_{ni}^j + \delta_i^{j,x} + \epsilon_{ni}^j$ where $d_{ni,d}$ is an indicator variable that takes a value of one when the distance between countries n and i is in the d^{th} distance interval.[34] β_d^j is the industry-year-specific effect of being in interval d. b_{ni}^j is the industry-specific effect of sharing a border. $\delta_i^{j,x}$ is the coefficient on a dummy variable that takes a value of one when i is an exporting country for industry j as in Waugh (2010). When $i \neq o,p$, then $\delta_i^{j,x} \equiv \theta^j \ln(t_i^j)$. For $i = o$ and $i = p$, respectively, $\delta_o^{j,x} \equiv -\ln\left\{(t_o^j)^{-\theta^j}\left[1+\left[\frac{\lambda_p^j}{\lambda_o^j}\left(\frac{c_p^j}{c_o^j}\right)^{-\theta^j}\right]^{\frac{1}{1-\nu}}\right]^{-\nu}\right\}$ and $\delta_p^{j,x} \equiv -\ln\left\{\lambda_p^j(c_p^j)^{-\theta^j}(t_p^j)^{-\theta^j}\left[1+\left[\frac{\lambda_o^j}{\lambda_p^j}\left(\frac{c_o^j}{c_p^j}\right)^{-\theta^j}\right]^{\frac{1}{1-\nu}}\right]^{-\nu}\right\}$.[35]

Since π_{pp}^j=0, equation (14) is undefined when $n = p$, and shipments for processing only show up as exports. Consequently, the industry-specific fixed effect for processing does not identify its unit cost. We discuss how to measure $\lambda_p^j/\lambda_{us}^j$ shortly. Moving observed tariffs to the left hand side

[33] See Amiti and Khandelwal (2013) pg. 482 for more on this point.

[34] Intervals are in miles: [0,375); [375,750); [750,1500); [1500,3000); [3000,6000); and [6000,maximum].

[35] The extra terms for China reflect the correlated Fréchet draws. Because ordinary and processing producers only compete in external markets as a result of restrictions on domestic sales of the processing sector, the terms in the square brackets show up in the exporting effect and disappear for ordinary when the correlation (ν) goes to zero.

of (14) delivers the following gravity regression where δ_i^j is a country fixed effect within a given industry-level regression:[36]

$$\ln\left(\frac{\pi_{ni}^j}{\pi_{nn}^j}\right) + \theta^j ln(1+\tau_{ni}^j) = \delta_i^j - \delta_n^j - \sum_{d=1}^{6} \beta_d^j d_{ni,d} - b_{ni}^j - \delta_i^{j,x} + \epsilon_{ni}^j \tag{15}$$

where ϵ_{ni}^j is an error term that is assumed to have the usual i.i.d. properties.

With the fitted values $\widehat{\delta}_i^j$ in hand, we can exponentiate the ratio, $\widehat{\delta}_i^j / \widehat{\delta}_{us}^j$ and use equation (1) to obtain

$$\exp\left(\widehat{\delta}_i^j - \widehat{\delta}_{us}^j\right) = \frac{\lambda_i^j}{\lambda_{us}^j}\left(\frac{c_i^j}{c_{us}^j}\right)^{-\theta^j}. \tag{16}$$

In this type of analysis, it is typical to assume common factor cost shares across countries within an industry, such that c_i^j / c_{us}^j is a function of relative input prices and industry-specific common Cobb-Douglas factor shares across countries γ_L^j, γ_K^j. This allows recovery of estimates of $\lambda_i^j / \lambda_{us}^j$. However, it is not obvious that this restriction holds in the data, especially for the case of China in which value added can be low relative to other countries. We therefore follow Caves, Christensen and Diewert (1982) and allow for more general production functions that are well-approximated by the translog function. This allows us to write (16) as

$$exp\left(\widehat{\delta}_i^j - \widehat{\delta}_{us}^j\right) = \frac{\lambda_i^j}{\lambda_{us}^j}\left[\left(\frac{w_i}{w_{us}}\right)^{\tilde{\gamma}_{L,i}^j}\left(\frac{r_i}{r_{us}}\right)^{\tilde{\gamma}_{K,i}^j} \Pi_{k=1}^{J+1}\left(\frac{p_i^k}{p_{us}^k}\right)^{\tilde{\gamma}_i^{kj}}\right]^{-\theta^j} \tag{17}$$

where $\tilde{\gamma}_{L,i}^j \equiv \frac{\gamma_{L,i}^j + \gamma_{L,us}^j}{2}$. $\tilde{\gamma}_{K,i}^j$ and $\tilde{\gamma}_i^{kj}$ are defined analogously. While this calculation is general up to a translog approximation, when we move to our counterfactual analyses, we assume that country-industry-specific factor cost shares are invariant to equilibrium factor prices (i.e. Cobb-Douglas). In this sense our counterfactual simulations rely on more restrictive assumptions than our productivity calculations but still allow the shape of the production function to vary across countries and industries.

Equation (17) shows that we require data on factor prices (w_i and r_i), Cobb-Douglas cost shares, and a value of θ^j to extract estimates of $\frac{\lambda_i^j}{\lambda_{us}^j}$. Data on w_i, r_i, $\gamma_{L,n}^j$, $\gamma_{K,n}^j$, and γ_n^{jk} are described in

[36]There are two reasons for moving the term involving tariffs to the left hand side: first, because of concerns about the endogeneity of tariffs; and second, because of widespread agreement about values of θ^j. In the robustness section, when we examine our results with respect to alternate values of θ^j, we also change its value in this estimation stage.

section 4, and, following Simonovska and Waugh (2014), we use a constant value of $\theta = 4$ for θ^j. This leaves us requiring empirical counterparts of $\frac{p_i^k}{p_{us}^k}$ to obtain empirical counterparts of $\frac{\lambda_i^j}{\lambda_{us}^j}$ which we obtain following Shikher (2012) and Levchenko and Zhang (2016).[37]

5.22 $\lambda_p^j / \lambda_{us}^j$

To obtain productivity for processing in China, we set $t_o^j = t_p^j$ and obtain:

$$\frac{\exp\left(\widehat{\delta}_o^j\right)\exp\left(\widehat{-\delta}_o^{j,x}\right)}{\exp\left(\widehat{-\delta}_p^{j,x}\right)} = \left(\frac{\lambda_o^j}{\lambda_p^j}\right)^{\frac{1}{1-\nu}} \left(\frac{c_o^j}{c_p^j}\right)^{-\frac{\theta^j}{1-\nu}}. \tag{18}$$

Using a similar approach as in equation (17), factor prices cancel between the numerator and denominator of c_o^j / c_p^j but we still require an empirical counterpart for $\Pi_{k=1}^{J+1}\left(\frac{p_p^k}{p_o^k}\right)^{\tilde{\gamma}_{op}^{kj}}$ where $\tilde{\gamma}_{op}^{kj} \equiv \frac{\gamma_o^{kj}+\gamma_p^{kj}}{2}$. We can use equation (8) for ordinary and processing, and then manipulate the resulting expression to deliver the price index for processing relative to ordinary in an industry:

$$\frac{p_p^k}{p_o^k} = \left[\pi_{oo}^k + \sum_i^N (1+\tau_{oi}^k)^{\theta^k} \pi_{oi}^k\right]^{-\frac{1}{\theta^k}}. \tag{19}$$

This is a function of observable data (trade shares and tariffs), and the parameter θ^k. This expression has the intuitive interpretation that the difference in price indexes between ordinary and processing is related to a weighted average of tariffs imposed on ordinary (but not processing) imports. It is easy to see that when processing does not possess a tariff exemption, $p_p^k = p_o^k$ as both regimes source from the same set of suppliers in a given industry with identical trade costs/tariffs.

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[37]To obtain these, take the ratio of π_{ii}^k and $\pi_{us,us}^k$, and equation (8) to obtain: $\frac{\pi_{ii}^k}{\pi_{us,us}^k} = \left(\frac{p_i^k}{p_{us}^k}\right)^{\theta^k} \frac{\lambda_i^k \left(c_i^k\right)^{-\theta^k}}{\lambda_{us}^k \left(c_{us}^k\right)^{-\theta^k}}$. This can easily be manipulated using equation (17) to obtain the empirical counterpart of p_n^k / p_{us}^k, $\widehat{p_n^k / p_{us}^k}$, in terms of data, $\pi_{ii}^k / \pi_{us,us}^k$, and previously estim lues $\frac{\widehat{\delta}_i^k}{\widehat{\delta}_{us}^k}$: $\widehat{\left(p_i^k / p_{us}^k\right)}^{\theta^k} = (\pi_{ii}^k / \pi_{us,us}^k) / \left[\exp\left(\hat{\delta}_i^k - \hat{\delta}_{us}^k\right)\right]$. With these in hand, we can easily calculate $\Pi_{k=1}^{J+1}\left(\frac{\widehat{p}_i^k}{\widehat{p}_{us}^k}\right)^{\tilde{\gamma}^{kj}}$, and obtain values of $\lambda_i^j / \lambda_{us}^j$ from equation (17). See Online Appendix B.6 for details of how to construct the price index for non-traded goods.

6. Results

There are three components of our analysis: the estimation of the gravity model, estimates of total factor productivity in processing and ordinary, and finally, our counterfactuals. We discuss each in turn.

6.1 Gravity Model

The first step in our empirical approach is to estimate a gravity model for each industry-year pair jt. This amounts to estimating equation (15) separately for each of the 109 industries for years 2000-2007. The estimated equations fit the data very well: for 109 estimated equations in the year 2000, the mean and median R^2 are 0.961 and 0.968, respectively.[38]

6.2 Productivity

Estimating productivity differences between ordinary and processing using conventional methods requires measures of real output and inputs.[39] Because of differences between ordinary and processing in tariff treatment on intermediate inputs and final goods, the destination (origin) of output (inputs), as well as transfer pricing, input and output prices will likely differ between the two. In such a setting, the use of the same set of input and output deflators for ordinary and processing–as has been done–potentially biases estimates of productivity.

Although more restrictive in some dimensions (e.g. market structure), our approach allows progress on these issues. First, by inverting unit costs from expenditure share data, we mitigate issues of output price measurement. Second, we explicitly take into account differences in input

[38]The minimum is 0.875 and the maximum is 0.995. The mean value for the estimated coefficient on each dummy variable for distance is monotonically decreasing for the six intervals in increasing order of distance. The effect of sharing a border is positive for 105 out of 109 industries.

[39]Several recent papers estimate productivity differences between ordinary and processing firms in China using firm-level data and find lower productivity within an industry in processing: Yu (2015), Manova and Yu (2016), Dai et al. (2016). One potential explanation for this behavior is negative selection into processing resulting from the preferential treatment extended to processing firms. These papers find that processing exporters are on average less productive than ordinary exporters but ignore heterogeneity across industries, which may be a source of comparative advantage.

Table 1: Total Factor Productivity in China: Ordinary and Processing Production (Levels)

Variable	N	Unweighted Mean	Unweighted sd	Weighted Mean	Weighted sd	min	max
$TFP^{j}_{o,2000}$	109	0.398	0.176	0.471	0.241	0.074	1.623
$TFP^{j}_{p,2000}$	108	0.385	0.183	0.601	0.396	0.078	1.629
$TFP^{j}_{p,2000}/TFP^{j}_{o,2000}$	108	0.963	0.073	0.956	0.078	0.738	1.185
$TFP^{j}_{o,2007}$	109	0.527	0.181	0.600	0.138	0.186	1.200
$TFP^{j}_{p,2007}$	109	0.510	0.190	0.680	0.235	0.186	1.245
$TFP^{j}_{p,2007}/TFP^{j}_{o,2007}$	109	0.965	0.062	0.948	0.068	0.814	1.225

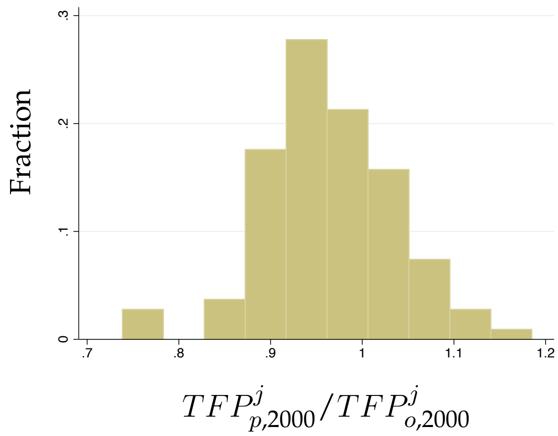
Notes: This table presents measures of total factor productivity for ordinary and processing production as represented by $(\widehat{\lambda^{j}_{o,t}/\lambda^{j}_{us,t}})^{\frac{1}{\theta}}$ and $(\widehat{\lambda^{j}_{p,t}/\lambda^{j}_{us,t}})^{\frac{1}{\theta}}$. These estimates are created using the procedure described in section 5 and a value of $\theta^{j} = 4$ for all j. In the "Weighted" columns, observations are weighted by total industry ordinary shipments for ordinary productivity, total industry processing exports for processing productivity, and total industry shipments for relative measures. All values are relative to the US.

prices paid by ordinary and processing producers arising from the treatment of imported intermediate inputs [equation (19)].

Table 1 reports summary statistics for average productivity for ordinary and processing relative to the US (and relative to each other) for 2000 and 2007. All numbers refer to average underlying productivity $(\widehat{\lambda^{j}_{o,t}/\lambda^{j}_{us,t}})^{\frac{1}{\theta}}$ or $(\widehat{\lambda^{j}_{p,t}/\lambda^{j}_{us,t}})^{\frac{1}{\theta}}$. The "Unweighted" columns show that unweighted average productivity in ordinary production in China was approximately 40% of the US in 2000 and productivity in processing only slightly lower. Weighting by industry size (the "Weighted" columns of Table 1), processing's advantage in certain large sectors emerges: processing productivity in 2000 was 60% of the US level compared to 47% for ordinary productivity. Within industries (row 3), processing was approximately 4% less productive on average.[40] However, there is substantial heterogeneity around the mean with a minimum-maximum interval of [-26.2%,+18.5%], a finding

[40]We use the Delta Method to obtain confidence intervals for each $TFP^{j}_{p,t}/TFP^{j}_{o,t}$. In 2000, 12 industries had higher productivity in processing than in ordinary at the 90% confidence interval, and 53 had lower productivity at the same confidence level. For the remaining 43 industries, we cannot reject the null that they are the same. Standard errors in estimation of equation (15) are two-way clustered at the exporter- and importer-levels.

Figure 1: Histogram of $TFP^j_{p,2000}/TFP^j_{o,2000}$



Notes: This figure presents a histogram of $TFP^j_{p,2000}/TFP^j_{o,2000}$ calculated as described in the text setting $\theta^j = 4\ \forall j$.

that is new to the literature. The histogram in Figure 1 captures this heterogeneity.[41]

The bottom three rows of Table 1 reveal that ordinary and processing narrowed the gap in productivity vis-à-vis the U.S. at similar rates between 2000 and 2007, while within sectors, productivity differences between the two forms were largely unchanged on average. Weighting by industry size, convergence was actually faster for ordinary with ordinary's mean productivity rising to 60% of the US compared to 68% for processing. There are two potential reasons for this behavior: first, productivity in ordinary grew fastest in large sectors; and second, sectors in which relative TFP for ordinary was initially highest grew the most rapidly. We find that most of the convergence (91%) was due to the former: productivity in ordinary grew fastest in large sectors.

Table 2 presents cumulative productivity growth for China in ordinary and processing production during this time. Consistent with results elsewhere [e.g Brandt et al. (2017)], there was tremendous catch-up in underlying productivity with average growth in both ordinary and

[41]The four ISIC sectors in which the processing premium is the lowest are Tobacco (1600), Motor Vehicles (3410), Cement/Lime/Plaster (2694), and Weapons (2927). The four sectors for which it is the highest are Office and Computing Machinery (3000), Bodies for Motor Vehicles (3420), Steam Generators (2813), and Watches and Clocks (3330).

Table 2: Total Factor Productivity in China: Ordinary and Processing Production (Growth)

variable	N	mean	sd	min	max
$TFP^{j}_{o,2007}/TFP^{j}_{o,2000}$	109	1.378	0.305	0.566	2.608
$TFP^{j}_{p,2007}/TFP^{j}_{p,2000}$	108	1.385	0.283	0.579	2.462

Notes: This table presents cumulative growth for underlying total factor productivity relative to the United States for ordinary and processing production. These estimates are constructed using the procedure described in section 5 and a value of $\theta^{j} = 4$ for all j.

processing productivity relative to the US of approximately 38% (4.1% per annum).[42]

In which kind of activities and industries might the processing sector in China hold a comparative advantage? Task differences may interact with industry characteristics to determine productivity differences between organizational forms at the industry level. Table 3 reports simple univariate regression coefficients between processing's relative productivity and industry characteristics. Processing appears to have a comparative advantage in industries that are more skill intensive, output is more differentiated [from Rauch (1999)], which rely on relationship-specific inputs [from Nunn (2007)], and depend more heavily on external finance as measured by Kroszner, Laeven and Klingebiel (2007). On the other hand, the productivity differential is negatively correlated with industry capital intensity.[43] These correlations are consistent with the view that processing in China specialized in the labor-intensive final assembly of skill-intensive, differentiated goods using customized imported intermediates.

[42]Our estimates of productivity growth in processing and industry are relative to the US. Adding the productivity growth in the US over this period implies productivity growth on the order of 6% per annum. This compares with aggregate TFP growth of 5.1% as measured by the Penn World Tables, which is consistent with lower measured productivity growth in services during this period.

[43]Skill and capital intensity come from Bartelsman and Gray (1996). Our results echo those in Manova and Yu (2016), Table 7 despite the fact that we examine productivity differences, and they look at within-firm shares of exports through processing. We find that processing productivity is higher in less capital intensive industries, more skill intensive industries, and industries that rely more on external finance and relationship-specific inputs. Manova and Yu (2016) find that processing is more common at the firm level in industries that are less capital intensive, more skill intensive, and industries that rely more on external finance and (sometimes) relationship-specific inputs.

Table 3: TFP of Processing Production to Ordinary Production and Industry Characteristics

Dependent Variable: $TFP^j_{p,2000}/TFP^j_{o,2000}$	(1)	(2)	(3)	(4)	(5)
Capital Intensity^j	-0.036***				
	(0.012)				
Skill Intensity^j		0.035**			
		(0.015)			
Differentiation^j			0.066***		
			(0.022)		
Relationship-Specificity^j				0.109***	
				(0.041)	
Dependence on External Finance^j					0.100***
					(0.027)
Observations	107	107	107	106	105
R^2	0.080	0.049	0.108	0.082	0.127

Notes: This table reports OLS coefficients for $TFP^j_{p,2000}/TFP^j_{o,2000}$ regressed on different industry characteristics at the 4-digit ISIC level. Capital intensity and labor intensity are derived from Bartelsman and Gray (1996). Capital intensity is the log ratio of capital stock to total payroll. Skill intensity is the log ratio of the payroll of non-production workers to the payroll of the production workers. Output differentiation comes from Rauch (1999) and is the share of HS 6-digit products within a ISIC 4-digit industry labeled as differentiated using the liberal classification. Input relationship-specificity Nunn (2007) and is the share of customized inputs. Dependence on external finance is comes from Kroszner et al. (2007). Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

6.3 *Model Fit*

We briefly assess model fit by comparing the raw data to model-generated data using our estimated parameters to solve for a baseline equilibrium.[44] As suggested by the high R^2 statistics from the gravity model estimation, π^j_{ni} and its model-generated counterpart, $\widehat{\pi}^j_{ni}$, are highly correlated.[45] The correlation between the two is 0.90 and the slope coefficient from a regression of $\widehat{\pi}^j_{ni}$ on π^j_{ni} is 0.84.[46] Because of our interest in ordinary relative to processing trade, we also examine the model-implied share of aggregate exports through processing trade. In the data in 2000, this share was 60% while the model delivers 62%. For 2007, the share in the data was 51% while the model delivers 54%. This is reassuring given that this moment is not directly targeted in our estimation.

[44]In the context of these experiments, "hats" represent model-generated data while variables without hats correspond to raw data.

[45]Online Appendix C describes the solution algorithm.

[46]The coefficient on a reverse regression of π^j_{ni} on $\widehat{\pi}^j_{ni}$ is 0.97.

Table 4: Real Wages and Income: Counterfactual Simulations

Specification Number	Processing Specification Description	Real Wage (rel. to US) (1)	Real Factor Income (rel. to US) (2)	Real Income (rel. to US) (3)
(1)	Benchmark	1.000	1.000	1.000
(2)	No exemption	0.999	1.000	1.001
(3)	No exemption, sells domestically	1.057	1.029	1.022
(4)	Sells domestically	1.072	1.031	1.023
(5)	No Processing	0.984	0.996	0.995

Notes: Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (3) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty\ \forall j,n$. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. $\theta^j = 4$ and $\nu = 0.78$.

6.4 *Welfare Effects*

Processing is not a single policy lever: it combines several instruments each of which has potentially different welfare effects. For this reason, our counterfactuals examine the effect of each individual policy in isolation and also in combination with the other policy measures. As criteria for welfare, we calculate real wages, real factor (labor and capital) income, and real income (factor income plus tariff revenue). Each comparison is relative to the United States. The first row of Table 4 calculates these outcomes in a benchmark model that uses the actual values of productivity and tariffs for 2000 and in which processing cannot sell domestically. For ease in interpreting counterfactual welfare effects in the rows that follow, we normalize each baseline outcome to one.

Row 2 examines the benefit from the duty-free treatment of processing by calculating welfare if processing were subject to the same tariffs as ordinary production (i.e. processing loses its duty exemption).[47] The full set of general equilibrium interactions is complex and priors are not obvious. For example, Panagariya (1992) argues that the welfare effect of the introduction of full duty drawbacks for exports is ambiguous when there are tariffs elsewhere in the economy. Looking

[47] More precisely, we set $\tau^j_{pn} = \tau^j_{on}$ instead of setting $\tau^j_{pn} = 0$ as in the benchmark case (row 1).

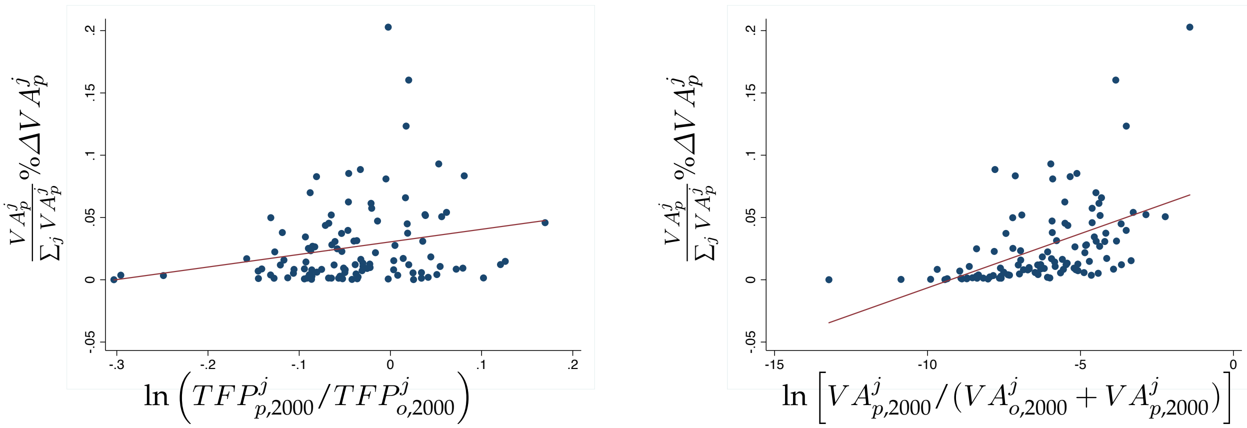
at columns (1)-(3), there is nearly no change. Real wages and real total income only change in the third decimal place, while real factor income is essentially unchanged. These small changes reflect the relatively small share of processing exports in gross manufacturing output, which is on the order of approximately 10% and are consistent with the relatively small effects of incremental trade liberalization found in Eaton and Kortum (2002). It is also consistent with already low tariffs on intermediate inputs as documented in Brandt et al. (2017).

Our second counterfactual experiment focuses on the other major policy component of processing: the restriction from selling to domestic agents. Row 3 of Table 4 presents our results for the counterfactual in which processing producers can sell to domestic consumers but lose their tariff exemption. Specifically, we impose $\kappa^j_{pp} = \kappa^j_{op} = 1$ and $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Differences in productivity between the two forms of organization are important for understanding this counterfactual. Less than perfectly correlated productivity draws and different states of technology introduce the possibility of welfare gains due to comparative advantage both within and across industries.

In the context of our model, real wages rise by 5.7% in a counterfactual world in which Chinese consumers can buy from processing producers but processing loses its tariff exemption. Several factors are responsible for such a large increase. First, within industries, processing production is much more labor intensive than ordinary production. The mean labor share for processing is 0.08 compared to only 0.04 for ordinary.[48] Second, because of transportation costs, consumers spend a much larger share of their incomes on domestically sourced goods than imported goods. Consequently, any policy affecting the menu of prices offered by domestic producers will have a much larger effect than a policy that simply affects the prices charged on imports. Third, processing grows dramatically from 13% to 45% of gross manufacturing output. The second column shows that real factor income grows by less (2.9%), reflecting that the gains for labor are larger than the gains to capital. Finally, real total income grows by slightly less than total factor income (2.2%). This is because increased domestic sales by processing crowd out imports, and tariff revenue falls despite the elimination of a duty drawback in this counterfactual. This is seen as imports fall from

[48]See Online Appendix B.4 for measurement details.

Figure 2: Counterfactual Growth of Processing Across Industries
(No Exemption, No Restriction)



Notes: The panel on the left presents the share of aggregate processing value added growth accruing to industry j, $\frac{VA_p^j}{\sum_j VA_p^j}\%\Delta VA_p^j$, between the counterfactual in row (3) and row (1) of Table 4 on the vertical axis and $\ln\left(TFP_{p,2000}^j/TFP_{o,2000}^j\right)$ calculated in Table 1 on the horizontal axis. Each dot represents an industry. The line is an OLS best fit with a coefficient of 0.10 and a bootstrapped t-statistic of 2.78. The panel on the right also plots the counterfactual change in value added on the vertical axis but plots the benchmark (log) initial share of value added in the industry accruing to processing on the horizontal axis. The line is an OLS best fit with a coefficient of 0.01 and a bootstrapped t-statistic of 4.26.

22.5% of total absorption to 19.6% between the baseline and the counterfactual.

Figure 2 helps to illustrate the mechanisms at play in the counterfactual for the easing of the domestic sales restriction while also removing processing's tariff exemption. On the left of Figure 2, we graph the contribution of industry j to the total percentage change in processing value added, $\frac{VA_p^j}{\sum_j VA_p^j}\%\Delta VA_p^j$, between the benchmark and the counterfactual, against relative productivity in processing in 2000. Each dot represents an industry. The fact that all points are above the origin shows that processing's share expands in *all* industries with the new access to the domestic market.[49] The strong positive relationship suggests that contributions from relaxing the restriction are greatest in those sectors in which processing is most productive relative to ordinary. The panel on the right of Figure 2 plots the same vertical axis variable against processing's (model) value added share in 2000. The positive relationship shows that industries in which processing

[49]This is not surprising even though processing is less productive than ordinary. Processing output originally was subject to a prohibitive iceberg domestic sales cost and is now freely available to Chinese agents.

was more important in 2000 contributed the most to processing's value-added growth under the counterfactual.

Figure 3 in Appendix A presents analogous figures for the case in which processing loses its duty drawback but still cannot sell domestically. Processing in all sectors contracts when it loses its exemption, and this is most pronounced for industries in which processing has a large productivity advantage (left) or in which it provides a larger share of industry value-added (right). These changes are small relative to the changes for domestic market access shown in Figure 2 as can be seen in the range of the vertical axis.

Row (4) shows that the welfare effects of allowing domestic market access are even larger when processing is allowed to keep its duty drawback. Real wages, real factor income, and real total income increase by 7.2%, 3.1%, and 2.3% respectively. While the incremental increases relative to row (3) are small in columns (2) and (3), they are also consistent with the small gains from processing's tariff exemption in row (2). However, the difference in the change in real wages [column (1)] between rows (3) and (4) is much larger than increase in row (2). This suggests some complementarity between domestic market access and duty drawbacks in their effects on real wages.

Row (5) considers the complete elimination of the processing regime including access to processing technology in China. It does this by assuming that processing can not sell to *any* location by setting $\kappa_{ip}^{j} = \infty \; \forall i,j$, which is equivalent to saying that there is no processing activity at all in China.[50] This differs from row (3) in that no Chinese firms organize through processing and the regime and its technology levels are eliminated as a source of output. The effect on real factor incomes and total incomes is very small, however real wages fall by 1.6% relative to the benchmark. This highlights the positive contribution of the more labor-intensive processing sector to labor demand and earnings. The magnitude of this effect is limited by the overall size of the processing sector in the economy in the benchmark.

[50]Because we assume that the ordinary/processing dichotomy only exists in China this also means that processing does not exist elsewhere in the world.

7. Robustness

First, we assess how robust our results are to alternative values of θ^j and ν^j. Second, we examine the robustness of our results to various modelling assumptions including: i) the possibility that Chinese consumers may not value processing output; ii) using a model of imperfect competition and firm heterogeneity as in Hsieh and Ossa (2016); and iii) allowing for "roundabout" shipping. We discuss the results below but relegate all tables to the Robustness Appendix [Appendix B] at the end of the paper.

7.1 *Alternate Values of* θ^j *and* ν^j

We first replicate our results from Table 4 imposing the values of θ^j estimated in Caliendo and Parro (2015).[51] These results appear in Table 5 in the Robustness Appendix, and suggest only minor differences with our original findings. The equilibrium in which Chinese consumers and producers can buy from processing producers delivers 2.1% higher real income and 6.4% higher real wages than the baseline equilibrium. We also examine how heterogeneity in ν affects our results. To do this, we estimate ν^j for each industry at the two-digit ISIC level using equation (13). Table 6 presents estimates $\hat{\nu}^j$ across 20 industries, and Table 7 (both in the Robustness Appendix) presents our welfare results in the same format as Table 4. Real wages, real factor income, and real total income increase by 8%, 3.2%, and 3.2% when processing is allowed to sell domestically but loses its duty drawback, or increases slightly larger than originally reported. In short, our welfare effects change little. Table 8 in the Robustness Appendix presents results letting both θ^j and ν^j vary by industry. Results are unaffected. We also use values of θ^j derived from Ossa (2015) both holding ν^j constant (table 9) and allowing ν^j to vary by industry (table 10).

We next examine the importance of using the multivariate Fréchet distribution relationship relative to a model in which ordinary and processing draws are assumed to be uncorrelated. For this, we set $\nu = 0$ and $\theta^j = 4$ for all industries. This maximizes heterogeneity between the two organizational forms, and the possible gains from allowing processing to sell domestically. Table 11

[51] We also reestimate ν which retains its value up to two decimal places.

presents these results. Importantly, we find that assuming that Fréchet draws are uncorrelated between ordinary and processing leads us to overestimate the welfare gains from allowing processing to sell domestically dramatically, underscoring the importance of our nested Fréchet structure.

7.2 Hat Algebra

Table 12 replicates Table 4 using hat algebra rather than solving the entire model for our full sample of 23 countries and 109 manufacturing industries. Because we do not need to calculate productivity for this solution method (as it "cancels out"), these results shows that our total welfare estimates are not sensitive to the precise measurement of productivity on which we rely.[52] The increase in real wages when processing can sell domestically are slightly smaller now, but the increase in real wages is still larger than the increases in real factor or total income.

7.3 Chinese Consumption Value of Processing Output

A large body of research suggests that preferences for quality vary with income levels.[53] If processing output is higher quality and incomes in China are lower, our welfare results may be overstated if we impose the assumption that Chinese consumers value processing and ordinary output equally. To assess this possibility, we take an extreme position that Chinese *consumers* do not value processing output at all, which still allows for gains through the use of inputs produced by processing and indirect effects on consumption through input-output linkages.[54] As mentioned in section 2, processing exports are not only consumption goods but capital equipment and intermediate inputs as well, suggesting potentially large effects through this mechanism. Results appear in Table 13 using our baseline values of θ=4 and ν=0.78.

The total welfare effects are smaller than in the baseline: 1.5% relative to the baseline instead of 2.2%. While this gain is 32% smaller than in the full model, it is still sizeable. It reflects two

[52]This does not diminish the importance of productivity differences, it only shows that our results do not depend on the details of their measurement.

[53]e.g. Schott (2004), Hallak (2006), Hallak (2010), and Caron, Fally and Markusen (2014).

[54]This implies that the share of final consumption $\alpha^j I_c$ accruing to the processing sector is zero.

separate mechanisms. First, Chinese firms now have access to an additional source of intermediate inputs for production. Second, while Chinese consumers do not derive any direct value from this output, they do value ordinary consumption output which may now be produced at lower cost.

7.4 *Monopolisitc Competition and Firm Heterogeneity*

A limitation of our analysis is that we do not consider the welfare effects of new varieties or the explicit role of firms. Our benchmark analysis did this for two reasons. First, by relying on the Caliendo and Parro (2015) model with perfect competition and constant returns to scale, we could abstract from the boundary of the firm which is important given the prevalence of "hybrid" firms which engage in both ordinary and processing [Yu (2015) and Manova and Yu (2016)]. Second, multi-sector models of monopolistic competition and increasing returns to scale tend to deliver qualitatively similar but quantitatively larger welfare gains from liberalization than models based on perfect competition [Costinot and Rodríguez-Clare (2014) especially Table 4.3].

For completeness, we examine how our welfare results change using a model based on Hsieh and Ossa (2016) which incorporates firm heterogeneity, monopolistic competition, increasing returns to scale, and input-output linkages. Online Appendix D describes the model in detail. Following Hsieh and Ossa (2016), we solve the model in differences using "hat algebra" which removes the need to calculate productivity differences. Again, these robustness results should also mitigate concerns about the gravity model estimation and calculation of productivity.

Following Hsieh and Ossa (2016), we work at a higher level of aggregation.[55] We assume that there are two countries (China and the Rest of the World) and 13 industries–the same number of industries as in Hsieh and Ossa (2016).[56] Results appear in panel A of Table 14 in the Robustness

[55] This is due to computational difficulties arising from a larger number of endogenous variables than in a Caliendo and Parro (2015) type model.

[56] These industries are 1) "Food, beverages, and tobacco", 2) "Textiles and leather", 3) "Wood and products of wood and cork", 4) "Pulp, paper, printing and publishing", 5) "Chemicals and chemical products", 6) "Rubber and plastics", 7) "Other non-metallic minerals", 8) "Basic metals and fabricated metals", 9) "Other machinery", 10) "Electrical and optical equipment", 11) "Transport equipment", 12) "Other manufacturing and recycling", and 13) a non-traded sector. We drop "coke, refined petroleum, and nuclear fuel" due to data availability. In all hat algebra models, all accounting identities hold.

Appendix. Differences between the results in panel A and Table 4 are due to model selection [Caliendo and Parro (2015) vs. Hsieh and Ossa (2016)], the level of aggregation (109 industries vs. 13 industries), and the solution method (levels versus hat algebra). To provide a more precise comparison, Panel B solves a Caliendo and Parro (2015) model with 13 industries using hat algebra.

The welfare gains from allowing processing to sell domestically continue to be large in panels A and B, rows 3 and 4. However, duty drawbacks are welfare improving in panel A [Hsieh and Ossa (2016)] while it has little effect in panel B [Caliendo and Parro (2015)]. In addition, capital gains more than labor in panel A than it does in panel B.[57]

7.5 *Roundabout Shipping*

Table 15 in the Robustness Appendix considers a set of counterfactuals relative to a baseline that includes the possibility of "roundabout" shipping. In this alternate baseline, processing can ship its goods out of China to the nearest destination (Hong Kong), re-enter, and sell on the domestic market after having incurred the appropriate transport costs and import duties to access the domestic market. In reality, this seems very rare. Customs data records re-imports of processing goods from China and back into China. While China is a relatively large source of processing imports into China (6.7%), far fewer of its ordinary imports (0.7%) are listed as coming from China.[58] As expected, the welfare gains are smaller but still positive (1-4%) with the option of roundabout shipping, and larger than the welfare effects of the duty-drawbacks. The distributional effects are also the same as under the original counterfactual.

8. Conclusion

Export processing zones and processing regimes have figured prominently in the strategies of many export-oriented developing countries. This paper assesses the quantitative welfare effects

[57]Additional simulations available upon request show that this is due to the fact that entry costs are paid for using more capital intensive ordinary production. Fixed costs payable in terms of processing restores the original result.

[58]For the vast majority of these shipments, the transfer country is listed as Hong Kong. Online Appendix B describes how data are constructed in this case.

of two common instruments of these regimes for China: duty drawbacks on processing imports and restrictions on domestic sales for processing output. The latter entails a form of incomplete liberalization: local agents are not able to consume goods produced by export processors or use them as intermediates. Through the lens of a Ricardian model, if processing production possesses a comparative advantage in certain industries relative to ordinary, there are potential welfare gains that are left unrealized.

We highlight several key results from our analysis. First, we find significant differences across industries in China in relative productivity between ordinary and processing. Moreover, these differences appear to be tied to important industry characteristics. Second, the welfare effects of duty drawbacks are quantitatively small. This is in line with other work suggesting that the gains from incremental trade liberalization are small. Third, there are large forgone welfare gains associated with restricting Chinese processing producers from selling domestically. We also find that the gains are especially large for labor for two reasons: first, processing is generally more labor intensive than ordinary production; and second, the processing sector grows from 13% to 45% of tradable output in the counterfactual. And fourth, reflecting the higher labor intensity of the processing sector, labor bears the costs of eliminating the processing sector, technology included, from China. Real wage income is 1.6% lower in this case, in line with processing's modest overall role in the economy.

Processing is often argued to offer benefits such as foreign exchange earnings, technology transfer, and learning-by-doing. Spillovers through processing to the rest of the domestic economy however may be more limited compared to other organizational forms. These dimensions do not show up in our model. In light of our finding of welfare costs from incomplete liberalization, this raises an important policy question: Is there an alternative set of policies that can facilitate foreign exchange earnings, access to new technology, and knowledge accumulation and dissemination that does not entail the costly distortions that come from the restrictions commonly associated with processing?

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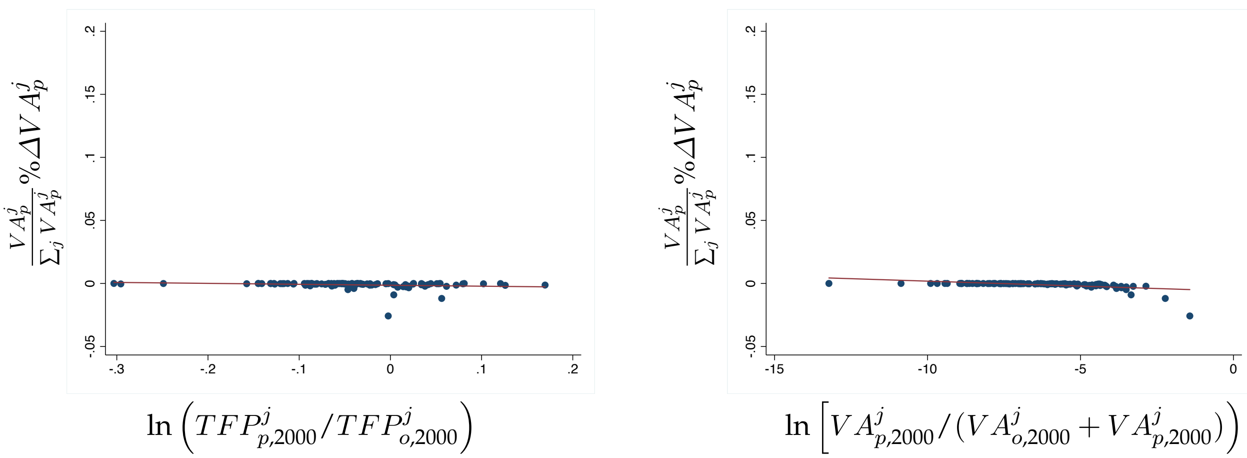
Appendix A. Additional Results

A. Figures

Figure 3: Counterfactual Growth of Processing Across Industries
(No Exemption)



Notes: The panel on the left presents the share of aggregate processing value added growth accruing to industry j, $\frac{VA_p^j}{\sum_{j'} VA_p^{j'}} \frac{VA_p^{j'} - VA_p^j}{VA_p^j}$, between the counterfactual in row (2) and row (1) of Table 4 on the vertical axis and $\ln\left(TFP_{p,2000}^j / TFP_{o,2000}^j\right)$ calculated in Table 1 on the horizontal axis. Each dot represents an industry. For ease of comparison, the scale on the vertical axis is the same as in Figure 2. The line is an OLS best fit with a coefficient of -0.01 and a bootstrapped t-statistic of -2.99. The panel on the right also plots the counterfactual change in value added on the vertical axis but plots the benchmark (log) initial share of value added in the industry accruing to processing on the horizontal axis. The line is an OLS best fit with a coefficient of -0.001 and a bootstrapped t-statistic of -2.73.

B. Robustness

Table 5: Real Wages and Income: Counterfactual Simulations with Heterogeneous θ^j

Specification Number	Processing Specification Description	Real Wage (rel. to US) (1)	Real Factor Income (rel. to US) (2)	Real Income (rel. to US) (3)
(1)	Benchmark	1.000	1.000	1.000
(2)	No exemption	0.999	1.001	1.000
(3)	No exemption, sells domestically	1.064	1.028	1.021
(4)	Sells domestically	1.070	1.030	1.021
(5)	No Processing	0.985	0.997	0.996

Notes: Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (3) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty\ \forall j,n$. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. θ^j from Caliendo-Parro (2015) and $\nu = 0.78$.

Table 6: Estimates $\hat{\nu}^j$

ISIC Code	ISIC Description	$\hat{\nu}^j$	Standard Error
15	Food and Beverages	0.77	0.04
17	Textiles	0.08	0.12
18	Wearing Apparel	0.44	0.13
19	Leather Products	0.96	0.07
20	Wood and Wood products, except furniture	0.90	0.07
21	Paper and Paper products	-0.04	0.06
22	Publishing	0.63	0.03
24	Chemicals and Chemical Products	0.64	0.04
25	Rubber and Plastic Products	1.12	0.06
26	Non-metallic Mineral Products	1.21	0.16
27	Basic Metals	0.49	0.15
28	Fabricated Metal Products	1.13	0.09
29	Machinery and Equipment n.e.c.	0.95	0.03
30	Office, Accounting, and Computing machinery	0.80	0.04
31	Electrical Machinery and Apparatus n.e.c	0.93	0.03
32	Radio, Television, and Communication equipment	1.15	0.05
33	Medical, Precision, and Optical instruments	0.77	0.04
34	Motor vehicles	0.41	0.05
35	Other transport equipment	0.63	0.03
36	Furniture; manufacturing n.e.c	0.92	0.05
–	Non-Traded	0.78	–

Notes: These estimates of ν^j are based on estimation of equation (13) using two-digit subsamples of the four-digit pooled data described in the text. The first two columns is the ISIC revision 3 two-digit ISIC code and its verbal description. The third column is the point estimate, and the fourth column is the standard errors clustered by country-triads. While the point estimates for industries 21, 25, 26, 28, and 32 do not satisfy the theoretical restriction of $0 \leq \nu < 1$, only for industry 32 cannot reject the null that they it is equal to unity at p=0.05. In the counterfactual simulations these values are set equal to 0 (for industry 21) and 0.99 (the remainder). We set $\nu^{non-traded} = 0.78$.

Table 7: Real Wages and Income: Counterfactual Simulations with Hetreogeneous ν^j

Specification Number	Processing Specification Description	Real Wage (rel. to US)	Real Factor Income (rel. to US)	Real Income (rel. to US)
(1)	Benchmark	1.000	1.000	1.000
(2)	No exemption	1.000	1.001	1.001
(3)	No exemption, sells domestically	1.080	1.032	1.032
(4)	Sells domestically	1.083	1.032	1.032
(5)	No Processing	0.985	0.995	0.995

Notes: Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on} \; \forall \; j,n$. Row (3) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on} \; \forall \; j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty \; \forall j,n$. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. $\theta^j = 4$ and ν^j are calculated for two-digit industries.

Table 8: Real Wages and Income: Counterfactual Simulations with Heterogeneous θ^j and ν^j

Specification Number	Processing Specification Description	Real Wage (rel. to US)	Real Factor Income (rel. to US)	Real Income (rel. to US)
		(1)	(2)	(3)
(1)	Benchmark	1.000	1.000	1.000
(2)	No exemption	0.999	1.000	1.000
(3)	No exemption, sells domestically	1.073	1.034	1.026
(4)	Sells domestically	1.077	1.036	1.027
(5)	No Processing	0.985	0.996	0.995

Notes: Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on} \; \forall \; j,n$. Row (3) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on} \; \forall \; j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty \; \forall j,n$. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. θ^j are from Caliendo-Parro (2015) and ν^j are calculated for two-digit industries.

Table 9: Real Wages and Income: Counterfactual Simulations with Heterogeneous θ^j Based on Estimates from Ossa (2015)

Specification Number	Processing Specification Description	Real Wage (rel. to US)	Real Factor Income (rel. to US)	Real Income (rel. to US)
(1)	Benchmark	1.000	1.000	1.000
(2)	No exemption	0.999	1.000	1.000
(3)	No exemption, sells domestically	1.063	1.027	1.021
(4)	Sells domestically	1.070	1.031	1.022
(5)	No Processing	0.982	0.994	0.994

Notes: Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (3) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty\ \forall j,n$. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. θ^j calculated based on estimates from Ossa (2015). We interpret the trade elasticities from Ossa (2015) as Armington elasticities, we calculate $\theta^j = \sigma^j - 1$ to transform them into Fréchet parameters. $\nu = 0.78$.

Table 10: Real Wages and Income: Counterfactual Simulations with Heterogeneous θ^j Based on Estimates from Ossa (2015) and Heterogeneous ν^j

Specification Number	Processing Specification Description	Real Wage (rel. to US)	Real Factor Income (rel. to US)	Real Income (rel. to US)
(1)	Benchmark	1.000	1.000	1.000
(2)	No exemption	1.000	1.000	1.000
(3)	No exemption, sells domestically	1.078	1.038	1.031
(4)	Sells domestically	1.083	1.041	1.031
(5)	No Processing	0.985	0.995	0.993

Notes: Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (3) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty\ \forall j,n$. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. θ^j calculated based on estimates from Ossa (2015). We interpret the trade elasticities from Ossa (2015) as Armington elasticities, we calculate $\theta^j = \sigma^j - 1$ to transform them into Fréchet parameters. ν^j are calculated for two-digit industries.

Table 11: Real Wages and Income: Counterfactual Simulations with $\nu^j = 0$

Specification Number	**Processing Specification Description**	**Real Wage (rel. to US)**	**Real Factor Income (rel. to US)**	**Real Income (rel. to US)**
(1)	Benchmark	1.000	1.000	1.000
(2)	No exemption	0.999	1.000	1.000
(3)	No exemption, sells domestically	1.130	1.101	1.091
(4)	Sells domestically	1.132	1.103	1.092
(5)	No Processing	0.978	0.987	0.982

Notes: Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (3) allows processing firms to sell to to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty\ \forall j,n$. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. $\theta^j = 4$ and $\nu^j = 0$.

Table 12: Real Wages and Income: Counterfactual Simulations (Based on Hat-Algebra)

Specification Number	**Processing Specification Description**	**Real Wage (rel. to US)**	**Real Factor Income (rel. to US)**	**Real Income (rel. to US)**
		(1)	(2)	(3)
(1)	Baseline	1.000	1.000	1.000
(2)	No exemption	1.008	1.006	1.011
(3)	No exemption, sells domestically	1.027	1.012	1.017
(4)	Sells domestically	1.104	1.031	1.031
(5)	No Processing	0.964	0.987	0.980

Notes: Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (3) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty\ \forall j,n$. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. $\theta^j = 4$ and $\nu = 0.78$.

Table 13: Real Wages and Income: Counterfactual Simulations

Specification Number	**Processing Specification Description**	**Real Wage (rel. to US)** (1)	**Real Factor Income (rel. to US)** (2)	**Real Income (rel. to US)** (3)
(1)	Benchmark	1.000	1.000	1.000
(2)	No exemption	0.999	1.000	1.001
(3)	No exemption, sells domestically	1.057	1.029	1.022
(4)	Sells domestically	1.072	1.031	1.023
(5)	No Processing	0.984	0.996	0.995
(6)	Row (3) + no value for final consumption	1.063	1.024	1.015
(7)	Row (4) + no value for final consumption	1.069	1.025	1.015

Notes: Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on} \ \forall \ j,n$. Row (3) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on} \ \forall \ j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty \ \forall j,n$. Row (6) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on} \ \forall \ j,n$, and assumes that the varieties from the processing sector are not valued for final consumption. Row (7) is the same as row (6) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Real factor income=wage+capital income. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. $\theta^j = 4$ and $\nu = 0.78$.

Table 14: Real Wages and Income:
Extended HO and CP Models at the Same Level of Aggregation (Based on Hat-Algebra)

Specification Number	Processing Specification Description	Real Wage	Real Factor Income	Real Income
		(1)	(2)	(3)
	Panel A: Hsieh and Ossa (HO) Model			
(1)	Baseline	1.000	1.000	1.000
(2)	No exemption	0.978	0.975	0.978
(3)	No exemption, sells domestically	1.026	1.038	1.038
(4)	Sells domestically	1.061	1.073	1.072
(5)	No Processing	0.892	0.891	0.891
	Panel B: Caliendo and Parro (CP) Model			
(1)	Baseline	1.000	1.000	1.000
(2)	No exemption	1.000	1.000	1.003
(3)	No exemption, sells domestically	1.077	1.024	1.026
(4)	Sells domestically	1.081	1.026	1.022
(5)	No Processing	0.994	0.999	0.999

Notes: Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (3) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on}\ \forall\ j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty\ \forall j,n$. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. $\theta^j = 4$, $\sigma^j = 2.5$ and $\nu^j = 0.78$.

Table 15: Real Wages and Income: Counterfactual Simulations with Roundabout Shipping

Specification Number	Processing Specification Description	Real Wage (rel. to US)	Real Factor Income (rel. to US)	Real Income (rel. to US)
(1)	Benchmark	1.000	1.000	1.000
(2)	No exemption	0.998	1.001	1.001
(3)	No exemption, sells domestically	1.038	1.012	1.008
(4)	Sells domestically	1.042	1.014	1.007
(5)	No Processing	0.988	0.997	0.997

Notes: All specifications correspond to the case of roundabout shipping as described in the text. Row (1) represents the baseline equilibrium in which actual values of productivity and tariffs are imposed and processing is not allowed to sell domestically. Outcomes are normalized to 1. Row (2) imposes that processing firms pay the same tariffs on imports that ordinary firms do: $\tau^j_{pn} = \tau^j_{on} \ \forall \ j,n$. Row (3) allows processing firms to sell to the ordinary sector and to the processing sector but loses their tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$ and $\tau^j_{pn} = \tau^j_{on} \ \forall \ j,n$. Row (4) is the same as row (3) but processing keeps its tariff exemption: $\kappa^j_{op} = \kappa^j_{pp} = 1$. Row (5) imposes infinite trade costs on all shipments out of the processing sector: $\kappa^j_{np} = \infty \ \forall j,n$. Real factor income=wage+capital income. Real income=wage+capital income+tariff revenue. $\theta^j = 4$ and $\nu^j = 0.78$.

Online Appendix to "Processing Trade and Costs of Incomplete Liberalization: The Case of China"

Appendix A. Proofs

A.1 Price Distributions

As in Eaton and Kortum (2002), we start by defining the distribution of equilibrium prices in each industry-destination pair jn. The distribution of prices that each non-Chinese exporting country i offers each destination n in industry j is defined to be

$$G_{ni}^{j}(p) \equiv Pr[p_{ni}^{j}(\omega^{j}) < p].$$

Using the properties of the Fréchet, this can be solved to be

$$G_{ni}^{j}(p) = 1 - \exp\left[\lambda_{i}^{j}\left(c_{i}^{j}\kappa_{ni}^{j}\right)^{-\theta^{j}} p^{\theta^{j}}\right]. \tag{A1}$$

For Chinese exporters (the sum of ordinary and processing exporters), the multivariate Fréchet delivers the following expression

$$G_{nc}^{j}(p) = 1 - \exp\left[\left(\left(\lambda_{o}^{j}\right)^{\frac{1}{1-\nu^{j}}}\left(c_{o}^{j}\kappa_{no}^{j}\right)^{-\frac{\theta^{j}}{1-\nu^{j}}} + \left(\lambda_{p}^{j}\right)^{\frac{1}{1-\nu^{j}}}\left(c_{p}^{j}\kappa_{np}^{j}\right)^{-\frac{\theta^{j}}{1-\nu^{j}}}\right)^{1-\nu^{j}} p^{\theta^{j}}\right]. \tag{A2}$$

Non-China Destinations

The distribution of prices that n actually pays in industry j is given by

$$G_{n}^{j} = 1 - \left\{\left[\prod_{i=1}^{N}(1 - G_{ni}^{j}(p))\right]\left[1 - G_{nc}^{j}(p)\right]\right\}. \tag{A3}$$

Using equations (A1), (A2), and (A3), the distribution of prices in any non-Chinese destination market is given by

$$G_{n}^{j} = 1 - \exp\{-\Phi_{n}^{j} p^{\theta^{j}}\}, \tag{A4}$$

where

$$\Phi_{n}^{j} \equiv \left[\left(\lambda_{o}^{j}\right)^{\frac{1}{1-\nu^{j}}}\left(c_{o}^{j}\kappa_{no}^{j}\right)^{-\frac{\theta^{j}}{1-\nu^{j}}} + \left(\lambda_{p}^{j}\right)^{\frac{1}{1-\nu^{j}}}\left(c_{p}^{j}\kappa_{np}^{j}\right)^{-\frac{\theta^{j}}{1-\nu^{j}}}\right]^{1-\nu^{j}} + \left[\sum_{i=1}^{N}\lambda_{i}^{j}\left(c_{i}^{j}\kappa_{ni}^{j}\right)^{-\theta^{j}}\right]. \tag{A5}$$

Ordinary Importing in China

The distribution of prices that the ordinary sector actually pays in industry j is given by

$$G_{o}^{j} = 1 - \left\{\left[\prod_{i=1}^{N}(1 - G_{oi}^{j}(p))\right]\left[1 - G_{oo}^{j}(p)\right]\right\}.$$

Note that the last term is different from (A3) because the ordinary sector cannot purchase from processing producers in China. The distribution of prices in the Chinese ordinary processing sector is given by

$$G_o^j = 1 - \exp\{-\Phi_o^j p^{\theta^j}\},$$

where

$$\Phi_o^j \equiv \lambda_o^j \left(c_o^j \kappa_{oo}^j\right)^{-\theta^j} + \sum_{i=1}^N \lambda_i^j \left(c_i^j \kappa_{oi}^j\right)^{-\theta^j}.$$

Processing Importing in China

The distribution of prices that the processing sector actually pays in industry j is given by

$$G_p^j = 1 - \left\{ \left[\prod_{i=1}^N (1 - G_{pi}^j(p)) \right] \left[1 - G_{po}^j(p)\right] \right\}.$$

The processing sector cannot purchase from processing producers in China. Therefore, the distribution of prices in the Chinese processing sector is given by

$$G_p^j = 1 - \exp\{-\Phi_p^j p^{\theta^j}\},$$

where

$$\Phi_p^j \equiv \lambda_o^j \left(c_o^j \kappa_{po}^j\right)^{-\theta^j} + \sum_{i=1}^N \lambda_i^j \left(c_i^j \kappa_{pi}^j\right)^{-\theta^j}.$$

A.2 Expenditure Shares

Non-China Sources, Non-China Destinations

For non-China destinations, expenditure shares π_{ni}^j are straightforward applications of the Fréchet machinery. As in Eaton and Kortum (2002) (pg. 1748), the precise definition of π_{ni}^j is $\pi_{ni}^j \equiv Pr\left[p_{ni}^j(\omega^j) \leq \min\left\{p_{ns}^j(\omega^j); s \neq i\right\}\right] = \int_0^\infty \prod_{s\neq i}\left[1 - G_{ns}^j(p)\right] dG_{ni}^j(p)$. Using equations (A4) and (A5), this is equivalent to

$$\pi_{ni}^j = \frac{\lambda_i^j (c_i^j \kappa_{ni}^j)^{-\theta^j}}{\left[\left(\lambda_o^j\right)^{\frac{1}{1-\nu}} \left(c_o^j \kappa_{no}^j\right)^{\frac{-\theta^j}{1-\nu}} + \left(\lambda_p^j\right)^{\frac{1}{1-\nu}} \left(c_p^j \kappa_{np}^j\right)^{\frac{-\theta^j}{1-\nu}}\right]^{1-\nu} + \sum_{i'=1}^N \lambda_{i'}^j \left(c_{i'}^j \kappa_{ni'}^j\right)^{-\theta^j}}.$$

Non-China Sources, China as a Destination

Because ordinary agents cannot purchase processing output, the share of expenditure by ordinary producers on goods from country i can be derived using the expression above and $\kappa_{op}^j = \infty$:

$$\pi_{oi}^j = \frac{\lambda_i^j (c_i^j \kappa_{oi}^j)^{-\theta^j}}{\lambda_o^j \left(c_o^j \kappa_{oo}^j\right)^{-\theta^j} + \sum_{i'=1}^N \lambda_{i'}^j \left(c_{i'}^j \kappa_{oi'}^j\right)^{-\theta^j}}.$$

Similarly, with $\kappa_{pp}^j = \infty$, the expenditure share of processing sector is given by:

$$\pi_{pi}^j = \frac{\lambda_i^j (c_i^j \kappa_{pi}^j)^{-\theta^j}}{\lambda_o^j \left(c_o^j \kappa_{po}^j\right)^{-\theta^j} + \sum_{i'=1}^N \lambda_{i'}^j \left(c_{i'}^j \kappa_{pi'}^j\right)^{-\theta^j}}.$$

Chinese Ordinary Exports to Non-China Destinations

For this section, it helps to define two small pieces of additional notation. First, denote the minimum productivity level that a Chinese ordinary exporter must have so that his delivery price of a given variety in industry j and market n is lower than all other non-Chinese exporters.

$$w_n^j(\omega^j) \equiv c_o^j \kappa_{no}^j \max_{i \neq o,p} \left\{ \frac{z_i^j(\omega^j)}{c_i \kappa_{ni}^j} \right\}.$$

Under the Fréchet distribution, $w_n^j(\omega^j)$ will be distributed as follows

$$G_n^j(w_n^j) = \exp \left[- \underbrace{(c_o^j \kappa_{no}^j)^{\theta^j} \sum_{i \neq o,p} \lambda_i^j (c_i^j \kappa_{ni}^j)^{-\theta^j}}_{\lambda_{w_n}^j} {w_n^j}^{-\theta^j} \right] \tag{A6}$$

Second, define $\mu_n^j = \frac{c_o^j \kappa_{no}^j}{c_p^j \kappa_{np}^j}$ as the relative delivery prices (exclusive of productivity differences) for ordinary and processing shipments of a variety of good j to destination n. The share of expenditure on goods accruing to the ordinary sector in China in a given destination-industry pair nj is given by

$$\pi_{no}^j = Prob(z_o^j(\omega^j) > \max\{\mu_n^j z_p^j(\omega^j), w_n^j(\omega^j)\}).$$

This is the probability that a given variety sourced from Chinese ordinary sector is cheaper than that sourced from Chinese processing sector *and* also that from all other non-Chinese exporters.

$$\pi_{no}^j = \int_0^\infty \left[\int_0^{w_n^j/\mu_n^j} \int_{w_n^j}^\infty f(z_o^j, z_p^j) dz_o^j dz_p^j + \int_{w_n^j/\mu_n^j}^\infty \int_{\mu_n^j z_p^j}^\infty f(z_o^j, z_p^j) dz_o^j dz_p^j \right] g_n^j(w_n^j) dw_n^j$$

where

$$\int_0^{w_n^j/\mu_n^j} \int_{w_n^j}^\infty f(z_o^j, z_p^j) dz_o^j dz_p^j = \frac{w_n^j}{\mu_n^j} - \exp \left[- \left({\lambda_o^j}^{\frac{1}{1-\nu^j}} {w_n}^{-\frac{\theta^j}{1-\nu^j}} + {\lambda_p^j}^{\frac{1}{1-\nu^j}} \left(\frac{w_n^j}{\mu_n^j} \right)^{-\frac{\theta^j}{1-\nu^j}} \right)^{1-\nu^j} \right]$$

$$\int_{w_n^j/\mu_n^j}^\infty \int_{\mu_n^j z_p^j}^\infty f(z_o^j, z_p^j) dz_o^j dz_p^j = 1 - \frac{w_n^j}{\mu_n^j} - \frac{{\lambda_p^j}^{\frac{1}{1-\nu^j}}}{{\lambda_o^j}^{\frac{1}{1-\nu^j}} \left(\mu_n^j\right)^{\frac{-\theta^j}{1-\nu^j}} + {\lambda_p^j}^{\frac{1}{1-\nu^j}}} \left[1 - \exp \left[- \left({\lambda_o^j}^{\frac{1}{1-\nu^j}} {w_n}^{-\frac{\theta^j}{1-\nu^j}} + {\lambda_p^j}^{\frac{1}{1-\nu^j}} \left(\frac{w_n^j}{\mu_n^j} \right)^{-\frac{\theta^j}{1-\nu^j}} \right)^{1-\nu^j} \right] \right]$$

Adding last two expressions delivers

$$\frac{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}}{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}}\left\{1-exp[-\left(\lambda_o^{j\frac{1}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}\mu_n^{j\frac{\theta^j}{1-\nu^j}}\right)^{1-\nu^j}(w_n^j)^{-\theta^j}]\right\} \tag{A7}$$

Integrating equations (A7) over w_n, we get

$$\begin{aligned}
\pi_{no}^j &= \frac{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}}{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}}\int_0^\infty\left\{1-exp[-(\lambda_o^{j\frac{1}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}\mu_n^{j\frac{\theta^j}{1-\nu^j}})^{1-\nu^j}w_n^{j-\theta^j}]\right\}g(w_n^j)dw_n^j \\
&= \frac{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}}{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}}-\frac{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}}{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}}\int_0^\infty\theta^j\lambda_{w_n}^j exp\Big[-[(\lambda_o^{j\frac{1}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}\mu_n^{j\frac{\theta^j}{1-\nu^j}})^{1-\nu^j}+\lambda_{w_n}^j]w_n^{j-\theta^j}\Big]w_n^{j-\theta^j-1}dw_n^j \\
&= \frac{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}}{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}}-\frac{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}}{\lambda_o^{j\frac{1}{1-\nu^j}}\mu_n^{j-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}}\frac{\lambda_{w_n}^j}{(\lambda_o^{j\frac{1}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}\mu_n^{j\frac{\theta^j}{1-\nu^j}})^{1-\nu^j}+\lambda_{w_n}^j} \\
&= \frac{\lambda_o^{j\frac{1}{1-\nu^j}}}{\lambda_o^{j\frac{1}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}\mu_n^{j\frac{\theta^j}{1-\nu^j}}}\frac{(\lambda_o^{j\frac{1}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}\mu_n^{j\frac{\theta^j}{1-\nu^j}})^{1-\nu^j}}{(\lambda_o^{j\frac{1}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}\mu_n^{j\frac{\theta^j}{1-\nu^j}})^{1-\nu^j}+\lambda_{w_n}^j}
\end{aligned}$$

where the second equality follows from the distribution function (A6). Substitute in $\mu_n^j=\frac{c_o^j\kappa_{no}^j}{c_p^j\kappa_{np}^j}$ and $\lambda_{wn}^j=(c_o^j\kappa_{no}^j)^{\theta^j}\sum_{i\neq o,p}\lambda_i^j(c_i^j\kappa_{ni}^j)^{-\theta^j}$ into the last equality, π_{no}^j can be rewritten as

$$\pi_{no}^j=\frac{\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}}{\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}(c_p^j\kappa_{np}^j)^{-\frac{\theta^j}{1-\nu^j}}}\frac{[\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}(c_p^j\kappa_{np}^j)^{-\frac{\theta^j}{1-\nu^j}}]^{1-\nu^j}}{[\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}(c_p^j\kappa_{np}^j)^{-\frac{\theta^j}{1-\nu^j}}]^{1-\nu^j}+\sum_{i\neq o,p}\lambda_i^j(c_i^j\kappa_{ni}^j)^{-\theta^j}}$$

Note that the term $\frac{\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}}{\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}(c_p^j\kappa_{np}^j)^{-\frac{\theta^j}{1-\nu^j}}}$ captures the relative size of ordinary trade in market nj. It is higher when the productivity of ordinary trade is relative higher, or relative cost of ordinary trade is lower. The second term $\frac{[\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}(c_p^j\kappa_{np}^j)^{-\frac{\theta^j}{1-\nu^j}}]^{1-\nu^j}}{[\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}(c_p^j\kappa_{np}^j)^{-\frac{\theta^j}{1-\nu^j}}]^{1-\nu^j}+\sum_{i\neq o,p}\lambda_i^j(c_i^j\kappa_{ni}^j)^{-\theta^j}}$ captures the market share of China as a whole in market nj.

Chinese Processing Exports to Non-China Destinations

Similarly, the expenditure share on goods from processing sector is

$$\pi_{np}^j=\frac{\lambda_p^{j\frac{1}{1-\nu^j}}(c_p^j\kappa_{np}^j)^{-\frac{\theta^j}{1-\nu^j}}}{\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}(c_p^j\kappa_{np}^j)^{-\frac{\theta^j}{1-\nu^j}}}\frac{[\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}(c_p^j\kappa_{np}^j)^{-\frac{\theta^j}{1-\nu^j}}]^{1-\nu^j}}{[\lambda_o^{j\frac{1}{1-\nu^j}}(c_o^j\kappa_{no}^j)^{-\frac{\theta^j}{1-\nu^j}}+\lambda_p^{j\frac{1}{1-\nu^j}}(c_p^j\kappa_{np}^j)^{-\frac{\theta^j}{1-\nu^j}}]^{1-\nu^j}+\sum_{i\neq o,p}\lambda_i^j(c_i^j\kappa_{ni}^j)^{-\theta^j}}$$

A. A.3 Market Clearing

Because income equals expenditure:

$$\sum_{j=1}^{J+1}\sum_{i=1}^{N+2}X_n^j\frac{\pi_{ni}^j}{1+\tau_{ni}^j}=\sum_{j=1}^{J+1}\sum_{i=1}^{N+2}X_i^j\frac{\pi_{in}^j}{1+\tau_{in}^j}. \tag{A8}$$

The left hand side captures all income accruing to country n and the right hand side captures total world expenditure going to country n. A similar expression also holds for China based on ordinary and processing trade:

$$\sum_{j=1}^{J+1}\sum_{i=1}^{N+2} X_o^j \frac{\pi_{oi}^j}{1+\tau_{oi}^j} + \sum_{j=1}^{J+1}\sum_{i=1}^{N+1} X_p^j \pi_{pi}^j = \sum_{j=1}^{J+1}\sum_{i=1}^{N+2} X_i^j \frac{\pi_{io}^j}{1+\tau_{io}^j} + \sum_{j=1}^{J+1}\sum_{i=1}^{N} X_i^j \frac{\pi_{ip}^j}{1+\tau_{ip}^j} \tag{A9}$$

Outside of China, aggregate factor payments are given by:

$$\sum_{j=1}^{J+1} \gamma_{L,n}^j \sum_{i=1}^{N+2} X_i^j \frac{\pi_{in}^j}{1+\tau_{in}^j} = w_n L_n \quad \text{and} \quad \sum_{j=1}^{J+1} \gamma_{K,n}^j \sum_{i=1}^{N+2} X_i^j \frac{\pi_{in}^j}{1+\tau_{in}^j} = r_n K_n. \tag{A10}$$

For China, these expressions are

$$\sum_{j=1}^{J+1} \gamma_{L,o}^j \sum_{i=1}^{N+2} X_i^j \frac{\pi_{io}^j}{1+\tau_{io}^j} + \sum_{j=1}^{J} \gamma_{L,p}^j \sum_{i=1}^{N} X_i^j \frac{\pi_{ip}^j}{1+\tau_{ip}^j} = w_c L_c \tag{A11}$$

and

$$\sum_{j=1}^{J+1} \gamma_{K,o}^j \sum_{i=1}^{N+2} X_i^j \frac{\pi_{io}^j}{1+\tau_{io}^j} + \sum_{j=1}^{J} \gamma_{K,p}^j \sum_{i=1}^{N} X_i^j \frac{\pi_{ip}^j}{1+\tau_{ip}^j} = r_c K_c \tag{A12}$$

Appendix B. Data

B.1 Countries

The following countries comprise our dataset: Australia*, Austria*, Canada*, China* (ordinary and processing), Colombia, Finland*, France*, Germany*, Great Britain*, Hungary*, Indonesia*, India*, Italy*, Japan*, Malaysia, Norway, Poland*, Portugal*, South Korea*, Spain*, Sweden*, United States*, Vietnam. Countries with asterisks are in the WIOD data set of Timmer et al. (2015). This is relevant in the data construction process described below.

B.2 Industries

In addition to a non-traded sector, the following 118 four-digit ISIC revision 3 industries comprise our dataset although missing data for output leads to fewer industries that depend on the year: 1511, 1512, 1513, 1514, 1520, 1531, 1532, 1533, 1541, 1542, 1543, 1544, 1549, 1551, 1552, 1553, 1554, 1600, 1711, 1721, 1722, 1723, 1729, 1730, 1810, 1820, 1911, 1912, 1920, 2010, 2021, 2022, 2023, 2029, 2101, 2102, 2109, 2211, 2212, 2213, 2219, 2221, 2222, 2411, 2412, 2413, 2421, 2422, 2423, 2424, 2429, 2430, 2511, 2519, 2520, 2610, 2691, 2692, 2693, 2694, 2695, 2696, 2699, 2710, 2720, 2811, 2812, 2813, 2893, 2899, 2911, 2912, 2913, 2914, 2915, 2919, 2921, 2922, 2923, 2924, 2925, 2926, 2927, 2929, 2930, 3000, 3110, 3120, 3130, 3140, 3150, 3190, 3210, 3220, 3230, 3311, 3312, 3313, 3320, 3330, 3410, 3420, 3430, 3511, 3512, 3520, 3530, 3591, 3592, 3599, 3610, 3691, 3692, 3693, 3694, 3699. We discuss selection and the unbalanced nature of our dataset below.

B.3 Data Sources

The source of trade data for China is the same as in Brandt and Morrow (2017) which comes at the HS six-digit level and is disaggregated by ordinary and processing trade for the years 2000-2006. This paper extends the analysis to 2007. For the rest of the world, trade data are available through UN Comtrade (via BACI) and is also available at the HS six-digit level for the same time period. As we discuss below, we aggregate this up to the four-digit ISIC level using a crosswalk.[59]

Output data comes from the United Nations Industrial Demand-Supply Balance (IDSB) Database data set. This data set contains both output and world exports data which can be used to construct domestic sales data. Because not every country-industry pair has output or world exports data, we start by interpolating some values and then establish a maximum number of missing observations beyond which we drop the country. We do this as follows: we start by merging these data with the BACI trade data. We then run a regression of world exports from the IDSB data base on total exports as found in the BACI data. An observation in this regression is at the 4-digit ISIC-country-year level. The R^2 from this regression is 0.9746. We then replace world exports with the fitted value from this regression if it is less than reported output and if the fitted value is strictly positive. For observations that are still missing either output or world exports data, we replace *both* with their values lagged by one year (if available). We then keep countries for which there are at least 73 out of 118 industries. On average, the remaining countries in the data set have 94/118 industries.

Cobb-Douglas consumption shares are from the WIOD data that provide α^j for each of the WIOD industries. We convert NACE industries to ISIC industries by assuming that each ISIC industry's Cobb-Douglas cost share is equal to the NACE consumption share times the share of the NACE industry output accounted for by the ISIC industry within it.

The UN INDSTAT data base contains data on output, value added, and total wages at the 4-digit ISIC level of aggregation and is our source for $\gamma^j_{L,n}$ and $\gamma^j_{K,n}$. Data on total labor and capital endowments come from the Penn World Tables 9.0. Next, we require empirical counterparts for γ^{jk}_n, the Cobb-Douglas share of product j used in production of k in country n. Next we need input-output Cobb-Douglas shares for the countries in our data set. For this we rely on two data sets. First is the WIOD dataset which after dropping agriculture, mining, petroleum, and services allows us to construct a 13 by 13 IO matrix at the NACE level which roughly corresponds to the 2-digit ISIC (revision 3) level. Second we use output from the Industrial Demand-Supply Balance (IDSB) Database at the four-digit ISIC (revision 3) level and a proportionality assumption as in Trefler and Zhu (2010) to contruct the full 116 by 166 IO matrix. We discuss this in detail now.

Let j represent four digit ISIC industries and j' index the two-digit NACE level to which they belong. The WIOD data let us observe $M^{j'k'}$ which is the total amount of good j' used in production of good k'. Define the Cobb-Douglas parameter $\gamma^{j'k'}$ as the share of the total cost of k' that accrues to j'. We want to obtain measures at the four-digit level γ^{jk}. The output side is trivial: we assume that all output industries k inherit the IO structure of the more aggregate industry k' in which they reside. This allows us to write $\gamma^{jk} = \gamma^{jk'}\ \forall k \in k'$. To allocate shares of j' across j, we make a proportionality assumption:

$$\gamma^{jk} = \frac{Q^j_w}{\sum_{j=1}^J Q^j_w}\gamma^{j'k}$$

[59]This crosswalk is available at http://wits.worldbank.org/product_concordance.html.

where Q^j_w is world production of good j. This is equivalent to assuming that the share of inputs provided by industry j to industry k equals the share of inputs provided by industry j' to k times the share of world output of industry j' accounted for by industry j.

B.4 Estimating $\gamma^j_{L,o}$, $\gamma^j_{K,o}$, $\gamma^j_{L,p}$, and $\gamma^j_{K,p}$

The Chinese manufacturing data collected by NBS do not include inputs by organization of production. Because most four-digit ISIC industries in China have strictly positive ordinary *and* processing exports, this means that input data are pooled across organization forms. However, we wish to obtain cost shares for ordinary and processing separately within an industry. We describe here our procedure for obtaining these measures. First, we use the linked Customs to firm-level data that are a product of annual surveys by the National Bureau of Statistics (NBS). This dataset has been used extensively in the China trade literature [e.g. Kee and Tang (2016) and Brandt and Morrow (2017)]. This results in a sub-sample that covers 32 percent of the aggregate export value in 2000 and 37 percent in 2006. We then map the Chinese CIC industrial classification codes to ISIC industries as used in this paper. Let f index $f$irms. At the firm-level we calculate the wage share of output as well as the share of intermediate inputs in production. We represent these as $\gamma^j_{L,ft}$ and $\gamma^j_{m,ft}$ respectively. At the firm level, we then calculate the ordinary share of "production" as $s^j_{ft} \equiv \frac{v^j_{ft} - x^j_{IA,ft} - x^j_{PA,ft}}{v^j_{ft}}$ where v^j_{ft} is total output by firm f residing in ISIC industry j in year t, $x^j_{IA,ft}$ is import and assembly exports at the same level, and $x^j_{PA,ft}$ is pure assembly exports at the same level. We take "processing" to be the sum of pure assembly and import and assembly. We then estimate the following equation at the industry-year level

$$\gamma^j_{L,ft} = \beta^j_t + \gamma^j_t s^j_{ft} + \epsilon^j_{ft}$$

where ϵ^j_{ft} has the usual favorable properties. We weight observations by total firm output. In the manufacturing data, firms are nearly always assigned to one industry (unlike the transactions data). This estimation gives us JT estimates of β^j_t and another JT estimates of γ^j_t. We construct $\widehat{\gamma}^j_{L,ot} \equiv \widehat{\beta}^j_t + \widehat{\gamma}^j_t$ and $\widehat{\gamma}^j_{L,pt} \equiv \widehat{\beta}^j_t$ such that our cost shares are what would be expected from a firm engaging in only ordinary ($s^j_{ft} = 1$) or only processing ($s^j_{ft} = 0$) production. Construction of intermediate inputs' share $\gamma^j_{m,ot}$ follows analogously from a similar regression with $\gamma^j_{m,ft}$ on the left hand side. $\widehat{\gamma}^j_{K,ot}$ is then constructed as $1 - \widehat{\gamma}^j_{L,ot} - \widehat{\gamma}^j_{m,ot}$.

B.5 Measuring X^j_{oo} and X^j_{po}

Recall that X^j_{ni} is sales from i to n of good j. The empirical strategy outlined in section 5 requires some data that is not readily available. Specifically, for each industry j it requires data on sales by ordinary firms to other ordinary firms X^j_{oo}, sales by ordinary firms to processing firms X^j_{po}, sales by processing firms to ordinary firms X^j_{op}, and sales by processing firms to other processing firms X^j_{pp}. We discuss a method to obtain these data that relies on a combination of data identities, input-output data, and identifying restrictions.

In the notation below, a subscript c is for China and is the aggregate of the ordinary and processing sectors. Y_i^j represents total production of j by i, and (with a slight abuse of notation) X_{ni}^j represents total sales of j by i to n. Starting with data identities we obtain expressions where total Chinese production is the sum of ordinary and processing production, and the total value of production equals the sum of sales to each destination:

$$Y_c^j = Y_o^j + Y_p^j$$

$$Y_o^j = \sum_{n=1}^{N} X_{no}^j + X_{oo}^j + X_{po}^j$$

$$Y_p^j = \sum_{n=1}^{N} X_{np}^j + X_{op}^j + X_{pp}^j.$$

With J traded industries, after exploiting the trade data X_{no}^j and X_{np}^j, this gives us $3J$ equations and $6J$ unknowns : Y_o^j, Y_p^j, X_{oo}^j, X_{po}^j, X_{op}^j, X_{pp}^j for each j. Because processing firms are not allowed to sell to ordinary firms, X_{op}^j=0 $\forall\ j$. We also assume that processing firms cannot sell to other processing firms such that X_{pp}^j=0 $\forall\ j$. The first is a legal restriction, the second is an identifying assumption.[60] This gives the following system of equations:

$$Y_c^j = Y_o^j + Y_p^j$$

$$Y_o^j = \sum_{n=1}^{N} X_{no}^j + X_{oo}^j + X_{po}^j$$

$$Y_p^j = \sum_{n=1}^{N} X_{np}^j.$$

Now processing production Y_p^j can be measured by total processing exports $\sum_{n=1}^{N} X_{np}^j$, and ordinary production Y_o^j can be measured as the difference between total production Y_c^j and processing production Y_p^j. This brings us down to one equation and two unknowns for each j, X_{oo}^j and X_{po}^j:

$$Y_o^j - \sum_{n=1}^{N} X_{no}^j = X_{oo}^j + X_{po}^j$$

where we need to decompose total domestic ordinary production into sales to other ordinary firms X_{oo}^j and sales to processing firms X_{po}^j. The final step in this decomposition starts by using

$$\frac{X_{po}^j}{X_{oo}^j} = \frac{X_p^j / \Phi_p^j}{X_o^j / \Phi_o^j} \qquad \text{(A13)}$$

where

$$\Phi_p^j = \lambda_o^j \left(c_o^j \kappa_{po}^j\right)^{-\theta^j} + \sum_{i'=1}^{N} \lambda_{i'}^j \left(c_{i'}^j \kappa_{pi'}^j\right)^{-\theta^j} \qquad \Phi_o^j = \lambda_o^j \left(c_o^j \kappa_{oo}^j\right)^{-\theta^j} + \sum_{i'=1}^{N} \lambda_{i'}^j \left(c_{i'}^j \kappa_{oi'}^j\right)^{-\theta^j}.$$

[60] The latter is not fully true because we know that processing firms *can* sell to other processing firms but we assume that this is small enough to be safely assumed to be zero.

The fact that unit costs of delivery of ordinary goods to both the ordinary and processing sector are identical allows for this expression. Similarly, where W represents the sum of all non-China countries in the world, we can write

$$\frac{X^j_{pW}}{X^j_{oW}} = \frac{\sum_{i=1}^N \lambda^j_i \left(c^j_i \kappa^j_{pi}\right)^{-\theta^j}}{\sum_{i=1}^N \lambda^j_i \left(c^j_i \kappa^j_{oi}\right)^{-\theta^j}} \frac{X^j_p/\Phi^j_p}{X^j_o/\Phi^j_o} \tag{A14}$$

Simple manipulation and the fact that $\frac{\kappa^j_{pi}}{\kappa^j_{oi}} = (1+\tau^j_{ci})^{-1}$ allows us to write

$$\frac{X^j_{pW}}{X^j_{oW}} = \left[\frac{\sum_{i=1}^N (1+\tau^j_{ci})^{\theta^j} X^j_{oi}}{\sum_{i=1}^N X^j_{oi}}\right] \frac{X^j_p/\Phi^j_p}{X^j_o/\Phi^j_o}. \tag{A15}$$

Combining equations (A16) and (A15), we can obtain

$$\frac{X^j_{po}}{X^j_{oo}} = \frac{X^j_{pW}}{X^j_{oW}} \left[\frac{\sum_{i=1}^N (1+\tau^j_{ci})^{\theta^j} X^j_{oi}}{\sum_{i=1}^N X^j_{oi}}\right]^{-1} \tag{A16}$$

The relative domestic shipments of ordinary production to processing and ordinary firms in China $\frac{X^j_{po}}{X^j_{oo}}$ is a function of external shipments into those two sectors in a given industry as well as a weighted average of tariffs where weights correspond to the size of imports from a the country i against whom a tariff τ^j_{ci} is imposed. Intuitively, domestic shipments in China should be more skewed towards processing when the market size is larger (the first term) or when lower average tariffs make those industries more competitive (the second term).

B.6 Price Index and Relative Productivity of Nontraded Sector

To compute the price index of nontraded sector, we collect 1996 and 2011 data from the International Comparison of Prices Program (ICP). The price index of nontraded goods is constructed as the expenditure weighted average of prices in the following sectors: Health, Transport, Communication, Recreation and culture, Education, Restaurants and hotels, and Construction. Using data of PPP-adjusted per capita GDP from the Penn World Tables, we impute the price index for 2000 and 2007 by estimating the following model:

$$\ln p^{J+1}_{nt} = \beta_0 + \beta_1 \ln GDP_{nt} + \beta_2 \ln GDP^2_{nt} + \beta_3 \ln GDP^3_{nt} + \beta_4 \ln GDP^4_{nt} + \beta_5 \mathbf{1}(t=2011) + \varepsilon_{nt}.$$

In particular, the price index of nontraded goods in 2000 is computed as

$$p^{J+1}_{n,00} = \exp[\hat\beta_0 + \hat\beta_1 \ln GDP_{n,00} + \hat\beta_2 \ln GDP^2_{n,00} + \hat\beta_3 \ln GDP^3_{n,00} + \hat\beta_4 \ln GDP^4_{n,00} + \frac{4}{15}\hat\beta_5].$$

Similarly, the price index for 2007 is computed as

$$p^{J+1}_{n,07} = \exp[\hat\beta_0 + \hat\beta_1 \ln GDP_{n,07} + \hat\beta_2 \ln GDP^2_{n,07} + \hat\beta_3 \ln GDP^3_{n,07} + \hat\beta_4 \ln GDP^4_{n,07} + \frac{11}{15}\hat\beta_5].$$

Based on the imputed price indices, the relative productivity of non-traded sector is constructed from (the time index is suppressed):

$$\frac{\lambda_n^{J+1}}{\lambda_{us}^{J+1}} = \left[\left(\frac{w_n}{w_{us}} \right)^{\tilde{\gamma}_{0,n}^{J+1}} \left(\frac{r_n}{r_{us}} \right)^{\tilde{\gamma}_{1,n}^{J+1}} \Pi_{k=1}^{J+1} \left[\frac{p_n^k}{p_{us}^k} \right]^{\tilde{\gamma}^{k,J+1}} \right]^{\theta^{J+1}} \left[\frac{p_n^{J+1}}{p_{us}^{J+1}} \right]^{-\theta^{J+1}}$$

.

B.7 Measuring $(t_i^j/t_{us}^j)^{-\theta^j}$

Recall that the exporter fixed effects in the gravity regression can be categorized as follows:

$$\delta_i^{j,x} = -\ln \left[\left(t_i^j \right)^{-\theta^j} \right] \qquad i = 1,...,N \tag{A17}$$

$$\delta_o^{j,x} \equiv -\ln \left\{ (t_o^j)^{-\theta^j} \left[1 + \left[\frac{\lambda_p^j}{\lambda_o^j} \left(\frac{c_p^j}{c_o^j} \right)^{-\theta^j} \right]^{\frac{1}{1-\nu^j}} \right]^{-\nu^j} \right\} \tag{A18}$$

$$\delta_p^{j,x} \equiv -\ln \left\{ \lambda_p^j (c_p^j)^{-\theta^j} (t_p^j)^{-\theta^j} \left[1 + \left[\frac{\lambda_o^j}{\lambda_p^j} \left(\frac{c_o^j}{c_p^j} \right)^{-\theta^j} \right]^{\frac{1}{1-\nu^j}} \right]^{-\nu^j} \right\}. \tag{A19}$$

For non-China countries, we can exponentiate the estimate $\widehat{\delta}_i^{j,x}$ for $i \neq us$ to obtain a value for t_i^j/t_{us}^j conditional on θ^j:

$$exp\left(-\widehat{\delta}_i^{j,x} \right) = \left(\frac{t_i^j}{t_{us}^j} \right)^{-\theta^j}. \tag{A20}$$

The estimation is less straightforward for China because of the extra terms that appear in equations (A18) and (A19) that do not appear in (A17). To solve this, we impose the assumption that $t_o^j = t_p^j$ and refer to this common term as t_c^j. With the estimates of $\frac{\lambda_p^j}{\lambda_o^j} \left(\frac{c_p^j}{c_o^j} \right)^{-\theta^j}$ from equation (18) and the estimate of $\widehat{\delta}_o^{j,x}$, we can back out $\left(\frac{t_c^j}{t_{us}^j} \right)^{-\theta^j}$ from equation (A18).

B.8 Roundabout Shipping Data Construction

This appendix describes our estimation strategy for the case that processing firms can sell their products to China's market through roundabout trade. More specifically, they can ship their products out of China, and then re-sell the products back to China. If they sell to domestic ordinary firms, they incur both roundabout transportation cost and import tariffs. If they sell to domestic processing firms, they only incur the associated transportation cost.

Measuring X^j_{oo}, X^j_{po}, and X^j_{op}

If we allow processing firms to sell back to China through round-about trade, π^j_{op} and π^j_{pp} are no longer zero, and they are given by

$$\pi^j_{oo} = \frac{(\lambda^j_o)^{\frac{1}{1-\nu^j}} \left(c^j_o \kappa^j_{oo}\right)^{-\frac{\theta^j}{1-\nu^j}}}{(\lambda^j_o)^{\frac{1}{1-\nu^j}} \left(c^j_o \kappa^j_{oo}\right)^{-\frac{\theta^j}{1-\nu^j}} + (\lambda^j_p)^{\frac{1}{1-\nu^j}} \left(c^j_p \kappa^j_{op}\right)^{-\frac{\theta^j}{1-\nu^j}}} \times \frac{\left[(\lambda^j_o)^{\frac{1}{1-\nu^j}} \left(c^j_o \kappa^j_{oo}\right)^{-\frac{\theta^j}{1-\nu^j}} + (\lambda^j_p)^{\frac{1}{1-\nu^j}} \left(c^j_p \kappa^j_{op}\right)^{-\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j}}{\Phi^j_o}. \tag{A21}$$

$$\pi^j_{po} = \frac{(\lambda^j_o)^{\frac{1}{1-\nu^j}} \left(c^j_o \kappa^j_{po}\right)^{-\frac{\theta^j}{1-\nu^j}}}{(\lambda^j_o)^{\frac{1}{1-\nu^j}} \left(c^j_o \kappa^j_{po}\right)^{-\frac{\theta^j}{1-\nu^j}} + (\lambda^j_p)^{\frac{1}{1-\nu^j}} \left(c^j_p \kappa^j_{pp}\right)^{-\frac{\theta^j}{1-\nu^j}}} \times \frac{\left[(\lambda^j_o)^{\frac{1}{1-\nu^j}} \left(c^j_o \kappa^j_{po}\right)^{-\frac{\theta^j}{1-\nu^j}} + (\lambda^j_p)^{\frac{1}{1-\nu^j}} \left(c^j_p \kappa^j_{pp}\right)^{-\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j}}{\Phi^j_p}. \tag{A22}$$

$$\pi^j_{op} = \frac{(\lambda^j_p)^{\frac{1}{1-\nu^j}} \left(c^j_p \kappa^j_{op}\right)^{-\frac{\theta^j}{1-\nu^j}}}{(\lambda^j_o)^{\frac{1}{1-\nu^j}} \left(c^j_o \kappa^j_{oo}\right)^{-\frac{\theta^j}{1-\nu^j}} + (\lambda^j_p)^{\frac{1}{1-\nu^j}} \left(c^j_p \kappa^j_{op}\right)^{-\frac{\theta^j}{1-\nu^j}}} \times \frac{\left[(\lambda^j_o)^{\frac{1}{1-\nu^j}} \left(c^j_o \kappa^j_{oo}\right)^{-\frac{\theta^j}{1-\nu^j}} + (\lambda^j_p)^{\frac{1}{1-\nu^j}} \left(c^j_p \kappa^j_{op}\right)^{-\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j}}{\Phi^j_o}. \tag{A23}$$

$$\pi^j_{pp} = \frac{(\lambda^j_p)^{\frac{1}{1-\nu^j}} \left(c^j_p \kappa^j_{pp}\right)^{-\frac{\theta^j}{1-\nu^j}}}{(\lambda^j_o)^{\frac{1}{1-\nu^j}} \left(c^j_o \kappa^j_{po}\right)^{-\frac{\theta^j}{1-\nu^j}} + (\lambda^j_p)^{\frac{1}{1-\nu^j}} \left(c^j_p \kappa^j_{pp}\right)^{-\frac{\theta^j}{1-\nu^j}}} \times \frac{\left[(\lambda^j_o)^{\frac{1}{1-\nu^j}} \left(c^j_o \kappa^j_{po}\right)^{-\frac{\theta^j}{1-\nu^j}} + (\lambda^j_p)^{\frac{1}{1-\nu^j}} \left(c^j_p \kappa^j_{pp}\right)^{-\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j}}{\Phi^j_p}. \tag{A24}$$

Note that $\kappa^j_{op} = \kappa^j_{pp}(1 + \tau^j_{cp})$, where τ^j_{cp} denotes the tariff imposed on processing goods that re-enter China. (The empirical counterpart of τ^j_{cp} is the MFN tariff imposed on good j by China.) κ^j_{pp} captures transportation costs associated with two times the spatial distance between Hong Kong and Shanghai.[61] Similar to our baseline analysis, we assume that $\kappa^j_{oo} = \kappa^j_{po} = 1$. The remaining gravity equations are the same as our baseline case. With these relationships, we can derive the following equations.

$$\frac{X^j_{po}}{X^j_{oo}} = \left(\frac{X^j_{oo} + X^j_{op}}{X^j_{po} + X^j_{pp}}\right)^{\frac{\nu^j}{1-\nu^j}} \left(\frac{X^j_{pW}}{X^j_{oW}}\right)^{\frac{1}{1-\nu^j}} \left[\frac{\sum_{i=1}^N (1 + \tau^j_{ci})^{\theta^j} X^j_{oi}}{\sum_{i=1}^N X^j_{oi}}\right]^{-\frac{1}{1-\nu^j}} \tag{A25}$$

[61] We assume that transportation cost incurred by the roundabout trade equals to the shipping cost along the route Shanghai – Hong Kong – Shanghai.

$$\frac{X^j_{pp}}{X^j_{op}} = \left(\frac{X^j_{oo} + X^j_{op}}{X^j_{po} + X^j_{pp}}\right)^{\frac{\nu^j}{1-\nu^j}} \left(\frac{X^j_{pW}}{X^j_{oW}}\right)^{\frac{1}{1-\nu^j}} \left[\frac{\sum_{i=1}^N (1+\tau^j_{ci})^{\theta^j} X^j_{oi}}{\sum_{i=1}^N X^j_{oi}}\right]^{-\frac{1}{1-\nu^j}} \left(1+\tau^j_{cp}\right)^{\frac{\theta^j}{1-\nu^j}} \tag{A26}$$

To back out X^j_{oo}, X^j_{po}, and X^j_{op}, we use equations (A25) and (A26) and the following identity equations:

$$Y^j_c = Y^j_o + Y^j_p \tag{A27}$$

$$Y^j_o = \sum_{n=1}^N X^j_{no} + X^j_{oo} + X^j_{po} = X^j_{Wo} + X^j_{oo} + X^j_{po} \tag{A28}$$

$$Y^j_p = \sum_{n=1}^N X^j_{np} + X^j_{op} + X^j_{pp} = X^j_{Wp} + X^j_{op} + X^j_{pp} \tag{A29}$$

We calculate X^j_{pp}, i.e., total value shipment of processing sector to itself, from the customs transaction-level data. Together with the information on X^j_{Wo}, X^j_{Wp}, τ^j_{ci}, τ^j_{cp}, and Y^j_c, we can solve for X^j_{oo}, X^j_{po}, X^j_{op}, Y^j_o and Y^j_p from equations (A25)-(A29).

Measuring λ^j_o, λ^j_p, and t^j_c

We run the gravity equation (15) in the main text. In this case, π^j_{pi}/π^j_{pp} is well-defined, and hence we can simultaneous back out $\hat{\delta}^j_p$ and $\hat{\delta}^{j,x}_p$. More importantly, with round-about trade, the interpretations of the estimated fixed effects for processing and ordinary sectors are different:

$$\widehat{\delta}^j_o = \ln\left(\left[\lambda^j_o\right]^{\frac{1}{1-\nu^j}} \left[c^j_o\right]^{-\frac{\theta^j}{1-\nu^j}} \left[\left[\lambda^j_o\right]^{\frac{1}{1-\nu^j}} \left[c^j_o\right]^{-\frac{\theta^j}{1-\nu^j}} + \left[\lambda^j_p\right]^{\frac{1}{1-\nu^j}} \left[c^j_p \kappa^j_{op}\right]^{-\frac{\theta^j}{1-\nu^j}}\right]^{-\nu^j}\right) \tag{A30}$$

$$\widehat{\delta}^j_p = \ln\left(\left[\lambda^j_p\right]^{\frac{1}{1-\nu^j}} \left[c^j_p \kappa^j_{pp}\right]^{-\frac{\theta^j}{1-\nu^j}} \left[\left[\lambda^j_o\right]^{\frac{1}{1-\nu^j}} \left[c^j_o\right]^{-\frac{\theta^j}{1-\nu^j}} + \left[\lambda^j_p\right]^{\frac{1}{1-\nu^j}} \left[c^j_p \kappa^j_{pp}\right]^{-\frac{\theta^j}{1-\nu^j}}\right]^{-\nu^j}\right) \tag{A31}$$

$$\widehat{\delta}^{j,x}_o = -\ln\left(\left[t^j_o\right]^{-\theta^j} \left[\frac{\left[\lambda^j_o\right]^{\frac{1}{1-\nu^j}} \left[c^j_o\right]^{-\frac{\theta^j}{1-\nu^j}} + \left[\lambda^j_p\right]^{\frac{1}{1-\nu^j}} \left[c^j_p\right]^{-\frac{\theta^j}{1-\nu^j}}}{\left[\lambda^j_o\right]^{\frac{1}{1-\nu^j}} \left[c^j_o\right]^{-\frac{\theta^j}{1-\nu^j}} + \left[\lambda^j_p\right]^{\frac{1}{1-\nu^j}} \left[c^j_p \kappa^j_{op}\right]^{-\frac{\theta^j}{1-\nu^j}}}\right]^{-\nu^j}\right) \tag{A32}$$

$$\widehat{\delta}^{j,x}_p = -\ln\left(\left[t^j_p\right]^{-\theta^j} \left[\kappa^j_{pp}\right]^{\frac{\theta^j}{1-\nu^j}} \left[\frac{\left[\lambda^j_o\right]^{\frac{1}{1-\nu^j}} \left[c^j_o\right]^{-\frac{\theta^j}{1-\nu^j}} + \left[\lambda^j_p\right]^{\frac{1}{1-\nu^j}} \left[c^j_p\right]^{-\frac{\theta^j}{1-\nu^j}}}{\left[\lambda^j_o\right]^{\frac{1}{1-\nu^j}} \left[c^j_o\right]^{-\frac{\theta^j}{1-\nu^j}} + \left[\lambda^j_p\right]^{\frac{1}{1-\nu^j}} \left[c^j_p \kappa^j_{pp}\right]^{-\frac{\theta^j}{1-\nu^j}}}\right]^{-\nu^j}\right) \tag{A33}$$

We can solve for λ^j_o and λ^j_p from equations (A30) and (A31). As in our baseline analysis, we impose the restriction that $t^j_o = t^j_p = t^j_c$. The solution for t^j_c is the minimum distance estimator for equations (A32) and (A33). The calibration for λ^j_i and t^j_i for countries in the ROW remain the same as our baseline analysis.

Appendix C. Solution Algorithm

With parameters θ^j, ν (for a constant ν) , $\gamma^j_{L,n}$, $\gamma^j_{K,n}$, γ^{jk}_n, α^j, L_n and K_n, and estimates of $\tilde{\lambda}^j_n \equiv \frac{\lambda^j_i}{\lambda^j_{us}}$ and κ_{ni} ($i = 1,...,N$), we can solve the model using the following solution algorithm:

(1) Guess $\{w_n, r_n\}^{N,c}_{n=1}$. (Normalizing $w_{us} = 1$.)

- Solve prices P^j_n and variable production costs c^j_n from the following equations:

$$c^j_n \equiv \Upsilon^j_n w_n^{\gamma^j_{L,n}} r_n^{\gamma^j_{K,n}} \Pi^{J+1}_{k=1} [p^k_n]^{\gamma^{kj}_n} \quad \text{for all } n = 1,...,N,o \text{ and } j$$

For $j = 1,...,J$,

$$\begin{cases} p^j_n = \left[\left((\tilde{\lambda}^j_o)^{\frac{1}{1-\nu}} \left(c^j_o \kappa^j_{no} \right)^{-\frac{\theta^j}{1-\nu}} + (\tilde{\lambda}^j_p)^{\frac{1}{1-\nu}} \left(c^j_p \kappa^j_{np} \right)^{-\frac{\theta^j}{1-\nu}} \right)^{1-\nu} + \sum_{i=1}^N \tilde{\lambda}^j_i \left(c^j_i \kappa^j_{ni} \right)^{-\theta^j} \right]^{-\frac{1}{\theta^j}} & \forall n \neq o,p \\ p^j_o = \left[(\tilde{\lambda}^j_o) \left(c^j_o \kappa^j_{oo} \right)^{-\theta^j} + \sum_{i=1}^N \tilde{\lambda}^j_i \left(c^j_i \kappa^j_{oi} \right)^{-\theta^j} \right]^{-\frac{1}{\theta^j}} \\ p^j_p = \left[(\tilde{\lambda}^j_o) \left(c^j_o \kappa^j_{po} \right)^{-\theta^j} + \sum_{i=1}^N \tilde{\lambda}^j_i \left(c^j_i \kappa^j_{pi} \right)^{-\theta^j} \right]^{-\frac{1}{\theta^j}} \end{cases}$$

For $j = J + 1$,

$$\begin{cases} p^{J+1}_n = \left[\tilde{\lambda}^{J+1}_n \left(c^{J+1}_n \right)^{-\theta^{J+1}} \right]^{-\frac{1}{\theta^{J+1}}} & \forall n \neq o,p \\ p^{J+1}_o = \left[\tilde{\lambda}^{J+1}_o \left(c^{J+1}_o \right)^{-\theta^{J+1}} \right]^{-\frac{1}{\theta^{J+1}}} \\ p^{J+1}_p = +\infty \end{cases}$$

- Compute the expenditure on different goods as follows: for any country $n \neq o,p$

$$\begin{cases} \pi^j_{ni} = \frac{\tilde{\lambda}^j_i (c^j_i \kappa^j_{ni})^{-\theta^j}}{\left[(\tilde{\lambda}^j_o)^{\frac{1}{1-\nu}} \left(c^j_o \kappa^j_{no} \right)^{\frac{-\theta^j}{1-\nu}} + (\tilde{\lambda}^j_p)^{\frac{1}{1-\nu}} \left(c^j_p \kappa^j_{np} \right)^{\frac{-\theta^j}{1-\nu}} \right]^{1-\nu} + \sum_{i'=1}^N \tilde{\lambda}^j_{i'} \left(c^j_{i'} \kappa^j_{ni'} \right)^{-\theta^j}} & \forall n \neq o,p \\ \pi^j_{no} = \frac{(\tilde{\lambda}^j_o)^{\frac{1}{1-\nu}} \left(c^j_o \kappa^j_{no} \right)^{-\frac{\theta^j}{1-\nu}}}{(\tilde{\lambda}^j_o)^{\frac{1}{1-\nu}} \left(c^j_o \kappa^j_{no} \right)^{\frac{-\theta^j}{1-\nu}} + (\tilde{\lambda}^j_p)^{\frac{1}{1-\nu}} \left(c^j_p \kappa^j_{np} \right)^{\frac{-\theta^j}{1-\nu}}} \frac{\left[(\tilde{\lambda}^j_o)^{\frac{1}{1-\nu}} \left(c^j_o \kappa^j_{no} \right)^{\frac{-\theta^j}{1-\nu}} + (\tilde{\lambda}^j_p)^{\frac{1}{1-\nu}} \left(c^j_p \kappa^j_{np} \right)^{\frac{-\theta^j}{1-\nu}} \right]^{1-\nu}}{\left[(\tilde{\lambda}^j_o)^{\frac{1}{1-\nu}} \left(c^j_o \kappa^j_{no} \right)^{\frac{-\theta^j}{1-\nu}} + (\tilde{\lambda}^j_p)^{\frac{1}{1-\nu}} \left(c^j_p \kappa^j_{np} \right)^{\frac{-\theta^j}{1-\nu}} \right]^{1-\nu} + \sum_{i'=1}^N \tilde{\lambda}^j_{i'} \left(c^j_{i'} \kappa^j_{ni'} \right)^{-\theta^j}} \\ \pi^j_{np} = \frac{(\tilde{\lambda}^j_p)^{\frac{1}{1-\nu}} \left(c^j_p \kappa^j_{np} \right)^{-\frac{\theta^j}{1-\nu}}}{(\tilde{\lambda}^j_o)^{\frac{1}{1-\nu}} \left(c^j_o \kappa^j_{no} \right)^{\frac{-\theta^j}{1-\nu}} + (\tilde{\lambda}^j_p)^{\frac{1}{1-\nu}} \left(c^j_p \kappa^j_{np} \right)^{\frac{-\theta^j}{1-\nu}}} \frac{\left[(\tilde{\lambda}^j_o)^{\frac{1}{1-\nu}} \left(c^j_o \kappa^j_{no} \right)^{\frac{-\theta^j}{1-\nu}} + (\tilde{\lambda}^j_p)^{\frac{1}{1-\nu}} \left(c^j_p \kappa^j_{np} \right)^{\frac{-\theta^j}{1-\nu}} \right]^{1-\nu}}{\left[(\tilde{\lambda}^j_o)^{\frac{1}{1-\nu}} \left(c^j_o \kappa^j_{no} \right)^{\frac{-\theta^j}{1-\nu}} + (\tilde{\lambda}^j_p)^{\frac{1}{1-\nu}} \left(c^j_p \kappa^j_{np} \right)^{\frac{-\theta^j}{1-\nu}} \right]^{1-\nu} + \sum_{i'=1}^N \tilde{\lambda}^j_{i'} \left(c^j_{i'} \kappa^j_{ni'} \right)^{-\theta^j}} \end{cases}$$

For $n = o$,

$$\begin{cases} \pi^j_{oi} = \frac{\tilde{\lambda}^j_i (c^j_i \kappa^j_{oi})^{-\theta^j}}{\tilde{\lambda}^j_o \left(c^j_o \kappa^j_{oo} \right)^{-\theta^j} + \sum_{i'=1}^N \tilde{\lambda}^j_{i'} \left(c^j_{i'} \kappa^j_{oi'} \right)^{-\theta^j}} & \forall i \neq o,p \text{ and } j \\ \pi^j_{oo} = \frac{\tilde{\lambda}^j_o (c^j_o \kappa^j_{oo})^{-\theta^j}}{\tilde{\lambda}^j_o \left(c^j_o \kappa^j_{oo} \right)^{-\theta^j} + \sum_{i'=1}^N \tilde{\lambda}^j_{i'} \left(c^j_{i'} \kappa^j_{oi'} \right)^{-\theta^j}} & \forall j \\ \pi^j_{op} = 0 \quad \forall j \end{cases}$$

For $n = p$,

$$\begin{cases} \pi_{pi}^j = \frac{\tilde{\lambda}_i^j (c_i^j \kappa_{pi}^j)^{-\theta^j}}{\tilde{\lambda}_o^j \left(c_o^j \kappa_{po}^j\right)^{-\theta^j} + \sum_{i'=1}^N \tilde{\lambda}_{i'}^j \left(c_{i'}^j \kappa_{pi'}^j\right)^{-\theta^j}} & \forall i \neq o,p \text{ and } j \\ \pi_{po}^j = \frac{\tilde{\lambda}_o^j (c_o^j \kappa_{po}^j)^{-\theta^j}}{\tilde{\lambda}_o^j \left(c_o^j \kappa_{po}^j\right)^{-\theta^j} + \sum_{i'=1}^N \tilde{\lambda}_{i'}^j \left(c_{i'}^j \kappa_{pi'}^j\right)^{-\theta^j}} & \forall j \\ \pi_{pp}^j = 0 \quad \forall j \end{cases}$$

- Solve total demand from the following equations: for $n \neq o,p$,

$$X_n^j = \alpha_n^j \left(w_n L_n + r_n K_n + \sum_{j=1}^{J+1} \sum_{i=1}^{N+2} \tau_{ni}^j X_n^j \frac{\pi_{ni}^j}{1+\tau_{ni}^j} \right) + \sum_{k=1}^{J+1} \gamma_n^{jk} \sum_{i=1}^{N+2} X_i^k \frac{\pi_{in}^k}{1+\tau_{in}^k} \quad \forall j$$

For $n = o$,

$$X_o^j = \alpha_c^j \left(w_c L_c + r_c K_c + \sum_{j=1}^{J+1} \sum_{i=1}^{N+1} \tau_{oi}^j X_o^j \frac{\pi_{oi}^j}{1+\tau_{oi}^j} \right) + \sum_{k=1}^{J+1} \gamma_o^{jk} \sum_{i=1}^{N+2} X_i^k \frac{\pi_{io}^k}{1+\tau_{io}^k} \quad \forall j$$

For $n = p$,

$$X_p^j = \sum_{k=1}^{J+1} \gamma_p^{jk} \sum_{i=1}^{N} X_i^k \frac{\pi_{ip}^k}{1+\tau_{ip}^k} \quad \forall j$$

(2) Update $\{w_n', r_n'\}_{n=1}^{N,c}$ with the labor and capital clearing conditions:

$$\begin{cases} \sum_{j=1}^{J+1} \gamma_{L,n}^j \sum_{i=1}^{N+2} X_i^j \frac{\pi_{in}^j}{1+\tau_{in}^j} = w_n' L_n & \text{if } n \neq c \\ \sum_{j=1}^{J+1} \gamma_{L,o}^j \sum_{i=1}^{N+2} X_i^j \frac{\pi_{io}^j}{1+\tau_{io}^j} + \sum_{j=1}^{J} \gamma_{L,p}^j \sum_{i=1}^{N} X_i^j \frac{\pi_{ip}^j}{1+\tau_{ip}^j} = w_c' L_c & \text{if } n = c \end{cases}$$

and

$$\begin{cases} \sum_{j=1}^{J+1} \gamma_{K,n}^j \sum_{i=1}^{N+2} X_i^j \frac{\pi_{in}^j}{1+\tau_{in}^j} = r_n' K_n & \text{if } n \neq c \\ \sum_{j=1}^{J+1} \gamma_{K,o}^j \sum_{i=1}^{N+2} X_i^j \frac{\pi_{io}^j}{1+\tau_{io}^j} + \sum_{j=1}^{J} \gamma_{K,p}^j \sum_{i=1}^{N} X_i^j \frac{\pi_{ip}^j}{1+\tau_{ip}^j} = r_c' K_c & \text{if } n = c \end{cases}$$

(3) Repeat the above procedures until $\{w_n', r_n'\}_{n=1}^{N,c}$ equals $\{w_n, r_n\}_{n=1}^{N,c}$.

Appendix D. Hsieh-Ossa Model

A. Setup

Unless otherwise noted, notation is the same as in out baseline model. In addition to China, there are N countries indexed by i,n,m. In China, ordinary and processing are indexed o and p, respectively. For the sake of indexing, ordinary is the $N+1^{th}$ "country" and processing is the $N+2^{th}$. c indexes China specific variables common to both ordinary and processing. Industries are indexed by k,j with J traded industries as well as one non-traded industry for a total of $J+1$ industries. Within each country-industry pair i,j, a continuum of monopolistically competitive firms each produce a horizontally differentiated variety indexed ω_i^j. The mass of varieties delivered to a given destination n is an endogenous outcome whose value is represented M_{ni}^j. We analyze the "long-run" version of the model in which the mass of entrants $M_i^{e,j}$ is endogenous and profits are zero.

Utility for a representative consumer in n is given by

$$U_n = \prod_{j=1}^{J+1} \left(\sum_{i=1}^{N,c} \int_0^{M_{ni}^j} x_{ni}^{F,j}(\omega_i^j)^{\frac{\sigma^j-1}{\sigma^j}} d\omega_i^j \right)^{\frac{\sigma^j}{\sigma^j-1}\alpha_n^j},$$

where $x_{ni}^{F,j}$ represents final consumption of a given variety of j from i consumed in n, α_n^j denotes the consumption share of different goods. σ^j is the elasticity of substitution in consumption in industry j. Production is Cobb-Douglas in labor, capital and intermediate consumption. The aggregate input specific to industry j in country i is given by:

$$I_i^j = \left(\frac{1}{\eta_i^j} \left(\frac{L_i^j}{\gamma_{L,i}^j} \right)^{\gamma_{L,i}^j} \left(\frac{K_i^j}{\gamma_{K,i}^j} \right)^{\gamma_{K,i}^j} \right)^{\eta_i^j} \left(\frac{H_i^j}{1-\eta_i^j} \right)^{1-\eta_i^j},$$

where $\gamma_{L,i}^j + \gamma_{K,i}^j = 1$ and H_i^j is required intermediate consumption defined using a two tier Cobb-Douglas-CES aggregator:

$$H_n^j \equiv \prod_{k=1}^{J+1} \left(\sum_{i=1}^{N,c} \int_0^{M_{ni}^k} h_{ni}^{kj}(\omega_i^k)^{\frac{\sigma^j-1}{\sigma^j}} d\omega_i^k \right)^{\frac{\sigma^j}{\sigma^j-1}\gamma_n^{kj}},$$

where $\sum_k \gamma_n^{kj} = 1$. The cost of the aggregate input bundle is then given by

$$c_n^j = \left(w_n^{\gamma_{L,n}^j} r_n^{\gamma_{K,n}^j} \right)^{\eta_n^j} \prod_{k=1}^{J+1} (p_n^j)^{(1-\eta_n^j)\gamma_n^{kj}}. \tag{A34}$$

B. Firm Heterogeneity.

Firm heterogeneity by the following production process. Entrants in country i-sector j have to hire $f_i^{e,j}$ units of I_i^j to draw productivities z from Pareto distributions: $G_i^j(z) = 1 - \left(\frac{\lambda_i^j}{z}\right)^{\theta^j}$ where λ_i^j is the Pareto location parameter, and θ^j is the shape parameter. As in Hsieh and Ossa (2016), entrants into industry j of country i wishing to sell in country n further need to hire $(x^j_{ni}\kappa^j_{ni})/\left[z(1+\tau^j_{ni})\right]$ units of I^j_i and f^j_{ni} units of I^j_n to deliver x^j_{ni} units of output to country n where f^j_{ni} is a fixed marketing cost of serving country n. We divide by the tariff as we need to remove the tariff from the trade cost to obtain the iceberg cost. As in Hsieh and Ossa (2016), marketing costs are paid in units of the destination country aggregate. Entrants in China and sector j hire $f^{e,j}_o$ units of I^j_o to draw a vector of productivity $\{z_o,z_p\}$ from a multivariate Pareto distribution: $G^j_c(z_o,z_p) = 1-\left[\left(\lambda^j_o/z_o\right)^{\frac{\theta^j}{1-\nu^j}}+\left(\lambda^j_p/z_p\right)^{\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j}$ where ν^j governs the correlation of productivity draws as in our benchmark model. As before, λ^j_p and λ^j_p govern the location of the distribution while θ^j is the shape parameter.

C. Distribution of unit cost of selling to market n,j

Define $\varphi^j_{ni} \equiv \frac{z}{c^j_i\kappa^j_{ni}}$ as the inverse unit cost of delivering a unit of a variety of j from i to n, and κ^j_{ni} is as previousy defined. For firms in i selling to n, the CDF of φ^j_{ni} is $G^j_{ni}(\varphi^j_{ni}) = 1-\left(\frac{b^j_{ni}}{\varphi^j_{ni}}\right)^{\theta^j}$ where $b^j_{ni} \equiv \frac{\lambda^j_i}{c^j_i\kappa^j_{ni}}$. For firms in China, the inverse unit costs associated with o and p have the joint distribution $G^j_{nc}(\varphi^j_{no},\varphi^j_{np}) = 1-\left[\left(\frac{b^j_{no}}{\varphi^j_{no}}\right)^{\frac{\theta^j}{1-\nu^j}}+\left(\frac{b^j_{np}}{\varphi^j_{np}}\right)^{\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j}$ where $b^j_{no} = \frac{\lambda^j_o}{c^j_o\kappa^j_{nc}}$ and $b^j_{np} = \frac{\lambda^j_p}{c^j_p\kappa^j_{nc}}$.

D. Expenditure

Define X^j_{in} as the value of industry j trade flows from n to i. Total expenditure on industry j varieties in country $i \in \{1,...,N\}$ (outside China) is given by $E^j_i = \sum_{n=1}^{N+2} X^j_{in}$. E^j_i can be decomposed analogously to equation (23) in Hsieh and Ossa (2016) as follows:

$$\begin{aligned}E^j_i &= \alpha^j_i\left[\sum_{k=1}^{J+1}\left(\frac{w_iL^k_i}{\gamma^k_{L,i}}+M^{k,e}_i\bar{\pi}^k_i\right)+\sum_{m=1}^{N+2}\sum_{k=1}^{J+1}\frac{\tau^k_{im}X^k_{im}}{1+\tau^k_{im}}-\Omega_i\right]+\sum_{k=1}^{J+1}\gamma^{jk}_i\frac{1-\eta^k_i}{\eta^k_i}\frac{w_iL^k_i}{\gamma^k_{L,i}}\\&=\alpha^j_i\left[\sum_{k=1}^{J+1}\frac{w_iL^k_i}{\gamma^k_{L,i}}+\sum_{m=1}^{N+2}\sum_{k=1}^{J+1}\frac{\tau^k_{im}X^k_{im}}{1+\tau^k_{im}}-\Omega_i\right]+\sum_{k=1}^{J+1}\gamma^{jk}_i\frac{1-\eta^k_i}{\eta^k_i}\frac{w_iL^k_i}{\gamma^k_{L,i}}.\end{aligned} \tag{A35}$$

where all labor income, capital income, and profit income is distributed to households who are further assumed to make a transfer Ω_i which can be positive or negative, and satisfies $\sum_i^{N+2}\Omega_i = 0$ and $\Omega_p+\Omega_o = \Omega_c$ which is the Chinese trade surplus. The last equality follows because $\bar{\pi}^k_i$ is zero in the long run. For these countries, the transfer takes the same form as in Hsieh and Ossa (2016):

$$\Omega_i = \sum_{j=1}^{J+1}\frac{(1+\theta^j)(\sigma^j-1)}{\theta^j\sigma^j}\left(\sum_{n=1}^{N+2}\frac{X^j_{ni}}{1+\tau^j_{ni}}-\sum_{m=1}^{N+2}\frac{X^j_{im}}{1+\tau^j_{im}}\right) \qquad \forall i = 1,...,N.$$

The expenditure in China receives different treatments because processing sector is restricted from selling to the domestic market. For ordinary sector in China, we can define expenditure as $E_o^j = \sum_{m=1}^{N+2} X_{om}^j$ or

$$E_o^j = \alpha_c^j \left(\sum_{k=1}^{J+1} \left(\frac{w_c L_o^k}{\gamma_{L,o}^k} + \frac{w_c L_p^k}{\gamma_{L,p}^k} \right) + \sum_{m=1}^{N+2} \sum_{k=1}^{J+1} \frac{\tau_{om}^k X_{om}^k}{1+\tau_{om}^k} + \sum_{m=1}^{N+2} \sum_{k=1}^{J+2} \frac{\tau_{pm}^k X_{pm}^k}{1+\tau_{pm}^k} - \Omega_o \right) + \sum_{k=1}^{J+1} \gamma_o^{jk} \frac{1-\eta_o^k}{\eta_o^k} \frac{w_c L_o^k}{\gamma_{L,o}^k}, \tag{A36}$$

where the third term in parentheses will equal zero when processing has a tariff exemption, and as follows for expenditure in the processing sector, $E_p^j = \sum_{m=1}^{N+2} X_{pm}^j$,

$$E_p^j = \sum_{m=1}^{N+2} X_{pm}^j = -\alpha_c^j \Omega_p + \sum_{k=1}^{J+1} \gamma_p^{jk} \frac{1-\eta_p^k}{\eta_p^k} \frac{w_c L_p^k}{\gamma_{L,p}^k}. \tag{A37}$$

Ω_o is distinct from Ω_p because the transfer to Chinese consumers cannot be spent on processing output. The expressions for transfers Ω_o and Ω_p take the following form:

$$\Omega_o + \Omega_p = \sum_{j=1}^{J+1} \frac{(1+\theta^j)(\sigma^j-1)}{\theta^j \sigma^j} \left(\sum_{n=1}^{N+2} \frac{X_{no}^j}{1+\tau_{nc}^j} - \sum_{n=1}^{N+2} \frac{X_{on}^j}{1+\tau_{on}^j} \right) + \sum_{j=1}^{J+1} \frac{(1+\theta^j)(\sigma^j-1)}{\theta^j \sigma^j} \left(\sum_{n=1}^{N+2} \frac{X_{np}^j}{1+\tau_{nc}^j} - \sum_{n=1}^{N+2} \frac{X_{pn}^j}{1+\tau_{pn}^j} \right)$$

$$\Omega_p = \sum_{j=1}^{J+1} (1-\eta_p^j) \left[\frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{np}^j}{1+\tau_{nc}^j} + \frac{\theta^j - \sigma^j + 1}{\theta^j \sigma^j} \sum_{n=1}^{N+2} \frac{X_{pn}^j}{1+\tau_{pn}^j} \right] - \sum_{j=1}^{J} \sum_{n=1}^{N+2} X_{pn}^j,$$

with Ω_o easily calculated. It is easy to see that $\Omega_o + \Omega_p$ is simply the Chinese analog of the transfer based on China's *aggregate* trade surplus.

E. Cutoff Productivities

For each origin-destination pair i,n, there is a marketing cost given by $c_n^j f_{ni}^j$ that operates at a fixed cost. With CES monopolistic competition, free entry implies zero profits. With a continuum of firms and Pareto productivity draws, there is a unique cutoff inverse unit cost φ_{ni}^{*j} for each origin-destination-sector triplet i,n,j that represents the inverse unit cost of a firm whose revenue just covers its marketing cost in destination market n,j for firms from i:

$$\varphi_{ni}^{*j} = \left(\frac{\sigma^j c_n^j f_{ni}^j (1+\tau_{ni}^j)}{E_n^j} \right)^{\frac{1}{\sigma^j - 1}} \frac{\sigma^j}{\sigma^j - 1} \frac{1}{p_n^j}.$$

The mass of firms serving market n,j is given by $M_{ni}^j = M_{ni}^e Prob(\varphi_{ni}^j > \varphi_{ni}^{*j}) = M_{ni}^e \left(\frac{b_{ni}^j}{\varphi_{ni}^{*j}} \right)^{\theta^j}$. The mass of entrants in China is given by $M_c^{e,j}$. Each firm supplies a variety of j to market n if export revenue exceeds marketing cost $c_n^j f_{nc}^j$. Whether or not a firm sorts into ordinary or processing depends on the unit costs of the two organizational forms. Let $\varphi^j_{nc} \equiv \max\left(\varphi^j_{no}, \varphi^j_{np}\right)$. φ^j_{nc} then possesses the following CDF:

$$G^j_{nc}(\varphi^j_{nc}) = 1 - \left[\left(b^j_{no}\right)^{\frac{\theta^j}{1-\nu^j}} + \left(b^j_{np}\right)^{\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j} \left(\varphi^j_{nc}\right)^{-\theta^j} = 1 - \left(\frac{b^j_{nc}}{\varphi^j_{nc}}\right)^{\theta^j}.$$

where

$$b^j_{nc} \equiv \left[\left(b^j_{no}\right)^{\frac{\theta^j}{1-\nu^j}} + \left(b^j_{np}\right)^{\frac{\theta^j}{1-\nu^j}}\right]^{\frac{1-\nu^j}{\theta^j}} = \left[\left(\frac{\lambda^j_o}{c^j_o \kappa^j_{no}}\right)^{\frac{\theta^j}{1-\nu^j}} + \left(\frac{\lambda^j_p}{c^j_p \kappa^j_{np}}\right)^{\frac{\theta^j}{1-\nu^j}}\right]^{\frac{1-\nu^j}{\theta^j}}.$$

Similarly we can define a single cutoff productivity in China for exporting varieties of industry j to market n:

$$\varphi^{*j}_{nc} = \left(\frac{\sigma^j c^j_n f^j_{nc}(1+\tau^j_{nc})}{E^j_n}\right)^{\frac{1}{\sigma^j-1}} \frac{\sigma^j}{\sigma^j-1}\frac{1}{p^j_n}.$$

The share of Chinese firms exporting to market n,j through processing trade is given by $s^j_{np} = \frac{\left(b^j_{np}\right)^{\frac{\theta^j}{1-\nu^j}}}{\left(b^j_{no}\right)^{\frac{\theta^j}{1-\nu^j}} + \left(b^j_{np}\right)^{\frac{\theta^j}{1-\nu^j}}}$, and the share of firms exporting through ordinary is its complement, $s^j_{no} = 1 - s^j_{np}$. The mass of Chinese firms serving the market n,j is then given by

$$M^j_{nc} = M^{e,j}_{nc} \left[\left(b^j_{no}\right)^{\frac{\theta^j}{1-\nu^j}} + \left(b^j_{np}\right)^{\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j} (\varphi^{*j}_{nc})^{-\theta^j} = M^{e,j}_{c} \left(\frac{b^j_{nc}}{\varphi^{*j}_{nc}}\right)^{\theta^j}.$$

The mass of ordinary firms, and respectively processing firms, selling to the market are

$$M^j_{no} = M^{e,j}_{nc} \left(b^j_{no}\right)^{\frac{\theta^j}{1-\nu^j}} \left[\left(b^j_{no}\right)^{\frac{\theta^j}{1-\nu^j}} + \left(b^j_{np}\right)^{\frac{\theta^j}{1-\nu^j}}\right]^{-\nu^j} (\varphi^{*j}_{nc})^{-\theta^j}$$

and

$$M^j_{np} = M^{e,j}_{nc} \left(b^j_{np}\right)^{\frac{\theta^j}{1-\nu^j}} \left[\left(b^j_{no}\right)^{\frac{\theta^j}{1-\nu^j}} + \left(b^j_{np}\right)^{\frac{\theta^j}{1-\nu^j}}\right]^{-\nu^j} (\varphi^{*j}_{nc})^{-\theta^j}.$$

F. Price index

The composite price index in country n-sector j takes the familiar Melitz (2003) form: $p^j_n = \left(\sum_{i=1}^{N,c} M^j_{ni} \left(\frac{\sigma^j}{\sigma^j-1}\frac{1}{\tilde{\varphi}^j_{ni}}\right)^{1-\sigma^j}\right)^{\frac{1}{1-\sigma^j}}$ where $\tilde{\varphi}^j_{ni} = \left[\int_{\varphi^{*j}_{ni}}^{\infty} \varphi^{\sigma^j-1} dG^j_{ni}\left(\varphi^j_{ni} | \varphi^j_{ni} > \varphi^{*j}_{ni}\right)\right]^{\frac{1}{\sigma^j-1}} = \left[\frac{\theta^j}{\theta^j-\sigma^j+1}\right]^{\frac{1}{\sigma^j-1}} \varphi^{*j}_{ni}$. Which, after substantial substitution can be solved to be

$$p_n^j = \left(\frac{\theta^j}{\theta^j - \sigma^j + 1}\right)^{-\frac{1}{\theta^j}} \frac{\sigma^j}{\sigma^j - 1} \times$$
$$\left[\sum_{i=1}^{N} M_i^{e,j} \left(b_{ni}^j\right)^{\theta^j} \left(\frac{\sigma^j c_n^j f_{ni}^j (1+\tau_{ni}^j)}{E_n^j}\right)^{\frac{\sigma^j-1-\theta^j}{\sigma^j-1}} + M_c^{e,j} \left[(b_{no}^j)^{\frac{\theta^j}{1-\nu^j}} + (b_{np}^j)^{\frac{\theta^j}{1-\nu^j}}\right]^{1-\nu^j} \left(\frac{\sigma^j c_n^j f_{nc}^j (1+\tau_{nc}^j)}{E_n^j}\right)^{\frac{\sigma^j-1-\theta^j}{\sigma^j-1}}\right]^{-\frac{1}{\theta^j}}. \tag{A38}$$

G. Trade Flows

The trade flow of good j from country $i \in \{1,...,N\}$ (outside China) to $j \in \{1,...,N,o,p\}$ is given by

$$X_{ni}^j = \frac{M_i^{e,j} \left[f_{ni}^j (1+\tau_{ni}^j)\right]^{\frac{\sigma^j-\theta^j-1}{\sigma^j-1}} \left(b_{ni}^j\right)^{\theta^j}}{\sum_{m=1}^{N,c} M_m^{e,j} \left[f_{nm}^j (1+\tau_{nm}^j)\right]^{\frac{\sigma^j-\theta^j-1}{\sigma^j-1}} \left(b_{nm}^j\right)^{\theta^j}} E_n^j. \tag{A39}$$

We denote $\pi_{ni}^j = X_{ni}^j / E_n^j$ the share of expenditure by n on good j accruing to products from i, and $\pi_{no}^j = X_{no}^j / E_n^j$ (respectively, $\pi_{np}^j = X_{np}^j / E_n^j$) the share of expenditure by n on good j accruing to products from ordinary sector of China (respectively, processing sector in China). The trade flow of good j from China as a whole to n as

$$X_{nc}^j = \frac{M_c^{e,j} \left[f_{nc}^j (1+\tau_{nc}^j)\right]^{\frac{\sigma^j-\theta^j-1}{\sigma^j-1}} \left(b_{nc}^j\right)^{\theta^j}}{\sum_{m=1}^{N,c} M_m^{e,j} \left[f_{nm}^j (1+\tau_{nm}^j)\right]^{\frac{\sigma^j-\theta^j-1}{\sigma^j-1}} \left(b_{nm}^j\right)^{\theta^j}} E_n^j. \tag{A40}$$

The trade flows from the ordinary and processing sectors to $j \in \{1,...,N,o,p\}$ are then given by

$$X_{no}^j = s_{no}^j X_{nc}^j \qquad \text{and} \qquad X_{np}^j = s_{np}^j X_{np}^j. \tag{A41}$$

H. Expected profit and free entry condition

Free entry conditions allow us to solve for the mass of entrants from a source pair i,j, $M_i^{e,j}$. Denote the variable profit in destination n for such firms as $\pi_{ni}^{v,j}$. For potential entrants in i outside China in industry j, the expected profit is given by

$$\begin{aligned} \bar{\pi}_i^j &= \sum_{n=1}^{N+2} Prob(\varphi_{ni}^j > \varphi_{ni}^{*j}) \left(E[\pi_{ni}^{v,j} | \varphi_{ni}^j > \varphi_{ni}^{*j}] - c_n^j f_{ni}^j\right) - c_i^j f_i^{e,j} \\ &= \sum_{n=1}^{N+2} \frac{\sigma^j - 1}{\sigma^j \theta^j} \frac{\left[f_{ni}^j (1+\tau_{ni}^j)\right]^{\frac{\sigma^j-\theta^j-1}{\sigma^j-1}} \left(b_{ni}^j\right)^{\theta^j}}{\sum_{m=1}^{N,c} M_m^{e,j} \left[f_{nm}^j (1+\tau_{nm}^j)\right]^{\frac{\sigma^j-\theta^j-1}{\sigma^j-1}} \left(b_{nm}^j\right)^{\theta^j}} \frac{E_n^j}{1+\tau_{in}^j} - c_i^j f_i^{e,j}. \end{aligned} \tag{A42}$$

Because entry implies $\bar{\pi}_i^j = 0$, we can use equation (A39) to write the previous expression as

$$M_i^{e,j} c_i^j f_i^{e,j} = \sum_{n=1}^{N+2} \frac{\sigma^j - 1}{\sigma^j \theta^j} \frac{M_i^{e,j} \left[f_{ni}^j 1 + \tau_{ni}^j) \right]^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}} \left(b_{ni}^j \right)^{\theta^j}}{\sum_{m=1}^{N,c} M_m^{e,j} \left[f_{nm}^j (1 + \tau_{nm}^j) \right]^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}} \left(b_{nm}^j \right)^{\theta^j}} \frac{E_n^j}{1 + \tau_{ni}^j} = \sum_{n=1}^{N+2} \frac{\sigma^j - 1}{\sigma^j \theta^j} \frac{X_{ni}^j}{1 + \tau_{ni}^j}. \tag{A43}$$

For the mass of entrants in China, this can be written as:

$$M_c^{e,j} c_c^j f_c^{e,j} = \sum_{n=1}^{N+2} \frac{\sigma^j - 1}{\sigma^j \theta^j} \frac{M_c^{e,j} (f_{nc}^j (1 + \tau_{nc}^j))^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}} \left(b_{nc}^j \right)^{\theta^j}}{\sum_{m=1}^{N,c} M_m^{e,j} (f_{nm}^j (1 + \tau_{nm}^j))^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}} \left(b_{nm}^j \right)^{\theta^j}} \frac{E_n^j}{1 + \tau_{nc}^j} = \sum_{n=1}^{N+2} \frac{\sigma^j - 1}{\sigma^j \theta^j} \frac{X_{nc}^j}{1 + \tau_{nc}^j}. \tag{A44}$$

I. Factor Market Clearing Conditions

As in Hsieh and Ossa (2016), pg. 215, for countries $i = 1,...,N$, aggregate input market clearing requires

$$c_i^j I_i^j = M_i^{ej} c_i^j f_i^{e,j} + M_i^{e,j} c_i^j E(i_i^{v,j}) + \sum_{m=1}^{N} M_{im}^j c_i^j f_{im}^j + M_{ic}^j \left(s_{io}^j c_i^j f_{io}^j + s_{ip}^j c_i^j f_{ip}^j \right),$$

where $E(i_i^{v,j})$ denotes the expected demand for inputs used directly in production. We can show that

$$\begin{aligned} M_i^{e,j} c_i^j E(i_i^{v,j}) &= M_i^{e,j} \sum_{n=1}^{N+2} Prob(\varphi_{ni}^j > \varphi_{ni}^{*j}) c_i^j E(i_i^{v,j} | \varphi_{ni}^j > \varphi_{ni}^{*j}) \\ &= M_i^{e,j} \sum_{n=1}^{N+2} Prob(\varphi_{ni}^j > \varphi_{ni}^{*j}) E \left[\frac{\sigma^j - 1}{\sigma^j} \left(\frac{\sigma^j}{\sigma^j - 1} \frac{1}{\varphi_{ni}^j P_n^j} \right)^{1 - \sigma^j} \frac{E_n^j}{1 + \tau_{ni}^j} \middle| \varphi_{ni}^j > \varphi_{ni}^{*j} \right] \\ &= \sum_{n=1}^{N+2} \frac{\sigma^j - 1}{\sigma^j} \frac{M_i^{e,j} (f_{ni}^j (1 + \tau_{ni}^j))^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}} \left(b_{ni}^j \right)^{\theta^j}}{\sum_{m=1}^{N,c} M_m^{e,j} (f_{nm}^j (1 + \tau_{nm}^j))^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}} \left(b_{nm}^j \right)^{\theta^j}} \frac{E_n^j}{1 + \tau_{ni}^j} = \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{ni}^j}{1 + \tau_{ni}^j}. \end{aligned}$$

In addition, where r^j_{ni} represents revenue of an i firm in destination n,j,

$$\sum_{n=1}^{N} M^j_{in} c^j_i f^j_{in} + M^j_{ic}\Big(s^j_{io} c^j_i f^j_{io} + s^j_{ip} c^j_i f^j_{ip}\Big)$$

$$= \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j}\Bigg[\sum_{n=1}^{N} M^j_{in} E(r^j_{in}|\varphi^j_{in} > \varphi^{*j}_{in}) +$$

$$M^j_{ic}\Big(s^j_{io} E(r^j_{io}|\varphi^j_{io} > \varphi^{*j}_{ic}, \varphi^j_{io} = \varphi^j_{ic}) + s^j_{ip} E(r^j_{ip}|\varphi^j_{ip} > \varphi^{*j}_{ic}, \varphi^j_{ip} = \varphi^j_{ic})\Big)\Bigg]$$

$$= \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{n=1}^{N+2} \frac{X^j_{in}}{1 + \tau^j_{in}}.$$

Therefore, the intermediate input market clearing condition can be rewritten as

$$c^j_i I^j_i = (1 + \theta^j) M^{e,j}_i c^j_i f^{e,j}_i + \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{n=1}^{N+2} \frac{X^j_{in}}{1 + \tau^j_{in}} = \frac{w^j_i L^j_i}{\eta^j_i \gamma^j_{L,i}},$$

which can be rewritten as:

$$M^{e,j}_i = \frac{\frac{w^j_i L^j_i}{\eta^j_i \gamma^j_{L,i}} - \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X^j_{ni}}{1+\tau^j_{ni}} - \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{n=1}^{N+2} \frac{X^j_{in}}{1+\tau^j_{in}}}{c^j_i f^{e,j}_i}. \tag{A45}$$

Labor and capital market clearing conditions are respectively

$$L_i = \sum_{j=1}^{J+1} L^j_i \qquad\qquad K_i = \sum_{j=1}^{J+1} K^j_i. \tag{A46}$$

For ordinary sector in China, the market clearing condition for aggregate input is:

$$c^j_o I^j_o = M^{e,j}_c c^j_o f^{e,j}_c + M^{e,j}_c c^j_o E(i^{v,j}_o) + \sum_{n=1}^{N+2} M^j_{on} c^j_o f^j_{on} = \frac{w_c L^j_o}{\eta^j_o \gamma^j_{L,o}},$$

where

$$c^j_o E(i^{v,j}_o) = \sum_{n=1}^{N+2} Prob(\varphi^j_{no} > \varphi^{*j}_{nc}, \varphi^j_{no} = \varphi^j_{nc}) c^j_o E(i^{v,j}_o|\varphi^j_{no} > \varphi^{*j}_{nc}, \varphi^j_{no} = \varphi^j_{nc}).$$

We can show that

$$M^{e,j}_c c^j_o E(i^{v,j}_o) = \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{\left(b^j_{no}\right)^{\frac{\theta^j}{1-\nu^j}}}{\left(b^j_{no}\right)^{\frac{\theta^j}{1-\nu^j}} + \left(b^j_{np}\right)^{\frac{\theta^j}{1-\nu^j}}} \frac{M^{e,j}_c (f^j_{nc}(1+\tau^j_{nc}))^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}} \left(b^j_{nc}\right)^{\theta^j}}{\sum_{i=1}^{N,c} M^{e,j}_i (f^j_{ni}(1+\tau^j_{ni}))^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}} \left(b^j_{ni}\right)^{\theta^j}} \frac{E^j_n}{1 + \tau^j_{nc}}$$

$$= \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X^j_{no}}{1 + \tau^j_{nc}}.$$

$$\sum_{n=1}^{N+2} M_{on}^j c_o^j f_{on}^j = \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{n=1}^{N+2} E(r_{on}^j | \varphi_{on}^j > \varphi_{on}^{*j}) = \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{n=1}^{N+2} \frac{X_{on}^j}{1+\tau_{on}^j}.$$

Therefore,

$$M_c^{e,j} = \frac{\frac{w_c L_o^j}{\eta_o^j \gamma_{L,o}^j} - \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{no}^j}{1+\tau_{nc}^j} - \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{n=1}^{N+2} \frac{X_{on}^j}{1+\tau_{on}^j}}{c_o^j f_c^{e,j}}. \tag{A47}$$

The intermediate input market clearing condition for processing sector in China is

$$c_p^j I_p^j = M_c^{e,j} c_p^j E(i_p^{v,j}) + \sum_{n=1}^{N+2} M_{pn}^j c_p^j f_{pn}^j = \frac{w_c L_p^j}{\eta_p^j \gamma_{L,p}^j},$$

where

$$c_p^j E(i_p^{v,j}) = \sum_{n=1}^{N+2} Prob(\varphi_{np}^j > \varphi_{nc}^{*j}, \varphi_{np}^j = \varphi_{nc}^j) c_p^j E(i_p^{v,j} | \varphi_{np}^j > \varphi_{cn}^{*j}, \varphi_{np}^j = \varphi_{nc}^j).$$

Following similar steps as immediately preceding, we can show that

$$\begin{aligned} M_c^{e,j} c_p^j E(i_p^{v,j}) &= \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{\left(b_{np}^j\right)^{\frac{\theta^j}{1-\nu^j}}}{\left(b_{no}^j\right)^{\frac{\theta^j}{1-\nu^j}} + \left(b_{np}^j\right)^{\frac{\theta^j}{1-\nu^j}}} \frac{M_c^{e,j} (f_{nc}^j (1+\tau_{nc}^j))^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}} \left(b_{nc}^j\right)^{\theta^j}}{\sum_{i=1}^{N,c} M_i^{e,j} (f_{ni}^j (1+\tau_{ni}^j))^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}} \left(b_{ni}^j\right)^{\theta^j}} \frac{E_n^j}{1+\tau_{nc}^j} \\ &= \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{np}^j}{1+\tau_{nc}^j} \end{aligned}$$

$$\sum_{n=1}^{N+2} M_{pn}^j c_p^j f_{pn}^j = \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{n=1}^{N+2} E(r_{pn}^j | \varphi > \varphi_{pn}^{*j}) = \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{n=1}^{N+2} \frac{X_{pn}^j}{1+\tau_{pn}^j}$$

Therefore,

$$\frac{w_c L_p^j}{\eta_p^j \gamma_{L,p}^j} = \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{np}^j}{1+\tau_{nc}^j} + \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{n=1}^{N+2} \frac{X_{pn}^j}{1+\tau_{pn}^j}. \tag{A48}$$

Labor and capital market clearing conditions are respectively

$$L_c = \sum_{j=1}^{J+1} (L_o^j + L_p^j) \qquad K_c = \sum_{j=1}^{J+1} (K_o^j + K_p^j) \tag{A49}$$

J. Equilibrium

The endogenous variables are $\{E_i^j, c_i^j, p_i^j, L_i^j, K_i^j, M_i^{e,j}, w_i, r_i\}$, which can be solved by $r_i K_i^j = \frac{\gamma_{K,i}^j}{\gamma_{L,i}^j} w_i L_i^j \ \forall i = 1,...,N+2, j = 1,...,J+1$ along with the (N+2)(J+1) cost functions (A34), (N+2)(J+1) price Indexes (A38), (N+1)(J+1) entry equations (A43) and (A44), (N+2)(J+1) expenditure equations (A35), (A36), and (A37), (N+2)(J+1) input market clearing equations (A45), (A47), and (A48), 2(N+2) factor market clearing equations (A46) and (A49). The system has $5(N+2)(J+1) + (N+1)(J+3)$ equations and $5(N+2)(J+1) + (N+1)(J+3)$ unknowns. Trade flows X_{ijs} are determined by equations (1)-(3).

K. Exact Hat Algebra

We change in tariffs $\{\tau_{in}^{j}\}$ to $\{\tau_{in}^{j'}\}$ in the counterfactual experiments. We use x' to denote the counterfactual value of x, and $\hat{x}$ to denote x'/x. In the following expression, $\pi_{in}^{j}=\frac{X_{in}^{j}}{\sum_{m}^{N+2}X_{im}^{j}}$, and $\mu_{ni}^{j}=\frac{X_{ni}^{j}/(1+\tau_{ni}^{j})}{\sum_{m=1}^{N+2}X_{mi}^{j}/(1+\tau_{mi}^{j})}$. The equilibrium conditions from subsection J. are as follows:

$$\hat{r}_i\hat{K}_i^j=\hat{w}_i\hat{L}_i^j \qquad \forall i=1,...,N+2 \tag{A50}$$

$$\hat{c}_n^j=\left(\hat{w}_n^{\gamma_{L,n}^j}\hat{r}_n^{\gamma_{K,n}^j}\right)^{\eta_n^j}\prod_{k=1}^{J+1}(\hat{p}_n^j)^{(1-\eta_n^j)\gamma_n^{kj}}. \qquad \forall n=1,...,N+2 \tag{A51}$$

$$\begin{aligned}\hat{p}_n^j=\Bigg[&\sum_{i=1}^{N}\pi_{ni}^j\hat{M}_i^{e,j}\left(\hat{c}_i^j\hat{\kappa}_{ni}^j\right)^{-\theta^j}\left(\frac{\hat{c}_n^j\widehat{(1+\tau_{ni}^j)}}{\hat{E}_n^j}\right)^{\frac{\sigma^j-\theta^j-1}{\sigma^j-1}}+ \qquad \forall n=1,..,N+2\\ &\pi_{nc}^j\hat{M}_c^{e,j}\left(s_{no}^j\left(\hat{c}_o^j\hat{\kappa}_{no}^j\right)^{-\frac{\theta^j}{1-\nu^j}}+s_{np}^j\left(\hat{c}_p^j\hat{\kappa}_{np}^j\right)^{-\frac{\theta^j}{1-\nu^j}}\right)^{1-\nu^j}\left(\frac{\hat{c}_n^j\widehat{(1+\tau_{nc}^j)}}{\hat{E}_n^j}\right)^{\frac{\sigma^j-\theta^j-1}{\sigma^j-1}}\Bigg]^{-\frac{1}{\theta^j}}\end{aligned} \tag{A52}$$

$$\begin{cases}\hat{M}_i^{e,j}\hat{c}_i^j=\sum_{n=1}^{N+2}\mu_{ni}^j\frac{\hat{X}_{ni}^j}{\widehat{1+\tau_{ni}^j}} & \forall i=1,...,N\\ \hat{M}_c^{e,j}\hat{c}_o^j=\sum_{n=1}^{N+2}\mu_{nc}^j\frac{s_{no}^j\hat{X}_{no}^j+s_{np}^j\hat{X}_{np}^j}{\widehat{1+\tau_{np}^j}}\end{cases} \tag{A53}$$

$$\begin{cases}\hat{E}_i^j=\alpha_i^j\left(\sum_{k=1}^{J+1}\frac{w_iL_i^k}{E_i^j}\frac{\hat{w}_i\hat{L}_i^k}{\gamma_{L,i}^k}+\sum_{n=1}^{N+2}\sum_{k=1}^{J+1}\frac{\tau_{in}^{k'}X_{in}^k}{E_i^j(1+\tau_{in}^k)}\frac{\hat{X}_{in}^k}{\widehat{(1+\tau_{in}^k)}}-\frac{\Omega_i}{E_i^j}\right)+\sum_{k=1}^{J+1}\gamma_i^{jk}\frac{1-\eta_i^k}{\eta_i^k}\frac{w_iL_i^k}{E_i^j}\frac{\hat{w}_i\hat{L}_i^k}{\gamma_{L,i}^k} \qquad \forall i=1,...,N\\ \hat{E}_o^j=\alpha_o^j\Bigg(\sum_{k=1}^{J+1}\left(\frac{w_cL_o^k}{E_o^j}\frac{\hat{w}_c\hat{L}_o^k}{\gamma_{L,o}^k}+\frac{w_cL_p^k}{E_o^j}\frac{\hat{w}_c\hat{L}_p^k}{\gamma_{L,p}^k}\right)+\sum_{n=1}^{N+2}\sum_{k=1}^{J+1}\frac{\tau_{on}^{k'}X_{on}^k}{E_o^j(1+\tau_{on}^k)}\frac{\hat{X}_{on}^k}{\widehat{1+\tau_{on}^k}}+\\ \qquad \sum_{n=1}^{N+2}\sum_{k=1}^{J+1}\frac{\tau_{pn}^{k'}X_{pn}^k}{E_p^j(1+\tau_{pn}^k)}\frac{\hat{X}_{pn}^k}{\widehat{1+\tau_{pn}^k}}-\frac{\Omega_o}{E_o^j}\Bigg)+\sum_{k=1}^{J+1}\gamma_o^{jk}\frac{1-\eta_o^k}{\eta_o^k}\frac{w_cL_o^k}{E_o^j}\frac{\hat{w}_c\hat{L}_o^k}{\gamma_{L,o}^k}\\ \hat{E}_p^j=-\alpha_p^j\frac{\Omega_p}{E_p^j}+\sum_{k=1}^{J+1}\gamma_p^{jk}\frac{1-\eta_p^k}{\eta_p^k}\frac{w_cL_p^k}{E_p^j}\frac{\hat{w}_c\hat{L}_p^k}{\gamma_{L,p}^k}\end{cases} \tag{A54}$$

$$
\begin{cases}
\hat{M}_i^{e,j} = \dfrac{\frac{w_i L_i^j}{\eta_i^j \gamma_{L,i}^j} \hat{w}_i \hat{L}_i^j - \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{ni}^j}{1+\tau_{ni}^j} \frac{\hat{X}_{ni}^j}{\widehat{1+\tau_{ni}^j}} - \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{m=1}^{N+2} \frac{X_{im}^j}{1+\tau_{im}^j} \frac{\hat{X}_{im}^j}{\widehat{1+\tau_{im}^j}}}{M_i^{e,j} c_i^j f_i^{e,j} \hat{c}_i^j} & \forall i = 1,\ldots,N \\
\hat{M}_c^{e,j} = \dfrac{\frac{w_c L_o^j}{\eta_o^j \gamma_{L,o}^j} \hat{w}_c \hat{L}_o^j - \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{no}^j}{1+\tau_n^j} \frac{\hat{X}_{no}^j}{\widehat{1+\tau_{nc}^j}} - \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{m=1}^{N+2} \frac{X_{om}^j}{1+\tau_{om}^j} \frac{\hat{X}_{om}^j}{\widehat{1+\tau_{om}^j}}}{M_c^{e,j} c_o^j f_c^{e,j} \hat{c}_o^j} \\
0 = \frac{w_c L_p^j}{\eta_p^j \gamma_{L,p}^j} \hat{w}_c \hat{L}_p^j - \frac{\sigma^j - 1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{np}^j}{1+\tau_{nc}^j} \frac{\hat{X}_{np}^j}{\widehat{1+\tau_{nc}^j}} - \frac{\theta^j - \sigma^j + 1}{\sigma^j \theta^j} \sum_{m=1}^{N+2} \frac{X_{pm}^j}{1+\tau_{pm}^j} \frac{\hat{X}_{pm}^j}{\widehat{1+\tau_{pm}^j}}
\end{cases}
\tag{A55}
$$

$$
\begin{cases}
1 = \sum_{j=1}^{J+1} \frac{w_i L_i^j}{w_i L_i} \hat{L}_i^j & \forall i = 1,\ldots,N \\
1 = \sum_{j=1}^{J+1} \left(\frac{w_c L_o^j}{w_c L_c} \hat{L}_o^j + \frac{w_c L_p^j}{w_c L_c} \hat{L}_p^j \right)
\end{cases}
\tag{A56}
$$

$$
\begin{cases}
1 = \sum_{j=1}^{J+1} \frac{r_i K_i^j}{r_i K_i} \hat{K}_i^j & \forall i = 1,\ldots,N \\
1 = \sum_{j=1}^{J+1} \left(\frac{r_c K_o^j}{r_c K_c} \hat{K}_o^j + \frac{r_c K_p^j}{r_c K_c} \hat{K}_p^j \right)
\end{cases}
\tag{A57}
$$

$$
\begin{cases}
\hat{X}_{ni}^j = \dfrac{\hat{M}_i^{e,j} \left(\hat{c}_i^j \hat{\kappa}_{ni}^j \right)^{-\theta^j} \left(\hat{c}_n^j \left(\widehat{1+\tau_{ni}^j}\right) \right)^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}}}{\left(\hat{p}_n^j \right)^{-\theta^j}} \left(\hat{E}_n^j \right)^{\frac{\theta^j}{\sigma^j - 1}} & \forall i = 1,\ldots,N \\
\hat{X}_{no}^j = \dfrac{\hat{M}_c^{e,j} \left(\hat{c}_o^j \hat{\kappa}_{no}^j \right)^{-\frac{\theta^j}{1-\nu^j}} \left(s_{no}^j \left(\hat{c}_o^j \hat{\kappa}_{no}^j \right)^{-\frac{\theta^j}{1-\nu^j}} + s_{np}^j \left(\hat{c}_p^j \hat{\kappa}_{np}^j \right)^{-\frac{\theta^j}{1-\nu^j}} \right)^{-\nu^j} \left(\hat{c}_n^j \left(\widehat{1+\tau_{nc}^j}\right) \right)^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}}}{\left(\hat{p}_n^j \right)^{-\theta^j}} \left(\hat{E}_n^j \right)^{\frac{\theta^j}{\sigma^j - 1}} \\
\hat{X}_{no}^j = \dfrac{\hat{M}_c^{e,j} \left(\hat{c}_p^j \hat{\kappa}_{np}^j \right)^{-\frac{\theta_s}{1-\nu^j}} \left(s_{no}^j \left(\hat{c}_o^j \hat{\kappa}_{no}^j \right)^{-\frac{\theta_s}{1-\nu^j}} + s_{np}^j \left(\hat{c}_p^j \hat{\kappa}_{np}^j \right)^{-\frac{\theta_s}{1-\nu^j}} \right)^{-\nu^j} \left(\hat{c}_n^j \left(\widehat{1+\tau_{nc}^j}\right) \right)^{\frac{\sigma^j - \theta^j - 1}{\sigma^j - 1}}}{\left(\hat{p}_n^j \right)^{-\theta^j}} \left(\hat{E}_n^j \right)^{\frac{\theta^j}{\sigma^j - 1}}
\end{cases}
\tag{A58}
$$

Given the estimates of σ^j, θ^j, ν (with ν^j constant), $\gamma_{L,i}^j$, $\gamma_{K,i}^j$, γ_i^{kj}, η_i^j, α_i^j, and data on full matrix of bilateral trade flows X_{ni}^j and tariffs τ_{ni}^j (based on which to calculate π_{ni}^j, μ_{ni}^j, s_{no}^j and s_{np}^j), these equations can be employed to solve the counterfactual general equilibrium outcomes given a set of exogenous shocks.[62]

[62]For the counterfactual experiments where tariffs are unadjusted but iceberg costs change, $\tau_{ni}^{j'} = \tau_{ni}^j$ and $\widehat{1+\tau_{ni}^j} = 1$ in the above equations, while $\hat{\kappa}_{ni}^j$ remains.

L. Welfare

The welfare is given by

$$\begin{cases} V_i = \dfrac{\sum\limits_{j=1}^{J+1} \frac{w_i L_i^j}{\gamma_{L,i}^j} + \sum\limits_{n=1}^{N+2} \sum\limits_{j=1}^{J+1} \frac{\tau_{in}^j X_{in}^j}{1+\tau_{in}^j} - \Omega_i}{p_i} & \forall i = 1,...,N \\ V_c = \dfrac{\sum\limits_{j=1}^{J+1} \left(\frac{w_c L_o^j}{\gamma_{L,o}^j} + \frac{w_c L_p^j}{\gamma_{L,p}^j} \right) + \sum\limits_{n=1}^{N+2} \sum\limits_{j=1}^{J+1} \frac{\tau_{on}^j X_{on}^j}{1+\tau_{on}^j} + \sum\limits_{n=1}^{N+2} \sum\limits_{j=1}^{J+1} \frac{\tau_{pn}^j X_{pn}^j}{1+\tau_{pn}^j} - \Omega_o}{p_c} & \end{cases} \tag{A59}$$

where $p_i = \prod_{j=1}^{J+1} \left(\frac{p_i^j}{\alpha_i^j} \right)^{\alpha_i^j}$ and $p_c = \prod_{j=1}^{J+1} \left(\frac{p_o^j}{\alpha_i^j} \right)^{\alpha_c^j}$. The numerators in the above equations present the final consumption by households. Therefore, when tariff changes, the welfare changes are given by:

$$\begin{cases} \hat{V}_i = \dfrac{\sum\limits_{j=1}^{J+1} \frac{w_i L_i^j}{\gamma_{L,i}^j} \hat{w}_i \hat{L}_i^j + \sum\limits_{n=1}^{N+2} \sum\limits_{j=1}^{J+1} \frac{\tau_{in}^{j'} X_{in}^j}{1+\tau_{in}^j} \frac{\hat{X}_{in}^j}{\widehat{1+\tau_{in}^j}} - \Omega_i}{\sum\limits_{j=1}^{J+1} \frac{w_i L_i^j}{\gamma_{L,i}^j} + \sum\limits_{n=1}^{N+2} \sum\limits_{j=1}^{J+1} \frac{\tau_{in}^j X_{in}^j}{1+\tau_{in}^j} - \Omega_i} \dfrac{1}{\prod_{j=1}^{J+1} \left(\hat{p}_i^j \right)^{\alpha_i^j}} & \forall i = 1,...,N \\ \hat{V}_c = \dfrac{\sum\limits_{j=1}^{J+1} \left(\frac{w_c L_o^j}{\gamma_{L,o}^j} \hat{w}_c \hat{L}_o^j + \frac{w_c L_p^j}{\gamma_{L,p}^j} \hat{w}_c \hat{L}_p^j \right) + \sum\limits_{n=1}^{N+2} \sum\limits_{j=1}^{J+1} \frac{\tau_{on}^{j'} X_{on}^j}{1+\tau_{on}^j} \frac{\hat{X}_{on}^j}{\widehat{1+\tau_{on}^j}} + \sum\limits_{n=1}^{N+2} \sum\limits_{j=1}^{J+1} \frac{\tau_{pn}^{j'} X_{pn}^j}{1+\tau_{pn}^j} \frac{\hat{X}_{pn}^j}{\widehat{1+\tau_{pn}^j}} - \Omega_o}{\sum\limits_{j=1}^{J+1} \left(\frac{w_c L_o^j}{\gamma_{L,o}^j} + \frac{w_c L_p^j}{\gamma_{L,p}^j} \right) + \sum\limits_{n=1}^{N+2} \sum\limits_{j=1}^{J+1} \frac{\tau_{on}^j X_{on}^j}{1+\tau_{on}^j} + \sum\limits_{m=1}^{N} \sum\limits_{j=1}^{J+1} \frac{\tau_{pn}^j X_{on}^j}{1+\tau_{on}^j} - \Omega_o} \dfrac{1}{\prod_{j=1}^{J+1} \left(\hat{p}_o^j \right)^{\alpha_c^j}} & \end{cases} \tag{A60}$$

M. Discussion on data requirement

Given the data on bilateral trade flows and parameters $\{\theta^j, \sigma^j, \eta_i^j, \gamma_{L,i}^j, \gamma_{K,i}^j\}$, we back out the variables $\{\Omega_i, w_i L_i^j, r_i K_i^j, E_i^j\}$ and variables $\{X_{ii}^j, X_{oo}^j, X_{op}^j\}$ in the baseline equilibrium based on the following procedure.

(1) $M_i^{e,j} c_i^j f_i^{e,j} = \sum\limits_{n=1}^{N+2} \frac{\sigma^j - 1}{\sigma^j \theta^j} \frac{X_{ni}^j}{1+\tau_{ni}^j}$, and $M_c^{e,j} c_i^j f_c^{e,j} = \sum\limits_{n=1}^{N+2} \frac{\sigma^j - 1}{\sigma^j \theta^j} \frac{X_{nc}^j}{1+\tau_{nc}^j}$. Both these left hand sides can be calculated based on the data and known parameters.

(2) From equilibrium conditions (A35), (A36), (A37), (A43), (A44), (A45), (A47), and (A48), we back out transfers using the following equations

$$\begin{cases} \Omega_i = \sum\limits_{j=1}^{J+1} \frac{(1+\theta^j)(\sigma^j - 1)}{\theta^j \sigma^j} \left(\sum\limits_{n=1}^{N+2} \frac{X_{ni}^j}{1+\tau_{ni}^j} - \sum\limits_{m=1}^{N+2} \frac{X_{im}^j}{1+\tau_{im}^j} \right) & \forall i = 1,...,N \\ \Omega_o + \Omega_p = \sum\limits_{j=1}^{J+1} \frac{(1+\theta^j)(\sigma^j - 1)}{\theta^j \sigma^j} \left(\sum\limits_{n=1}^{N+2} \frac{X_{no}^j}{1+\tau_{nc}^j} - \sum\limits_{m=1}^{N+2} \frac{X_{om}^j}{1+\tau_{om}^j} \right) + \sum\limits_{j=1}^{J+1} \frac{(1+\theta^j)(\sigma^j - 1)}{\theta^j \sigma^j} \left(\sum\limits_{n=1}^{N+2} \frac{X_{np}^j}{1+\tau_{nc}^j} - \sum\limits_{m=1}^{N+2} \frac{X_{pm}^j}{1+\tau_{pm}^j} \right) & \\ \Omega_p = \sum\limits_{j=1}^{J+1} (1 - \eta_p^j) \left[\frac{\sigma^j - 1}{\sigma^j} \sum\limits_{n=1}^{N+2} \frac{X_{np}^j}{1+\tau_{nc}^j} + \frac{\theta^j - \sigma^j + 1}{\theta^j \sigma^j} \sum\limits_{m=1}^{N+2} \frac{X_{pm}^j}{1+\tau_{pm}^j} \right] - \sum\limits_{j=1}^{N+1} \sum\limits_{m=1}^{N+2} X_{pm}^j & \end{cases} \tag{A61}$$

(3) The data on $w_i L_i^j$ and $r_i K_i^j$ are also required. These data can be backed out from trade flows according to

$$\begin{cases} w_i L_i^j = \eta_i^j \gamma_{L,i}^j \left[\frac{(1+\theta^j)(\sigma^j-1)}{\sigma^j\theta^j} \sum_{n=1}^{N+2} \frac{X_{ni}^j}{1+\tau_{ni}^j} + \frac{\theta^j-\sigma^j+1}{\sigma^j\theta^j} \sum_{m=1}^{N+2} \frac{X_{im}^j}{1+\tau_{im}^j} \right] & \forall i = 1,...,N \\ w_c L_o^j = \eta_o^j \gamma_{L,o}^j \left[\frac{\sigma^j-1}{\sigma^j\theta^j} \sum_{n=1}^{N+2} \frac{X_{no}^j+X_{np}^j}{1+\tau_{nc}^j} + \frac{\sigma^j-1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{no}^j}{1+\tau_{nc}^j} + \frac{\theta^j-\sigma^j+1}{\sigma^j\theta^j} \sum_{m=1}^{N+2} \frac{X_{om}^j}{1+\tau_{om}^j} \right] \\ w_c L_p^j = \eta_p^j \gamma_{L,p}^j \left[\frac{\sigma^j-1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{np}^j}{1+\tau_{nc}^j} + \frac{\theta^j-\sigma^j+1}{\sigma^j\theta^j} \sum_{m=1}^{N+2} \frac{X_{pm}^j}{1+\tau_{pm}^j} \right] \end{cases} \tag{A62}$$

$$\begin{cases} r_i K_{is} = \eta_i^j \gamma_{K,i}^j \left[\frac{(1+\theta^j)(\sigma^j-1)}{\sigma^j\theta^j} \sum_{n=1}^{N+2} \frac{X_{ni}^j}{1+\tau_{ni}^j} + \frac{\theta^j-\sigma^j+1}{\sigma^j\theta^j} \sum_{m=1}^{N+2} \frac{X_{im}^j}{1+\tau_{im}^j} \right] & \forall i = 1,...,N \\ r_c K_{os} = \eta_o^j \gamma_{K,o}^j \left[\frac{\sigma^j-1}{\sigma^j\theta^j} \sum_{n=1}^{N+2} \frac{X_{no}^j+X_{np}^j}{1+\tau_{nc}^j} + \frac{\sigma^j-1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{no}^j}{1+\tau_{nc}^j} + \frac{\theta^j-\sigma^j+1}{\sigma^j\theta^j} \sum_{m=1}^{N+2} \frac{X_{om}^j}{1+\tau_{om}^j} \right] \\ r_c K_{ps} = \eta_p^j \gamma_{K,p}^j \left[\frac{\sigma^j-1}{\sigma^j} \sum_{n=1}^{N+2} \frac{X_{np}^j}{1+\tau_{nc}^j} + \frac{\theta^j-\sigma^j+1}{\sigma^j\theta^j} \sum_{m=1}^{N+2} \frac{X_{pm}^j}{1+\tau_{pm}^j} \right] \end{cases} \tag{A63}$$

In addition, $w_i L_i = \sum_{j=1}^{J+1} w_i L_i^j$, $r_i K_i = \sum_{j=1}^{J+1} r_i K_i^j$, $w_c L_c = \sum_{j=1}^{J+1} w_c (L_o^j + L_p^j)$, and $r_c K_c = \sum_{j=1}^{J+1} r_c (K_o^j + K_p^j)$.

(4) we can calculate $E_i^j = \sum_{n=1}^{N+2} X_{in}^j \ \forall i = 1,...,N+2$.

(5) After obtaining Ω_i, $w_i L_i^j$, $r_i K_i^j$ and E_i^j, we adjust $\{X_{ii}^j, X_{oo}^j, X_{po}^j\}$ based on (A35)-(A37) so that α_i^j is consistent with data.

These steps are important to ensure that all the identity equations hold in the baseline data. Data of σ^j and θ^j can be obtained from Table 6 in Hsieh and Ossa (2016). The bilateral trade flows and tariffs, and the remaining parameters are readily available in our data.