Processing-Trade-Induced Dutch Disease*

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Abstract

We propose a theory in which developing countries may lose from encouraging processing trade. Our model features that (i) processing exports have much lower domestic value added share (DVAS) than ordinary exports and domestic sales; and (ii) the production of intermediates exhibits increasing returns to scale. With these features, facilitating processing trade triggers a Dutch disease by (i) shifting labor from high DVAS production of ordinary exports and domestic sales to lower DVAS production of processing exports and (ii) shrinking the scale of domestic intermediate production. Using the Chinese firm-level data, we find that both features are empirically relevant. We then calibrate our model to the Chinese firm-level data and aggregate trade flows across 47 economies. Our counterfactual analysis suggests that duty exemption for processing imports decreases China's real income by 1.45%.

JEL classification: F10, F12, F13, F14, F17

Keywords: Processing trade, Dutch Disease, Increasing returns to scale

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1 Introduction

Processing trade–the activity of assembling imported inputs into re-exported final products–has been encouraged by many developing countries that conduct export-oriented growth strategies (Maurer and Degain 2012). A commonly adopted policy by developing countries is to offer duty exemption for imported inputs used to produce processing exports, which is referred to as *duty exemption* throughout this paper (WTO and IDE-JETRO 2011). Duty exemption is regarded as an effective policy to integrate developing countries into the global market while protecting their "infant industries" by high tariffs on ordinary imports (WorldBank 2020). However, there are concerns that this type of export subsidies would encourage excessive exports and lead to welfare losses (see, for example, Defever and Riaño 2017). The policy outcomes are also mixed. While China, the largest player in processing trade, has quadrupled its exports during 2001-2007 and experienced remarkable economic growth, the observations in other developing countries tend to be less optimistic. Countries like Mexico, Honduras, and Nicaragua have experienced rapid export growth, with processing exports accounting for about half of their exports. But their economic growth remain lackluster.[1] In sum, whether developing countries benefit from duty exemption for processing trade is still an open question in the literature, a gap this paper aims to fill.

In this paper, we propose a quantifiable general equilibrium model to understand the *costs* of duty exemption and processing trade for the long-term economic performances of developing countries. Our model builds on the framework developed by Eaton, Kortum, and Kramarz (2011) (henceforth EKK) in which firms are heterogeneous in productivity, sourcing intermediate inputs from and selling outputs to monopolistically competitive global markets. We extend the EKK model in two dimensions. First, we add a new trade regime, processing trade regime, in which firms can enjoy duty exemption for imported inputs but have to export the resulting outputs. Second, we allow firms to choose from two production technologies, with one using foreign inputs more intensively than the other.

Our model has the following key features that are relevant to processing trade. First, processing exports have much lower domestic value added share (DVAS) than ordinary exports and domestic sales. This is because firms using foreign inputs more intensively benefit more from duty exemption and therefore more likely to conduct processing trade. Second, the production of intermediate inputs exhibits increasing returns to scale, which is standard in the Dixit-Stiglitz economy.[2]

How do these features shape our understanding of the long-term impacts of processing trade regime? We show analytically that duty exemption for processing trade regime could trigger a Dutch disease in which external shocks shift factors of production from industries with fast productivity growth or strong scale economies to other industries.[3] In our model, processing trade reallocates labor from high DVAS

[1]From 1985 to 2008, trade-to-GDP ratio increases from 24.33% to 57.78% for Mexico, from 56.53% to 135.75% for Honduras, and from 36.59% to 96.79% for Nicaragua, and average GDP growth rate is 0.9% for Mexico, 1.2% for Honduras, and 0.1% for Nicaragua (Authors' own calculation based on data from World Bank: https://data.worldbank.org/). In 2006, the share of processing exports is 45% for Mexico, 55% for Honduras, 40% for Nicaragua (WTO and IDE-JETRO 2011).

[2]The increasing returns to scale in intermediate production are standard in the literature and have been regarded as a driving force of economic growth. See for example, Romer (1990), Grossman and Helpman (1991), and Acemoglu and Azar (2020).

[3]For the idea of Dutch disease, see Allcott and Keniston (2018), Corden and Neary (1982), Krugman (1987), and van Wijn-

production of ordinary exports and domestic sales to lower DVAS production of processing exports. This shrinks the scale of domestic intermediate production and, in the presence of scale economies in input production, leads to welfare losses. We show that, if the economies of scale are strong or the DVAS of processing exports are sufficiently low, this welfare loss could outweigh the welfare improving effect of duty exemption which arises from the expansion of imported input varieties.[4] This welfare loss led by duty exemption is magnified by the fact that the outputs of processing production are sold exclusively to the foreign markets. In this case, duty exemption does not reduce the prices faced by domestic consumers but effectively subsidizes foreign consumers. Overall, our model shows that duty exemption for processing trade that dramatically boosts a country's export is not necessarily welfare-improving.

To investigate the empirical relevance of our model, we bring it to the Chinese firm-level data and aggregate trade data for 47 economies. We compute intermediate expenditure shares between China's processing and ordinary production across source countries from the Chinese data, finding that processing production predominantly use foreign intermediates while the production of ordinary exports and domestic sales use domestic intermediates intensively. We then estimate the elasticity of substitution across input varieties using a new estimation strategy. This new strategy exploits the variation in the gaps of imported input shares between China's processing and ordinary production across source countries. Intuitively, the gap of imported input shares between processing and ordinary production becomes larger if the tariffs on imported inputs are higher. The elasticity of this gap with respect to tariff is increasing with the elasticity of substitution across input varieties.[5] Our estimated elasticity of substitution across input varieties indicates a strong economy of scale in intermediate production.

Armed with the estimated model, we conduct counterfactual exercises to quantify the welfare impacts of duty exemption for processing trade. We find that duty exemption *decreases* China's real income by 1.45%. We decompose this welfare loss and find that the welfare loss from the Dutch disease (-2.32%) outweighs the welfare gain from expanding the imported input varieties (1.06%). We then investigate to what extent the features of our model affect our quantitative evaluation of duty exemption. First, we consider an alternative model in which ordinary and processing production combine domestic and foreign inputs using the same technology. In this case, duty exemption *decreases* China's real income only by 0.14%. Second, we weaken the economies of scale in input production and find a smaller welfare loss for China led by duty exemption. In sum, our counterfactual exercises show that duty exemption for processing trade could trigger a Dutch disease by reallocating labor from high DVAS ordinary exports and domestic production to low DVAS processing exports, which shrinks the scale of domestic intermediate production and effectively subsidizes foreign consumers.

Related Literature. This paper does not intend to disentangle all underlying mechanisms behind

bergen (1984).

[4]The welfare improving effect of duty exemption has been emphasized by Brandt, Li, and Morrow (2018).

[5]Eaton, Kortum, and Kramarz (2011) cannot separately identify the elasticity of substitution since they have only one trade regime.

duty exemption and processing trade.[6] Rather, with our model, we highlight key features of processing trade regime that could trigger a Dutch disease, therefore offering a cautionary note for such development policies. This processing-trade-induced Dutch disease does not exist in the previous literature that evaluates trade policies such as duty exemption, duty-free zones and duty drawback schemes.[7] The recent work Brandt, Li, and Morrow (2018) quantify the welfare effects of the duty exemption under China's processing trade based on a multi-industry Ricardian model. The processing-trade-induced Dutch disease is absent in their paper since the Ricardian setting exhibits constant returns to scale. Chen, Erbahar, and Zi (2019) build a model featuring the coexistence of processing and ordinary trade within firm. But their model does not allow increasing returns to scale in input production. In sum, our paper complements the processing trade literature by proposing and quantifying the processing-trade-induced Dutch disease.

Our processing-trade-induced Dutch disease relates to the export subsidies with export share requirements discussed in Defever and Riaño (2017). Defever and Riaño (2017) show that if firms must export more than a certain share of their output to receive an export subsidy, such subsidy would induce excessive exports, crowd out domestic producers, and thereby lead to welfare losses. Their paper does not specify how this type of export subsidies is implemented. This paper complements their work by quantifying the impacts of a specific policy with export share requirements, duty exemption for processing trade, and emphasizing the novel welfare losses from the shrinking scale of domestic intermediate production.

This paper also contributes to the literature of trade in value added, especially, the line of works that estimates domestic content of exports when processing trade is pervasive, e.g. Koopman, Wang, and Wei (2012), Mattoo, Wang, and Wei (2013), De La Cruz, Koopman, Wang, and Wei (2013), Kee and Tang (2016). These papers find that processing exports have much lower DVAS than ordinary exports and domestic sales in both China and Mexico. Our paper shows that it is important to take their findings into account when evaluating the trade and welfare effects of duty exemption under processing trade.

Finally, our paper connects to the literature studying the implications of tariff changes under firm heterogeneity. Balistreri, Hillberry, and Rutherford (2011); Caliendo, Feenstra, Romalis, and Taylor (2015); Costinot and Rodríguez-Clare (2014); Costinot, Rodríguez-Clare, and Werning (2016); Demidova and Rodriguez-Clare (2009); Demidova (2017); Felbermayr, Jung, and Larch (2013); and Felbermayr, Jung, and Larch (2015)[8] provide good examples of this line of work. Allowing for two production technolo-

[6]For example, we do not consider technology spillovers from processing traders to domestic producers. In the presence of such spillovers, a country could substantially benefit from conducting duty exemption and processing trade. The empirical evidence for such spillovers is mixed. See Lu, Tao, and Zhu (2017) and Javorcik (2004).

[7]Hamada (1974), Rodriguez (1976), and Hamilton and Svensson (1982) study the welfare effects of import duty exemption on final goods inside a duty-free zone with a Heckscher-Ohlin model for a small country. Young (1987) studies the welfare effects of tariff reduction on intermediate goods inside a duty-free zone with a Heckscher-Ohlin model for a small country. Young and Miyagiwa (1987) extends Young's (1987) model by including Harris-Todaro type unemployment. Panagariya (1992) studies the welfare implications of duty exemption on imported inputs to produce exports with a model for a small country and three final goods.

[8]Costinot, Rodríguez-Clare, and Werning (2016); Demidova and Rodriguez-Clare (2009); Demidova (2017); and Felbermayr, Jung, and Larch (2013) study optimal tariffs in models of heterogeneous firms with different setups. Balistreri, Hillberry, and

gies with different intensities of foreign inputs, our model suggests that duty exemption could induce specialization in production activities that use foreign intermediates more intensively, reducing the scale of domestic intermediate production and triggering a Dutch disease.

Our paper is organized as follows. Section 2 presents our model. In Section 3, we derive the model's implication for how duty exemption affects welfare in the host country. Section 4 describes the data and model's estimation. In Section 5, we conduct counterfactual experiments to quantify the costs and benefits with duty exemption. Section 6 concludes.

2 Model

To show how duty exemption could trigger a Dutch disease in the implementation country, we extend the EKK model in two dimensions. First, we add a processing trade regime in which firms can enjoy duty exemption for imported inputs but have to export the resulting outputs. Second, firms can access two production technologies, with one using imported intermediate goods more intensively than the other.

The world economy is comprised of $i = 1, 2, ..., N$ countries. Each country i is endowed with a continuum of labor with measure L_i. Labor is the only primary factor of production. Labor is mobile within countries, but immobile across countries. To focus on effects of duty exemption on the implementation country, we consider the scenario in which only one country–country 1–establishes a processing trade regime in parallel with an ordinary trade regime, and firms in country 1 can access two production technologies, while other country $i \neq 1$ operates only an ordinary trade regime, and firms in these countries only have access to one technology to make composite intermediate goods as in the EKK model.

2.1 Setup

Preferences. A representative consumer in country i consumes composite manufacturing goods, Q_i^R, and non-manufacturing goods, Q_i^N, gaining utility according to the following functional form

$$U_i = \left(Q_i^R\right)^{\gamma_i} \left(Q_i^N\right)^{1-\gamma_i} \tag{1}$$

where γ_i is the share of income spent on manufacturing goods in country i. Non-manufacturing goods are non-tradable and produced one-for-one from labor in each country i.

Regular and Foreign-inputs-biased Technology. There are two production technologies available in country 1, with one using imported inputs more intensively than the other. We refer to the technology

Rutherford (2011) and Costinot and Rodríguez-Clare (2014) compare the welfare effects of tariff changes in models of heterogeneous firms with alternative quantitative trade models. Felbermayr, Jung, and Larch (2015) derive a formula for welfare change through tariffs that is similar to the formula for welfare change through iceberg trade costs in Arkolakis, Costinot, and Rodriguez-Clare (2012). Caliendo, Feenstra, Romalis, and Taylor (2015) use a multi-sector, heterogeneous firm trade model to study the trade and welfare effects of trade liberalization over the period from 1990 to 2010.

using foreign inputs more intensively as foreign-inputs-biased technology, and the other technology as regular technology. We use subscript R to denote the Regular technology, and subscript B to the foreign-inputs-Biased technology. Let subscript T denote the type of technology that can be either R or B. There is only one technology available in country $i \neq 1$, which is therefore referred to as regular technology.

Let Q_i^R denote manufacturing composite goods that is aggregated by regular technology in country i. Q_i^R is used in both firm production and final consumption, and is given by

$$Q_i^R = \left(\sum_{k=1}^{N} \int_{\omega \in \Omega_{ik}} f_{ik}(\omega) \alpha_{ik}(\omega)^{1/\sigma} q_{ik}(\omega)^{(\sigma-1)/\sigma} d\omega \right)^{\sigma/(\sigma-1)}, \tag{2}$$

where $\sigma > 1$ is the elasticity of substitution, Ω_{ik} is the set of manufacturing goods from country k available in country i, $\alpha_{ik}(\omega)$ is an exogenous demand shock specific to good ω in country i, and $f_{ik}(\omega)$ is the probability that good ω reaches buyers in country i. Each consumer in country i has access to a potentially different set of manufacturing goods, but the measure of manufacturing goods across consumers is identical and the corresponding distributions of prices are identical. The associated price index of Q_i^R is given by

$$P_i^R = \left(\sum_{k=1}^{N} \int_{\omega \in \Omega_{ik}} f_{ik}(\omega) \alpha_{ik}(\omega) p_{ik}(\omega)^{(1-\sigma)} d\omega \right)^{1/(1-\sigma)}, \tag{3}$$

where $p_{ik}(\omega)$ is the price of manufacturing good ω from country k in country i.

Let Q_1^B denote manufacturing composite goods that is aggregated by foreign-inputs-biased technology in country 1. We assume that Q_1^B is only used in firm production. Q_1^B is given by

$$Q_1^B = \left(\sum_{k=1}^{N} \int_{\omega \in \Omega_{1k}} f_{1k}(\omega) \left[\alpha_{1k}^B \alpha_{1k}(\omega) \right]^{1/\sigma} q_{1k}(\omega)^{(\sigma-1)/\sigma} d\omega \right)^{\sigma/(\sigma-1)}, \tag{4}$$

where α_{1k}^B measures the bias towards to inputs from country k. The associated price index of Q_1^B is given by

$$P_1^B = \left(\sum_{k=1}^{N} \int_{\omega \in \Omega_{ik}} f_{ik}(\omega) \left[\alpha_{1k}^B \alpha_{ik}(\omega) \right] p_{ik}(\omega)^{(1-\sigma)} d\omega \right)^{1/(1-\sigma)}. \tag{5}$$

Firm Production. A firm from country i can combine labor and composite intermediate goods Q_i^R to produce a differentiated good ω^R. The marginal cost is constant and given by

$$c_i \left(\omega^R \right) = \frac{\Upsilon (w_i)^\beta \left(P_i^R \right)^{1-\beta}}{z_i(\omega^R)}, \tag{6}$$

where $z_i \left(\omega^R \right)$ is the firm's efficiency, Υ is a constant, w_i is the wage rate in country i, and $\beta \geq 0$ is the share of labor cost.

A firm from country 1 could produce a second differentiated good ω^B by combining labor and Q_1^B. The marginal cost is given by

$$c_1\left(\omega^B\right) = \frac{\Upsilon(w_1)^{\beta}\left(P_1^B\right)^{1-\beta}}{z_1(\omega^B)}. \tag{7}$$

To illustrate the case in which a firm produces two goods with separate composite intermediate inputs, think of it as a firm owning two plants with identical efficiency $z_1(\omega^R) = z_1(\omega^B)$. One plant only produces good ω^R, while the other plant only produces ω^B.

Firms differ in efficiency. The measure of potential firms in country i with efficiency higher than z is

$$\mu_i^z\left(z\right) = T_i z^{-\theta}, z > 0,$$

where θ and T_i are parameters.

Trade Costs. As in the EKK model, firms pay iceberg trade costs and market penetration costs to sell in a market. We use d_{ni} to denote the iceberg trade costs of delivering goods from country i to country n, assuming that $d_{ni} \geq 1$ and $d_{ii} = 1$. Yet we impose that market penetration costs are firm-product-destination-specific. To sell to a fraction f of potential buyers in market n, a firm from country i selling ω^T produced with Q_i^T in country n must incur a market penetration cost

$$E_{ni}\left(\omega^T\right) = \varepsilon_n\left(\omega^T\right) E_{ni}^T M\left(f\right),$$

where E_{ni}^T is the constant component of the cost faced by all firms from country i selling goods produced with Q_i^T in destination n; and $\varepsilon_n\left(\omega^T\right)$ is the fixed cost shock specific to good ω^T in market n. The function $M\left(f\right) = \frac{1-(1-f)^{1-1/\lambda}}{1-1/\lambda}$, the same across destinations, relates a seller's cost of entering a market to the share of consumers it reaches there.

Ordinary and Processing Trade Regime. Each country i operates an ordinary trade regime, under which imported goods are subject to import tariff. Let τ_{ni} denote 1 plus the ad-valorem flat-rate tariff of goods imported from country i by market n.

Country 1 establishes a processing trade regime in parallel with its ordinary trade regime. Under the processing trade regime, firms can claim import tariff exemption for foreign inputs used to produce exports, but they also incur operation costs to meet the administrative requirements under processing trade regime. In practice, these costs includes using separate warehouses to store intermediate inputs and deposits required by the local custom authorities etc. We assume that these operation costs are ad-valorem. We use χ to denote this iceberg operation costs under processing trade regime.

Under such a policy, a country's total imports can be seen as containing two categories. The first is duty-free processing imports, used to produce processing exports. The second is ordinary imports that are not exempted from import duties. We refer to all final and intermediate exports except processing exports as ordinary exports. To simplify the exposition, let O and P denote ordinary and processing trade regime, respectively. Let TM denote trade regime that can be O or P.

2.2 Arranging Production under Trade Regimes

As there are two technologies and two trade regimes in country 1, firms in country 1 need to decide how to arrange production under trade regimes. We start by showing how firms decide to put production with Q_1^R under ordinary or processing trade regimes. The unit cost to a potential firm from country 1 with efficiency $z_1\left(\omega^R\right)$ delivering one unit of good ω^R to country n under ordinary trade regime is given by

$$c_{n1}^{RO}\left(\omega^R\right) = \frac{\Upsilon(w_1)^\beta \left(P_1^{RO}\right)^{1-\beta} d_{n1}}{z_1(\omega^R)}, \tag{8}$$

where P_1^{RO} is the price index of Q_1^R under ordinary trade regime. The unit cost to the firm delivering one unit of good ω^R to country $n \neq 1$ under processing trade regime is given by

$$c_{n1}^{RP}\left(\omega^R\right) = \frac{\chi\Upsilon(w_i)^\beta \left(P_i^{RP}\right)^{1-\beta} d_{n1}}{z_1(\omega^R)}, \tag{9}$$

where P_i^{RP} is the price index of Q_i^R under processing trade regime. Therefore, firms will always produce with regular technology under ordinary trade regime when $c_{n1}^{RO}\left(\omega^R\right) \leq c_{n1}^{RP}\left(\omega^R\right)$, and under the processing trade regime otherwise. We can calculate P_1^{RO} and P_1^{RP} according to equation (3). The only difference is that imported goods aggregated in Q_1^R are subject to tariffs under ordinary trade regime, and duty-free under processing trade regime.

Similarly, the unit cost to a potential firm from country 1 with efficiency $z_1\left(\omega^B\right)$ delivering one unit of good ω^B to country n under the trade regime TM is given by

$$c_{n1}^{BTM}\left(\omega^B\right) = \begin{cases} \frac{\Upsilon(w_1)^\beta \left(P_1^{BO}\right)^{1-\beta} d_{n1}}{z_1(\omega^B)}, & \text{if } TM = O, \\ \frac{\chi\Upsilon(w_1)^\beta \left(P_1^{BP}\right)^{1-\beta} d_{n1}}{z_1(\omega^B)}. & \text{if } TM = P. \end{cases}$$

Firms from country 1 will always produce with foreign-inputs-biased technology under ordinary trade regime when $c_{n1}^{BO}\left(\omega^B\right) \leq c_{n1}^{BP}\left(\omega^B\right)$, and under processing trade regime otherwise.

The operational cost of processing trade, χ, determines how firms arranging production under trade regimes. When χ is very small, firms always produce under processing trade regime as the benefits of duty-free imported inputs outweigh the costs with operating under processing trade regime. When χ is very large, firms always produce under ordinary trade regime as the benefits of duty-free imported inputs cannot compensate the costs with operating under processing trade regime. For the intermediate values of χ, firms sell in foreign markets with goods produced by regular technology under ordinary trade regime, and with goods produced by foreign-inputs-biased technology under processing trade regime.

As we observe both processing and ordinary exports in countries like Mexico and China, the only empirical relevant case is χ with intermediate values.[9] There is a one-to-one mapping between production and trade regime under this case, so we use R to denote RO, and B to BP. For example, P_1^B is the price index of Q_1^B under processing trade regime, and P_1^R is the price index of Q_1^R under ordinary trade regime.

2.3 Firm Optimization

Now we have all the information needed to solve the firm's optimization problem. The demand for good ω from country i in market n is given by

$$X_{ni}(\omega) = \alpha_n(\omega) f p^{1-\sigma} A_{ni},$$

where A_{ni} is the demand shifter for every good from country i selling in market n, which is given by

$$A_{ni} = \begin{cases} X_1^R \left(P_1^R/\tau_{1i}\right)^{(\sigma-1)} + \alpha_{1i}^B X_1^B \left(P_1^B\right)^{(\sigma-1)}, & \text{if } n = 1, \\ X_n^R \left(P_n^R/\tau_{ni}\right)^{(\sigma-1)}, & \text{if } n \neq 1. \end{cases} \tag{10}$$

where X_n^R is total expenditure on the composite good Q_n^R in country n, including final consumption and input expenditure by production with the regular technology, and X_n^B is total expenditure on the composite good Q_n^B, including only input expenditure by production with foreign-inputs-biased technology. $X_n^B = 0$ in country $n \neq 1$. $X_n \equiv X_n^R + X_n^B$ is the total absorption of manufactures in country n.

Given the constant return to scale production technology, perfect sorting between technologies and trade regimes and the separability of the firm-product-market-specific market penetration costs, the decision of a firm to sell a given product to a given market is independent of the decision to sell a different product to the market, and the decision to sell any products in other markets.

Under the ordinary trade regime, a firm producing good ω^R in country i selling in market n with unit cost $c_n^R\left(\omega^R\right)$ chooses price p and a fraction f of buyers to maximize its profit in the market:

$$\max_{p,f} \left(\frac{p - c_n^R\left(\omega^R\right)}{p}\right) \alpha_n\left(\omega^R\right) f p^{1-\sigma} A_{ni} - \varepsilon_n\left(\omega^R\right) E_{ni}^R M(f)$$

The following describes a firm's behavior under ordinary trade regime in market n in terms of its unit cost $c_n^R\left(\omega^R\right) = c$, demand shock $\alpha_n\left(\omega^R\right) = \alpha$, and entry shock $\eta_n\left(\omega^R\right) = \frac{\alpha_n\left(\omega^R\right)}{\varepsilon_n\left(\omega^R\right)} = \eta$. Solving the

[9] In our quantitative exercises, we calibrate χ such that firms are indifferent with arranging production with regular technology under ordinary and processing trade.

maximization problem yields

$$\begin{aligned} p_n(c) &= \overline{m}c, \text{ where } \overline{m} = \frac{\sigma}{\sigma-1} && (11)\\ f_{ni}^R(\eta, c) &= \begin{cases} 0, & \text{if } c > \overline{c}_{ni}^R(\eta); \\ 1 - \left(\frac{c}{\overline{c}_{ni}^R(\eta)}\right)^{\lambda(\sigma-1)}, & \text{if } c \le \overline{c}_{ni}^R(\eta), \end{cases} && (12) \end{aligned}$$

where

$$\overline{c}_{ni}^R(\eta) = \frac{1}{\overline{m}}\left(\eta \frac{1}{\sigma E_{ni}^R} A_{ni}\right)^{1/(\sigma-1)}. \tag{13}$$

Under the processing trade regime, a firm producing good ω^B in country 1 selling in market n with unit cost $c_n^B(\omega^B)$ chooses price p and a fraction f of buyers to maximize its profit in the market:

$$\max_{p,f} \left(\frac{p - c_n^B(\omega^B)}{p}\right) \alpha_n\left(\omega^B\right) f p^{1-\sigma} A_{ni} - \varepsilon_n\left(\omega^B\right) E_{n1}^B M(f)$$

Similarly, a firm's behavior under processing trade regime in market n can be also described in terms of unit cost, demand shock and entry shock related to the good produced with foreign-inputs-biased technology, which is given by

$$\begin{aligned} p_n(c) &= \overline{m}c, \text{ where } \overline{m} = \frac{\sigma}{\sigma-1} && (14)\\ f_{n1}^B(\eta, c) &= \begin{cases} 0, & \text{if } c > \overline{c}_{n1}^B(\eta); \\ 1 - \left(\frac{c}{\overline{c}_{n1}^B(\eta)}\right)^{\lambda(\sigma-1)}, & \text{if } c \le \overline{c}_{n1}^B(\eta), \end{cases} && (15) \end{aligned}$$

where

$$\overline{c}_{n1}^B(\eta) = \frac{1}{\overline{m}}\left(\eta \frac{1}{\sigma E_{n1}^B} A_{n1}\right)^{1/(\sigma-1)}. \tag{16}$$

The measure of goods that are produced with technology T and can be delivered from country i to country n at unit cost below c is

$$\mu_{ni}^T(c) = \Phi_{ni}^T c^\theta,$$

where

$$\Phi_{ni}^T = \begin{cases} T_i\left[\Upsilon(w_i)^\beta \left(P_i^R\right)^{1-\beta} d_{ni}\right]^{-\theta}, & \text{if } T = R, \\ T_1\left[\chi\Upsilon(w_1)^\beta \left(P_1^B\right)^{1-\beta} d_{n1}\right]^{-\theta}, & \text{if } T = B, n \neq 1 \text{ and } i = 1, \\ T_1\left[\Upsilon(w_1)^\beta \left(P_1^R\right)^{1-\beta} d_{n1}\right]^{-\theta}, & \text{if } T = B, n = 1 \text{ and } i = 1, \\ 0, & \text{if } T = B, \text{ and } i \neq 1. \end{cases} \tag{17}$$

Firms from country i that can deliver one unit of goods with costs lower than $\bar{c}_{ni}^{T}$ will produce with technology T and sell in market n. The total sales of goods produced with technology T can be written as

$$X_{ni}^{T}\left(\alpha,\eta,c\right)=\frac{\alpha}{\eta}\left[1-\left(\frac{c}{\bar{c}_{ni}^{T}\left(\eta\right)}\right)^{\lambda(\sigma-1)}\right]\left(\frac{c}{\bar{c}_{ni}^{T}\left(\eta\right)}\right)^{-(\sigma-1)}\sigma E_{ni}^{T} \tag{18}$$

To summarize, the relevant features of market n that apply across firms from country i are the demand shifter, A_{ni}, and the common component of the fixed cost E_{ni}^{T} for goods produced with technology T. Firms that produce with regular technology under ordinary trade and sell to market n differ in unit costs $c_{n}^{R}(\omega^{R})$, demand shocks $\alpha_{n}(\omega^{R})$, and entry shocks $\eta_{n}(\omega^{R})$. We treat the firm regular technology specific shocks $\alpha_{n}(\omega^{R})$ and $\eta_{n}(\omega^{R})$ as realizations of draws from the joint distribution $g^{R}(\alpha,\eta)$, which is identical across destinations and independent of $c_{n}^{R}(\omega^{R})$. Similarly, firms producing with foreign-inputs-biased technology under processing trade also differ in unit costs $c_{n}^{B}(\omega^{B})$, demand shocks $\alpha_{n}(\omega^{B})$, and entry shocks $\eta_{n}(\omega^{B})$. We treat the firm foreign-inputs-biased technology specific shocks as realizations of draws from the joint distribution $g^{B}(\alpha,\eta)$, which is identical across destinations n and independent of $c_{n}(\omega^{B})$.

2.4 Aggregation

Price Indices. According to equations (3), (14) and (16), we know the set of manufacturing goods available in country n, the price of each good in the set, and the probability that each good reaches buyers in country n. Then we can obtain price indices by using equation (3). The price index of Q_{n}^{R} is thus given by[10]

$$\left(P_{n}^{R}\right)^{1-\sigma}=\left(\overline{m}\right)^{-\theta}\sum_{i=1}^{N}\Psi_{ni}\left[A_{ni}\left(\tau_{ni}\right)^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}, \tag{19}$$

where $\Psi_{ni}=\sum_{T}\Psi_{ni}^{T}$, and

$$\Psi_{ni}^{T}=\kappa_{1}^{T}\Phi_{ni}^{T}\left(\tau_{ni}\right)^{-\theta}\left(\frac{1}{\sigma E_{ni}^{T}}\right)^{\theta/(\sigma-1)-1}, \tag{20}$$

and $\kappa_{1}^{T}=\left(\frac{\theta}{\theta-(\sigma-1)}-\frac{\theta}{\theta+(\sigma-1)(\lambda-1)}\right)\int\int\alpha\eta^{\theta/(\sigma-1)-1}g^{T}\left(\alpha,\eta\right)d\alpha d\eta$. Similarly, we obtain the price index of Q_{1}^{B}

$$\left(P_{1}^{B}\right)^{1-\sigma}=\left(\overline{m}\right)^{-\theta}\sum_{i=1}^{N}\alpha_{1i}^{B}\left(\tau_{1i}\right)^{\sigma-1}\Psi_{1i}\left(A_{1i}\left(\tau_{1i}\right)^{(\sigma-1)}\right)^{\theta/(\sigma-1)-1}. \tag{21}$$

There are two reasons that why P_{1}^{B} is different from P_{1}^{R}. First, the input mix in a unit of Q_{1}^{R} differs from that in a unit of Q_{1}^{B}. Second, imported intermediate goods aggregated in Q_{1}^{B} are duty-free.

[10]Derivation of equation (19) and (21) is given in the Appendix A.1.

Trade Shares. We start by the case that $n=1$ and $i=1$. We can first break down country 1's expenditure into X_1^R and X_1^B. Within each of these two categories, spending on goods from country 1 can be further broken down depending on the technology with which they are produced in country 1. Thus, country 1's expenditure on goods from country 1 can be divided into four segments, as shown in Figure 1.

The first two segments relate to spending on goods from country 1 aggregated in X_1^R. This comprises (i) goods from country 1 produced with its regular technology, with its share denoted as $\pi_{11}^{R,R}$ and the expenditure on such goods being $\pi_{11}^{R,R}X_1^R$; and (ii) goods from country 1 produced with its foreign-inputs-biased technology whose share among X_1^R is captured by $\pi_{11}^{R,B}$, thus expenditure on such goods being $\pi_{11}^{R,B}X_1^R$.

The other two parts speak to country 1's spending on goods from country 1 aggregated in X_n^B. This consists of (iii) goods from country $i=1$ produced with its regular technology, with its share denoted as $\pi_{11}^{B,R}$ and the expenditure on such goods being $\pi_{11}^{B,R}X_1^B$; and (iv) goods from country $i1$ produced with its foreign-inputs-biased technology whose share is denoted as $\pi_{11}^{B,B}$, and $\pi_{11}^{B,B}X_1^B$ is the expenditure on such goods.

We continue to define four trade shares $\pi_{ni}^{R,R}$, $\pi_{ni}^{R,B}$, $\pi_{ni}^{B,R}$ and $\pi_{ni}^{B,B}$ for the rest cases that either $n\neq 1$ or $i\neq 1$, which are going to be handy to define the equilibrium. In the case of $n=1$ and $i\neq 1$, $\pi_{1i}^{R,R}$ and $\pi_{1i}^{B,R}$ are well-defined. For example, $\pi_{1i}^{R,R}$ denotes the share of X_1^R that spends on good from country $i\neq 1$ produced with technology R. As there only exist technology R in country $i\neq 1$, we set $\pi_{1i}^{R,B}=\pi_{1i}^{B,B}=0$. In the case of $n\neq 1$ and $i=1$, $\pi_{n1}^{R,R}$ and $\pi_{n1}^{R,B}$ are well-defined. We set $\pi_{n1}^{B,R}=\pi_{n1}^{B,B}=0$ as $X_n^B=0$. In the case of $n\neq 1$ and $i\neq 1$, $\pi_{ni}^{R,R}$ is well-defined, and we set $\pi_{ni}^{B,R}=\pi_{ni}^{R,B}=\pi_{ni}^{B,B}=0$ as there does not exist technology B in both country $n\neq 1$ and $i\neq 1$.

To obtain $\pi_{ni}^{R,T}$, we calculate the total amount with given values of the demand shock α and entry shock η, then integrate across the joint density $g^R(\alpha,\eta)$ and divided by X_n^R, yielding

$$\pi_{ni}^{R,T}=\begin{cases}\dfrac{\Psi_{ni}^R\left[A_{ni}(\tau_{ni})^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}}{\sum_{k=1}^N\Psi_{nk}\left[A_{nk}(\tau_{nk})^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}}, & \text{if } T=R,\\ \dfrac{\Psi_{n1}^B\left[A_{n1}(\tau_{n1})^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}}{\sum_{k=1}^N\Psi_{nk}\left[A_{nk}(\tau_{nk})^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}}, & \text{if } T=B \text{ and } i=1,\\ 0 & \text{if } T=B \text{ and } i\neq 1.\end{cases} \tag{22}$$

To obtain $\pi_{ni}^{B,T}$, we calculate the total amount with given values of the demand shock α and entry

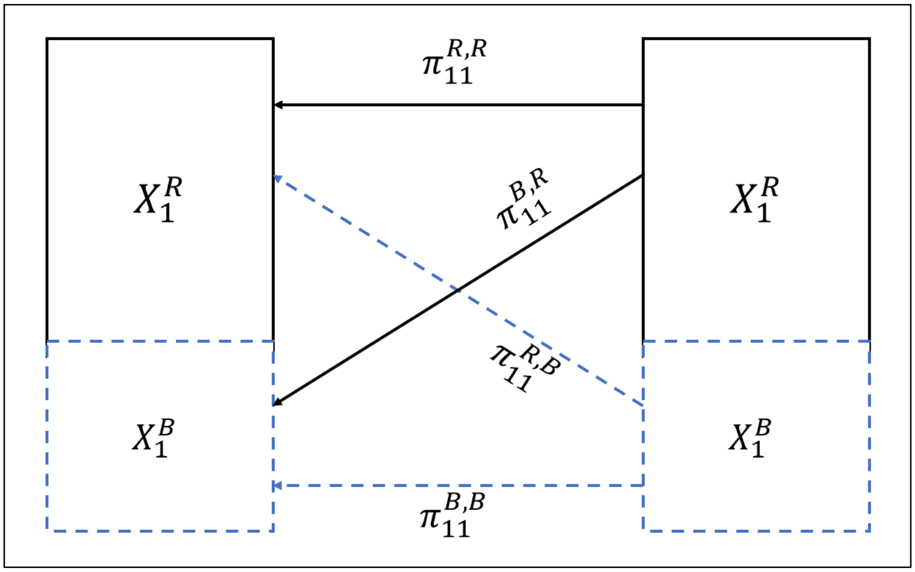

Figure 1: Decomposition of Country 1's Expenditure on Domestic Manufacturing Goods: Country 1's expenditure on domestic manufacturing goods are divided into four parts. $\pi_{11}^{R,R}X_1^R$ is the part in X_1^R that spends on domestic goods produced with regular technology; $\pi_{11}^{R,B}X_1^R$ is the part in X_1^R that spends on domestic goods produced with foreign-inputs-biased technology; $\pi_{11}^{B,R}X_1^B$ is the parts in X_1^B that spends on domestic goods produced with regular technology; and $\pi_{11}^{B,B}X_1^B$ is the part in X_1^B that spends on domestic goods produced with foreign-inputs-biased technology.

shock η, then integrate across the joint density $g^B(\alpha,\eta)$ and divided by X_n^B, yielding

$$\pi_{ni}^{B,T} = \begin{cases} 0, & \text{if } n \neq 1 \\ \dfrac{\alpha_{1i}^B(\tau_{1i})^{\sigma-1}\Psi_{1i}^R\left[A_{1i}(\tau_{1i})^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}}{\sum_{k=1}^N \alpha_{1k}^B(\tau_{1k})^{\sigma-1}\Psi_{1k}\left[A_{1k}(\tau_{1k})^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}}, & \text{if } n=1 \text{ and } T=R, \\ 0, & \text{if } n=1,\ T=B \text{ and } i\neq 1 \\ \dfrac{\alpha_{11}^B(\tau_{11})^{\sigma-1}\Psi_{11}^B\left[A_{11}(\tau_{11})^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}}{\sum_{k=1}^N \alpha_{1k}^B(\tau_{1k})^{\sigma-1}\Psi_{1k}\left[A_{1k}(\tau_{1k})^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}}, & \text{if } n=1,\ T=B \text{ and } i=1 \end{cases} \tag{23}$$

We now can compare the share of X_1^B that spends on goods from country i with the share of X_1^R. Let π_{1i}^B denote the share of X_1^B on goods from country i, and $\pi_{1i}^B \equiv \pi_{1i}^{B,R} + \pi_{1i}^{B,B}$ Similarly, let π_{1i}^R denote the share of X_1^B that spends on goods from country i, and $\pi_{1i}^R \equiv \pi_{1i}^{R,R} + \pi_{1i}^{R,B}$. Dividing π_{1i}^B by π_{1i}^R yields

$$\frac{\pi_{1i}^B}{\pi_{1i}^R} = \alpha_{1i}^B\left(\frac{P_1^B}{P_1^R}\tau_{1i}\right)^{(\sigma-1)}. \tag{24}$$

Note that α_{1i}^B measures relative efficiency of inputs from country i in production with foreign-inputs-biased technology. A larger value of α_{ni}^B implies a higher share of X_1^B that spends on inputs from country

i relative to the share of X_1^R. Refer to the left hand side of equation (24) as the relative expenditure share. A higher value of τ_{ni} also leads a higher relative expenditure share. Similarly, a greater substitutability among goods–a larger value of σ–also causes a higher relative expenditure share.

Equilibrium. We write country n's total absorption of manufactures as the sum of demand for final consumption and demand for intermediates:

$$X_n^R + X_n^B = \gamma I_n + \sum_{i=1}^{N} \frac{(1-\beta)}{\overline{m}} \left(\pi_{in}^R \frac{X_i^R}{\tau_{in}} + \pi_{in}^B X_i^B \right), \tag{25}$$

and the absorption of manufactures by processing production is given by

$$X_n^B = \frac{(1-\beta)}{\overline{m}} \sum_{i \neq n} \left(\pi_{in}^{R,B} \frac{X_i^R}{\tau_{in}} + \pi_{in}^{B,B} X_i^B \right), \tag{26}$$

where

$$I_n = w_n L_n + R_n + D_n^A + \Pi_n,$$

represents total income in country n, as the sum of labor income, tariff revenues R_n, the overall trade deficit, and profits Π_n. The tariff revenues in country n equal the sum of tariffs on goods imported under ordinary trade

$$R_n = \sum_{i=1}^{N} (\tau_{ni} - 1) \frac{\pi_{ni}^R}{\tau_{ni}} X_n^R.$$

The profits equal the gross profits minus market penetration costs

$$\Pi_n = \frac{1}{\sigma} \sum_{i=1}^{N} \left(\pi_{in}^R \frac{X_i^R}{\tau_{in}} + X_i^B \pi_{in}^B \right) - \frac{1}{\sigma} \frac{\theta - (\sigma - 1)}{\theta} \sum_{i=1}^{N} \left(\pi_{in}^R X_i^R + X_i^B \pi_{in}^B \right).$$

Finally, using the definition of expenditure and trade deficit yields

$$\sum_{i=1}^{N} \left(\pi_{ni}^R \frac{X_n^R}{\tau_{ni}} + \pi_{ni}^B X_n^B \right) - D_n = \sum_{i=1}^{N} \left(\pi_{in}^R \frac{X_i^R}{\tau_{in}} + \mathbb{I}_i^P \pi_{in}^B X_i^B \right). \tag{27}$$

This condition reflects that total expenditure, excluding tariff payments, in country n minus trade deficits equals the sum of each country's total expenditure, excluding tariff payments, on manufacturing goods from country n.

We assume that fixed costs are in units of labor in the destination. We thus decompose the country-technology-specific component of market penetration costs $E_{ni}^R = w_n F_{ni}^R$ and $E_{ni}^B = w_n F_{ni}^B$, where F_{ni}^R and F_{ni}^B reflect the labor required for entry for goods from i in market n that are produced with different types of technologies. Each country n's manufacturing deficit D_n and overall trade deficit D_n^A are exogenously given. We now formally define the equilibrium under tariff $\{\tau_{ni}\}$ and a processing trade regime in country 1 in this model.

Definition 1: Given L_n, D_n, D_n^A, α_{1i}^B, d_{ni} and F_{ni}^T, an equilibrium under the tariff structure and a processing trade regime in country 1, is a wage vector $\mathbf{w} \in \mathbf{R}_{++}^N$ and price vectors $\left(\mathbf{P}^R, P_1^B\right) \in \mathbf{R}_{++}^{N+1}$ that satisfy equilibrium conditions (19) (21) (22) (23) (25) (26), and (27) for all n.

3 Welfare Implications

We now turn to the model's implication for how duty exemption affects welfare in the implementation country. We are interested in overall welfare, as measured by real income.

3.1 Welfare Effects of Duty Exemption

We consider moving from the equilibrium in which country 1 does not offer duty exemption on processing imports to the equilibrium in which country 1 allows duty exemption. The change in real income of country 1 can be decomposed as follows.

Proposition 1. *Consider moving from the equilibrium in which country* 1 *does not offer duty exemption on processing imports to the equilibrium in which country* 1 *allows duty exemption. Denote any value in the new equilibrium of x as x', and define $\hat{x} = x'/x$ as its change.*

(1) The change in real income of country 1 *satisfies*

$$\ln\left(\frac{\hat{I}_1}{(\hat{w}_1)^{1-\gamma_1}(\hat{P}_1^R)^{\gamma_1}}\right) = \ln\left(\frac{\hat{w}_1}{\hat{P}_1^R}\right)^{\gamma_1} + \ln\left(\frac{w_1 L_1}{I_1} + \frac{R_1}{I_1}\frac{\hat{R}_1}{\hat{w}_1} + \frac{\Pi_1}{I_1}\frac{\hat{\Pi}_1}{\hat{w}_1}\right). \tag{28}$$

(2) The change in real wage in country 1 *satisfies*

$$\ln\left(\frac{\hat{w}_1}{\hat{P}_1^R}\right)^{\gamma_1} = \underbrace{\frac{\gamma_1}{\beta\theta}\ln\left(\frac{1}{\hat{\pi}_{11}^R}\right)}_{\textit{Direct Effect}} + \underbrace{\left(\frac{\gamma_1}{\beta(\sigma-1)} - \frac{\gamma_1}{\beta\theta}\right)\ln\left(\frac{\hat{X}_1}{\hat{w}_1}\frac{\frac{X_1^{O'}}{X_1'} + \frac{X_1^{B'}}{X_1'}\frac{\pi_{11}^{B'}}{\pi_{11}^{R'}}}{\frac{X_1^R}{X_1} + \frac{X_1^B}{X_1}\frac{\pi_{11}^B}{\pi_{11}^R}}\right)}_{\textit{Market Size Effect}}. \tag{29}$$

Proof. See Appendix A.2. □

Equation (28) shows that the change in real income of country 1 can be decomposed into the change in real wage and the weighted sum of changes in profits and tariff revenue. As profits are almost proportional to wages, the term $\ln\left(\frac{w_1 L_1}{I_1} + \frac{R_1}{I_1}\frac{\hat{R}_1}{\hat{w}_1} + \frac{\Pi_1}{I_1}\frac{\hat{\Pi}_1}{\hat{w}_1}\right)$ basically captures the change in tariff revenue. Thus, real income decreases through this term because duty exemption reduces tariff revenue.

As shown in equation (29), the change in real wage in country 1 can be further decomposed into gains from expanding the imported input varieties and losses from shrinking the scale of domestic intermediate production. We refer to former as *direct effect* and the latter as *market size effect*.

The *direct effect* captures welfare gains from the decline in the price index of imported inputs. In particular, duty exemption reduces the production costs of processing producers and thereby increases the demand for domestic labor. This effect is standard and has been emphasized by Brandt et al. (2018).

Our new *market size effect* captures welfare losses from the shrinking scale of the domestic intermediate production. The scale of domestic intermediate production is determined by the demand for domestic manufactures in country 1, which is measured by $\frac{X_1}{w_1}\left(\frac{X_1^R}{X_1}+\frac{X_1^B}{X_1}\frac{\pi_{11}^B}{\pi_{11}^R}\right)$. Notice that π_{11}^R differs from π_{11}^B so that the demand for domestic manufactures varies with the share of X_1^B in total expenditure. Specifically, duty exemption makes processing exports more competitive in the world market, shifting labor into the production activity with foreign-inputs-biased technology–expanding X_1^B while shrinking X_1^R. Since producing X_1^B requires a smaller share of domestic intermediates, duty exemption reduces the demand for domestic intermediates, shrinks the scale of domestic intermediate production, increases the price index P_1^R, and lowers the real wage.

The *market size effect* triggered by duty exemption is different from the *home market effect* triggered by lowering tariff emphasized by Venables (1987). In Venables (1987), lowering tariff decreases the price of foreign manufactures for final consumption, and the final demand for domestic manufactures decreases as they become relatively more expensive. In our model, duty exemption decreases the demand for domestic manufactures in the input market as processing exports expands, and does not directly boost the final demand for domestic manufacturing since it only applies for foreign inputs used for producing processing exports.

Notably, if the production of intermediates exhibits constant return to scale, or in our model, $\sigma \to \infty$, then the market size effect in Equation (28) diminishes. Therefore, our model departs from the Ricardian model considered in Brandt, Li, and Morrow (2018) by capturing this market size effect.

Finally, Equation (28) shows that the market size effect increases with the share of foreign inputs in the foreign-inputs-biased technology. Notice that the market size effect disappears if $\pi_{11}^B = \pi_{11}^R$, i.e. the foreign-inputs-biased technology has the same share of foreign inputs with the regular technology. Moreover, the market size effect increases with the degree of increasing returns to scale, which is measured by $\frac{1}{\sigma-1}$.

3.2 Numerical Examples

In this subsection, we use numerical examples to show how the welfare effects of duty exemption vary with the share of foreign inputs in the foreign-inputs-biased technology and with the degree of increasing returns to scale. We conduct two experiments in a two-country world. The parameter values in these numerical experiments are summarized in Table 1. In the first experiment, we fix $\sigma = 2.94$ and let α_{12}^B vary from 5 to 15. For each given value of α_{12}^B, we compute changes in labor allocation and real wage moving from the equilibrium without duty exemption to the equilibrium with country 1 offering duty exemption on processing imports. In the second experiment, we fix $\alpha_{12}^B = 10$ and let α_{12}^B vary from 2.5 to 5.5. For each given value of σ, we also compute changes in labor allocation and real wage moving from the equilibrium without duty exemption to the equilibrium with country 1 offering duty exemption on processing imports.

Table 1: Parameters of a Two-country World

Parameters	Description
$L_1 = L_2 = 10$	Labor size
$T_1 = 1, T_2 = 2$	Scale parameters of productivity distribution
$\theta = 5.66$	Shape parameter of productivity distribution
$\beta = 0.36$	Output elasticity of labor
$d_{12} = d_{21} = 1.1$	Iceberg trade costs
$\tau_{12} = \tau_{21} = 1.1$	Tariffs
$\chi = 1.0044$	iceberg operation cost under processing trade regime
$F^R_{11} = F^R_{22} = 1$, $F^R_{21} = F^R_{12} = 3$ $F^B_{11} = 1, F^B_{21} = 3$, $F^B_{12} = F^B_{22} = \infty^1$	Fixed export costs
$g^R(\alpha, \eta)$ is degenerate at $(1, 1)$ $g^B(\alpha, \eta)$ is degenerate at $(1, 1)$	Demand and entry shock distributions
$\alpha^B_{12} \in [5, 15]$	Reliance on foreign inputs of foreign-inputs-biased technology
$\sigma \in [2.5, 5.5]$	Elasticity of substitution

[1.] Assuming that $F^B_{12} = F^B_{22} = \infty^1$ is equivalent to assuming that firms in country 2 only has access to one technology for aggregating domestic and foreign inputs.

Figure 2 shows the results of the first experiment. The left panel of Figure 2 plots the change in labor used for production with foreign-inputs-biased technology against α^B_{12}–the reliance of foreign inputs of foreign-inputs-biased technology. The left panel of Figure 2 shows that duty exemption shifts more labor into production with foreign-inputs-biased technology, and the impact is larger with larger value of α^B_{12}. The right panel of Figure 2 plots the change in real wage against α^B_{12}, and it shows that duty exemption can actually decrease real wage, and the decrease is larger for the larger value of α^B_{12}.

Figure 3 shows the results of the second experiment. The left panel of Figure 3 plots the change in labor used for production with foreign-inputs-biased technology against σ–the level of increasing returns to scale. The left panel of Figure 3 shows that duty exemption shifts more labor into production with foreign-inputs-biased technology, but the change in labor is increasing with σ first, then decreasing.[11] The right panel of Figure 3 plots the change in real wage against σ, and the relationship is also not monotone. Duty exemption can increases real wage when σ is large (for example, $\sigma = 5$), which implies that the market size effect is dominated by the direct effect with lesser degree of increasing returns to scale.

[11] A higher value of σ implies a larger change in the intensive margin of trade triggered by duty exemption, but also a smaller change in the extensive margin of trade. These two forces jointly determine the change in the competitiveness of processing exports, but work in opposite directions, which generates the non-monotone relationship between the change in labor and σ.

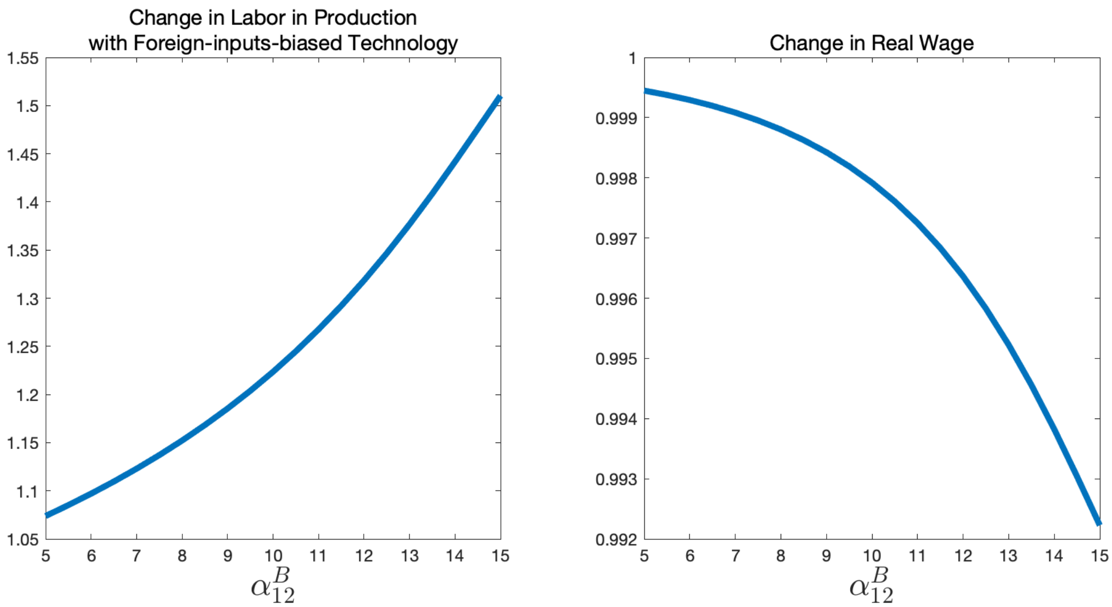

Figure 2: Changes in Labor Allocation and Real Wage w.r.t the Reliance on Foreign Inputs of Foreign-inputs-Biased Technology, α_{12}^{B}

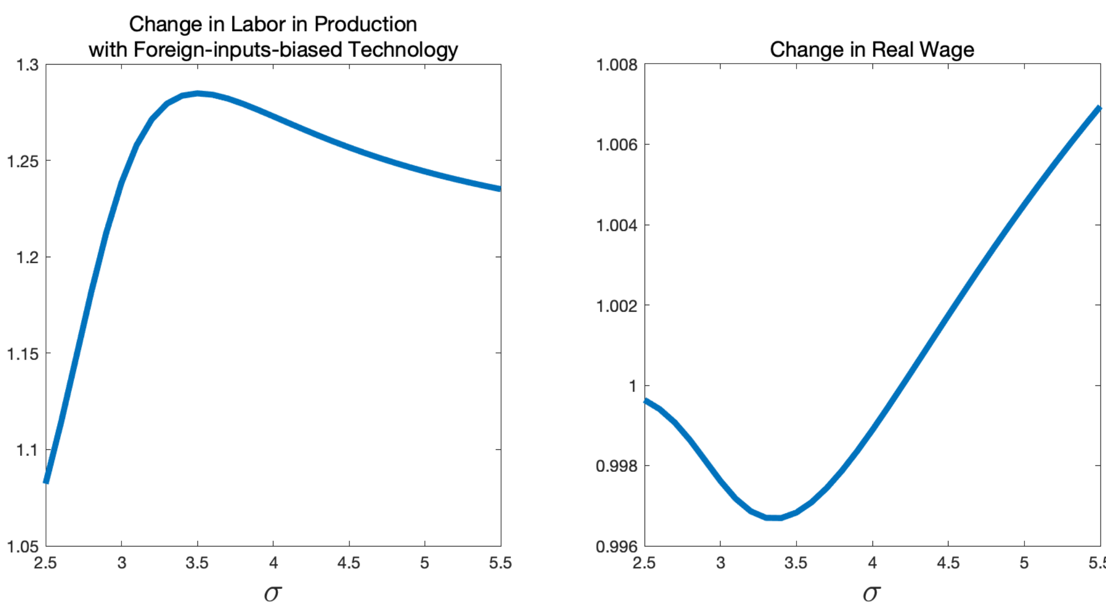

Figure 3: Changes in Labor Allocation and Real Wage w.r.t the Level of Increasing Returns to Scale (determined by the elasticity of substitution σ)

3.3 Comparing the Duty Exemption with and Uniform Changes in Tariffs for All Imports

To compare duty exemption with other forms of foreign shocks, such as changes in the iceberg trade costs and uniform changes in tariffs, we rewrite equation (29) as follows

$$\ln\left(\frac{\hat{w}_1}{\hat{P}_1^R}\right)^{\gamma_1} = \frac{\gamma_1}{\beta\theta} \underbrace{\ln\left(\frac{1}{\hat{\pi}_{11}}\right)}_{\substack{\text{change in}\\\text{openness}}} + \left(\frac{\gamma_1}{\beta(\sigma-1)} - \frac{\gamma_1}{\beta\theta}\right) \underbrace{\ln\left(\frac{\hat{X}_1}{\hat{w}_1}\right)}_{\substack{\text{change in}\\\text{total expenditure}}}$$

$$+ \frac{\gamma_1}{\beta(\sigma-1)} \underbrace{\ln\left(\frac{\frac{X_1^{R'}}{X_1'} + \frac{X_1^{B'}}{X_1'}\frac{\pi_{11}^{B'}}{\pi_{11}^{R'}}}{\frac{X_1^R}{X_1} + \frac{X_1^B}{X_1}\frac{\pi_{11}^B}{\pi_{11}^R}}\right)}_{\substack{\text{change in demand}\\\text{for domestic manufactures}}}. \tag{30}$$

The first term on the right-hand side of Equation 30 is identical to the sufficient statistics of welfare changes derived in Arkolakis et al. (2012) (henthforth ACR). This standard ACR term, associated with the second term on the right-hand side of Equation 30, captures the welare effects of a uniform tariff change for all imports. The third term on the right-hand side of Equation 30 highlights the distinctive features of duty exemption: it only applies for foreign inputs used for producing processing exports and thereby triggers labor reallocation towards production activities with very low domestic value-added shares.

4 Model's Estimation

In this section, we first describe the data. We then go through the structural estimation of two key parameters for our quantitative analysis: elasticity of substitution and trade elasticity. Last, we present the estimation results.

4.1 Data and Descriptive Statistics

To stimulate exports and economic growth, China has designated a processing trade regime, in parallel with the ordinary trade regime since mid-1980s. Chinese custom authorities distinguish the processing trade regime from the ordinary trade regime. Under the processing regime, imported material and components used in the production of final exported goods are exempted from tariffs. The duty exemption encourages the formation of processing trade relationships between local firms and overseas companies looking to offshore production to China. To become eligible to import under the processing regime, a firm needs to sign a contract with a foreign buyer first. Only with the signed contract can the firm apply permission from its local custom authority. The permission limits the varieties and quantities of imported intermediate inputs that can enjoy duty exemption. Each permission is tied to a specific contract.

Due to the costs associated with contracting and rigid administrative procedure, some firms may completely opt out of processing trade even though they use foreign inputs to produce exports, and some firms may partially opt out. When a firm partially opts out, only the foreign inputs imported under the processing regime are duty-free, and the foreign inputs under the ordinary regime are subject to import duties. In 2005, 41% of China's total manufacturing imports are under the processing regime, equivalent to 8.9% of China's GDP, and the corresponding processing exports account for 58% percent of China's total manufacturing exports.

The main data set we use is the Chinese Customs Trade Statistics (CCTS) for year 2005 collected by the Chinese Customs Office. The CCTS covers the universal shipments moving across Chinese customs. For each shipment, the information on the firm's name, exports or imports, 8-digit Harmonized System code, value, quantity, and destination or source country etc. are available. Two distinct features of the CCTS data set are important. First, whether a shipment is under processing or ordinary trade regime is recorded. In other words, each shipment is characterized by its trade regime. Second, shipments between two domestic firms, if the corresponding goods are used as inputs to produce processing exports by the purchasing firm, are also contained in the data set, because the Chinese custom authorities consider this type of domestic shipments moving across Chinese customs.

With the CCTS data set, we can compute China's processing production's share of spending on intermediate inputs from each sourcing country including China, and China's ordinary production's share of spending on intermediate inputs from each sourcing country.[12] These intermediate expenditure shares reflect the different levels of reliance on foreign inputs between ordinary and processing production, and are used for the estimation of the elasticity of substitution.

Figure 4 plots each production's intermediate expenditure shares for 7 sources: China, Japan, Taiwan, South Korea, the United States and Germany, and all other countries. The size of a slice in each panel denotes the intermediate expenditure share of either type of production that spends on intermediate inputs from a given source. For instance, as indicated in the left panel, China's processing production spends 13.2% of its intermediate expenditure on domestic goods, and 86.8% on foreign goods; while those shares are 85.78% and 14.22% for the ordinary production. As discuss in Section 3, the drastic different levels of reliance on foreign inputs between the two types of production are important to the welfare implication of the duty exemption.

4.2 Elasticity of Substitution

From the model, duty exemption and different technologies explain the different levels of reliance on foreign inputs between processing and ordinary production. According to equation (24), the logarithm of the ratio of intermediate expenditure shares of inputs imported from country n between processing

[12] To compute ordinary production' shares of spending on intermediate inputs for all sourcing countries, we also use China's total expenditure on manufactures and assume that ordinary production's shares of spending are identical to final consumption's share of spending on manufactures for all sourcing countries.

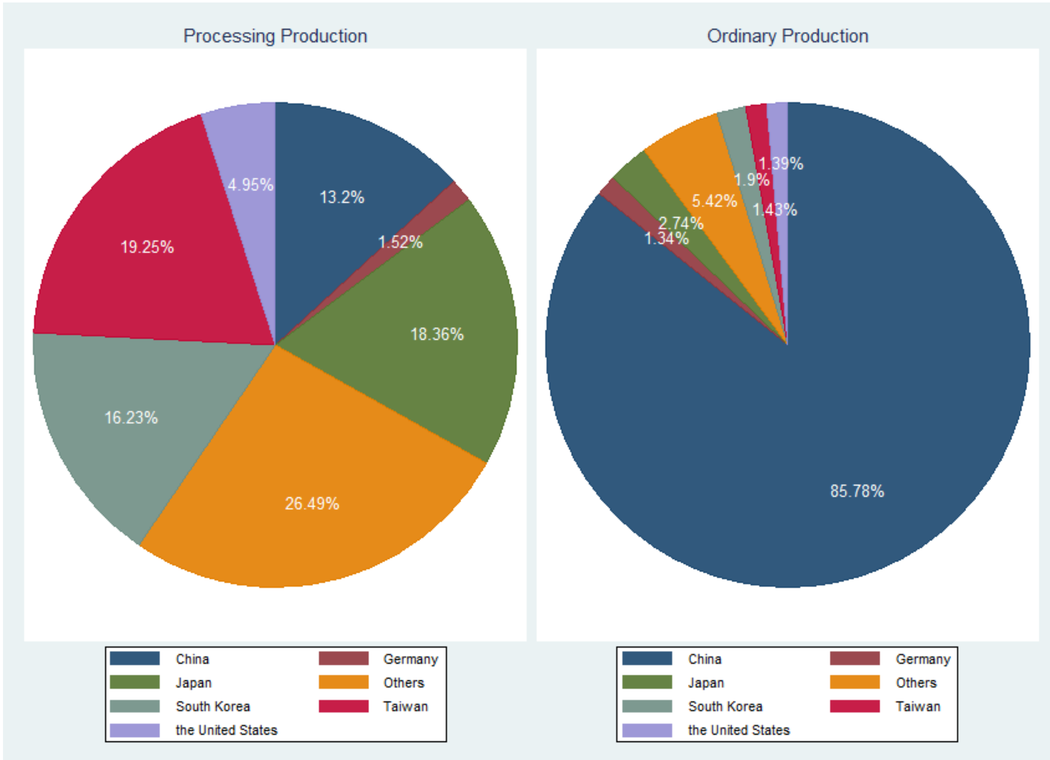

Figure 4: Input Expenditure Shares of Processing and Ordinary Production by Source Country

and ordinary production is given by

$$\ln \frac{\pi^B_{Cn}}{\pi^R_{Cn}} = (\sigma - 1) \ln \tau_{Cn} + (\sigma - 1) \ln \left(\frac{P^B_C}{P^R_C} \right) + \ln(\alpha^B_{Cn}). \tag{31}$$

The term on the left-hand side is the ratio of intermediate expenditure shares between processing and ordinary production that spend on goods from country n, and these ratios can be observed in the data.[13] Tariffs on the right-hand side are also observable in the data.[14] Although the second and third terms cannot be directly observed, year and country fixed effects can capture $(\sigma - 1) \ln \left(\frac{P^B_C}{P^R_C} \right)$ and $\ln(\alpha^B_{Cn})$, respectively. Therefore, the variation in the ratios of intermediate expenditure shares relative to the variations in tariffs can identify the elasticity of substitution measuring the degree of increase returns to scale.

The elasticity of substitution is estimated by running the following regression with data from 2000 to 2006

$$\ln \frac{\pi^B_{Cn,t}}{\pi^R_{Cn,t}} = (\sigma - 1) \ln \tau_{Cn,t} + \lambda_n + \lambda_t + \epsilon_{n,t},$$

[13]Section 4.2 have shown processing and ordinary production's intermediate expenditure shares for some sources.
[14]Construction and data source of tariffs can be found in Appendix D.3.

where λ_n indicates country fixed effects, λ_t time fixed effects, and $\epsilon_{n,t}$ the measurement error, assuming that it is orthogonal to tariffs. The estimates are reported with the other parameter estimates in section 4.4.

σ governs not only the substitutability across varieties, but also the degree of increase return to scale that is crucial for the quantification of the market size effect triggered by duty exemption. However, the structural estimation in EKK cannot separately identify the elasticity of substitution and the trade elasticity, here we propose a new strategy to estimate the elasticity of substitution. Our strategy also differ from the strategy proposed by Feenstra (1994), and refined by Broda and Weinstein (2006) in which they use U.S. data on import prices and demand over time to estimate the elasticity of substitution. The key difference is that we use tariffs and demand over time to exploit the differences in prices between the two trade regimes.

4.3 Trade Elasticity

The estimation of trade elasticity $\widetilde{\theta}$ follows EKK. We simulate a set of artificial Chinese firms under a given set of parameter values, with each firm assigned a productivity draw z, demand shock α^T and entry shock η^T. We solve each firm's entry and pricing decisions for each market under each trade regime, and compute the moments related to the entry and sales distributions across markets and trade regimes to match their counterparts in China's firm-level data. Details of data patterns about entry and sales distributions across markets and trade regimes, simulation algorithm, moments constructed and estimation procedure are provided in Appendix C.[15]

To complete the specification, we assume that $g^T(\alpha, \eta)$ is joint log normal. Specifically, $\ln \alpha^T$ and $\ln \eta^T$ are normally distributed with zero means and variances $\left(\sigma_\alpha^T\right)^2$ and $\left(\sigma_\eta^T\right)^2$, respectively, and correlation ρ^T. I can write κ_1^T and κ_2^T as

$$\kappa_1^T = \left[\frac{\widetilde{\theta}}{\widetilde{\theta}-1} - \frac{\widetilde{\theta}}{\widetilde{\theta}+\lambda-1}\right] \exp\left\{\frac{\sigma_\alpha^T + 2\rho^T\sigma_\alpha^T\sigma_\eta^T\left(\widetilde{\theta}-1\right) + \sigma_\eta^T\left(\widetilde{\theta}-1\right)^2}{2}\right\},$$

and

$$\kappa_2^T = \exp\left\{\frac{\left(\widetilde{\theta}\sigma_\eta^T\right)^2}{2}\right\}.$$

Eight parameters will be estimated:

$$\Theta = \left\{\widetilde{\theta}, \lambda, \sigma_\alpha^R, \sigma_\eta^R, \rho^R, \sigma_\alpha^B, \sigma_\eta^B, \rho^B\right\}.$$

[15]The simulation algorithm, targeted moments and estimation procedure are similar to those in EKK, so we delegate the details in the appendix. The only difference is that we add moments associated with entry and sales under processing trade, but the structure is the same. To see what data features identify these parameters, interested readers can read the discussion in EKK.

4.4 Results

Table 2 reports the estimates. We begin with the estimates of σ and $\widetilde{\theta}$, which will be used in the counterfactual exercises to answer the welfare implications of China's duty exemption with processing trade. Our estimate of σ is 2.94, which is very close to the calibrated value of σ, 2.98, in Eaton, Kortum, and Kramarz (2011). A slightly smaller σ means that manufacturing goods are less substitutable, so processing production spends a smaller share on imported intermediates with duty exemption than without for a given set of intermediates. The estimate of $\widetilde{\theta}$ is 2.92, which is larger than the estimated value of $\widetilde{\theta}$ in Eaton, Kortum, and Kramarz (2011). A larger $\widetilde{\theta}$ implies that processing production spends on a greater amount on imported intermediates with duty exemption than without it.

Table 2: Estimation Results

Parameters	σ	$\widetilde{\theta}$	λ	σ_α^R	σ_η^R	ρ^R	σ_α^B	σ_η^B	ρ^B
Estimates	2.94	2.92	1.77	1.99	0.37	0.63	2.61	0.64	0.42

The estimates of σ_α^R and σ_α^B imply huge idiosyncratic variation in firm sales across destinations, and the variation is even larger in firm sales under processing trade than ordinary trade. In particular, the ratio of the 75th to the 25th percentile of the demand shock σ_α^R is 14.69, and the ratio for σ_α^B is 34.17. The estimates of σ_η^R and σ_η^B indicate less variation in entry shocks, but the variation in entry shock under processing trade is still larger than that under ordinary trade. In particular, the ratio of the 75th to the 25th percentile of the entry shock σ_η^B is 2.37, and the ratio for σ_η^R is 1.65. Given the sales and entry shocks, the variance of sales within a market decrease in the coefficient of correlation. The estimates of ρ^R and ρ^B indicate that there is higher variation in sales under processing trade in a market than that under ordinary trade, given that variations in entry and demand are already higher under processing trade than ordinary trade. The estimate of λ means that firms reaching a small fraction of customers in a market incur a very small entry cost. In particular, a firm reaching 10% of customers only incurs one-fourteenth of the entry costs incurred by the firm reaching 90% of the customers, holding other things the same.

5 Counterfactual Experiments

We perform four counterfactual experiments to understand the welfare implication of duty exemption, what drives the welfare effects and its difference from an uniform tariff reduction. First, we directly quantifies welfare and trade effects of the duty exemption with China's processing trade, and uncovers whether direct effect or market size effect dominate the overall change of welfare. We further investigate to what extent two features of our model shape the welfare implications of duty exemption. Second, we consider an alternative model in which ordinary and processing production combine domestic and foreign inputs using the same technology. Third, we increase the elasticity of substitution across input varieties from our baseline estimate 2.94 into 4, weakening the economies of scale in input production. Finally, we compare the duty exemption with an uniform tariff reduction that generates identical reduction in tariff revenue.

Before presenting our results, it is important to note that our quantification does not intend to provide a comprehensive evaluation of the duty exemption with China's processing trade. Instead, we emphasize the quantification of the market size effect triggered by duty exemption that is absent in the previous literature and aim to understand how the features of our model determine its magnitude.

We implement our analysis to 46 economies, aggregating the rest of the world into the 47th.[16] we apply the "exact hat" method developed by Dekle, Eaton, and Kortum (2008) to compute the changes of equilibrium outcomes.[17] We assume that countries other than China only operates an ordinary trade regime, and there is only one type of technology (regular technology) for aggregating domestic and foreign inputs in these countries. In the rest of this section, we first describe the calibration of both trade shares and other parameters needed for computing counterfactual outcomes. We then present the results of the four counterfactual experiments.

5.1 Calibration Procedure

We combine data from several sources to calibrate the empirical counterparts of trade shares in the model (i.e. $\pi_{ni}^{R,R}, \pi_{ni}^{R,B}, \pi_{ni}^{B,R}, \pi_{ni}^{B,B}$). First, we obtain bilateral manufacturing trade flows M_{ni}–manufacturing imports of country n from country i–from the United Nations Statistics Division (UNSD) Commodity Trade (COMTRADE) database, excluding home sales. Second, we compute China's ordinary and processing trade flows by using CCTS, including country n's ordinary imports from China M_{nC}^{R} and processing imports from China M_{nC}^{B}, and China's processing imports from country i M_{Ci}^{B}. Third, we obtain country n's manufacturing output Y_n from the United Nations Industrial Development Organization Industrial Statistics Database. Fourth, we compute tariffs τ_{ni} by using UNSD Trade Analysis and Information System (TRAINS) database.[18]

We divide the trade shares into four cases based on whether source country i is China or not, and destination country n is China or not, and we show how to calculate them case by case. These four cases are listed in Table 3. As we assume that countries other than China only establish an ordinary trade regime, and have access to only one type of technology for aggregating domestic and foreign inputs, some of trade shares are zero implied by this assumption, which is also indicated in Table 3. Therefore, we only focus on these non-zero trade shares.

Case 1: $n \neq C$ and $i \neq C$. First, we obtain domestic sales M_{nn} in each country by computing the difference between manufactures output and total exports: $M_{nn} = Y_n - \sum_{k \neq n} M_{kn}$. Second, we calculate

[16] The list of economies can be found in Appendix D.3.
[17] The formal definition of equilibrium in relative changes is in Appendix D.2.
[18] More detailed information about these databases and computation can be found in Appendix D.3.

Table 3: Cases of Trade Shares are Assumed to Be Zeros

	$\pi_{ni}^{R,R}$	$\pi_{ni}^{R,B}$	$\pi_{ni}^{B,R}$	$\pi_{ni}^{B,B}$
$n \neq C$ and $i \neq C$	-	0	0	0
$n \neq C$ and $i = C$	-	-	0	0
$n = C$ and $i \neq C$	-	0	-	0
$n = C$ and $i = C$	-	-	-	-

Note: "0" means that trade shares are zeros implied by our assumption. "-" means that trades shares will be calibrated from data.

total expenditure on manufactures by summing up expenditures across all sources: $X_n^R = \sum_{k=1}^N M_{nk}\tau_{nk}$. Third, $\pi_{ni}^{R,R} = \frac{M_{ni}\tau_{ni}}{X_n^R}$.

Case 2: $n \neq C$ and $i = C$. Using data on China's ordinary and processing exports, we have $\pi_{nC}^{R,R} = \frac{M_{nC}^R \tau_{nC}}{X_n^R}$ and $\pi_{nC}^{R,B} = \frac{M_{nC}^B \tau_{nC}}{X_n^R}$.

Case 3: $n = C$ and $i \neq C$. First, using data on China's processing imports from country i, M_{Ci}^B, we have $\pi_{Ci}^{B,R} = \frac{M_{Ci}^B}{\sum_{k=1}^N M_{Ck}}$, where M_{CC}^B can be computed from Chinese custom data. Second, we compute the intermediate expenditure by production with foreign-inputs-biased technology according to equation (26): $X_C^B = \frac{1-\beta}{\overline{m}} \sum_{k \neq C} M_{kC}^B$. Third, we obtain the total expenditure on manufactures by final consumption and production with regular technology by summing across all sources: $X_C^R = \left[\sum_{k \neq C} \left(M_{Ck} - \pi_{Ck}^{B,R} X_C^B\right) \tau_{Ck}\right] + \left[Y_C - \sum_{k \neq C} M_{kC} - (1 - \sum_{k \neq C} \pi_{Ck}^{B,R}) X_C^B\right]$, where the expression in the second square bracket denotes expenditure on domestic manufacturing goods by final consumption and production with regular technology. Fourth, $\pi_{Ci}^{R,R} = \frac{M_{Ck} - \pi_{Ck}^{B,R} X_C^B}{X_C^R}$.

Case 4: $n = C$ and $i = C$. First, we treat China's ordinary imports from China M_{CC}^R directly computed from Chinese custom data as expenditure on domestic goods produced under processing trade regime by final consumption and production with regular technology, thus, we have $\pi_{CC}^{R,B} = \frac{M_{CC}^R}{X_C^R}$ and $\pi_{CC}^{R,R} = (1 - \sum_{k \neq C} \pi_{Ck}^{R,R}) - \pi_{CC}^{R,B}$. Second, we calculate $\pi_{CC}^{B,R} = 1 - \sum_{k \neq C} \pi_{Ck}^{B,R}$ with the assumption that $\pi_{CC}^{B,B} = 0$.

Table 4: Calibrated Model Parameters

Parameters	Value	Description
β	0.36	output elasticity of labor
γ_n	0.33(0.53)	share of total income that spends on manufacturing goods
χ	1.0044	iceberg operation cost under processing trade regime

Notes: Parameter value for γ_n refers to the average across N countries, and the value in parenthesis is the value for China.

Table 4 summarizes calibrated parameters needed for counterfactual exercises. We calibrate β from data on the share of manufacturing value added in gross production. Denoting the value added share as s^V, averaging across data from the United Nations Industrial Development Organization (UNIDO(2005)) gives us $s^V = 0.33$. Taking into account profits and fixed costs, we calculate

$$\beta = s^V \overline{m} - 1/\theta. \tag{32}$$

Substituting our estimates of σ and θ into equation (32), we have $\beta = 0.33$.

We calibrate γ_n from calculating the share of total income that spends on manufacturing goods according to equation (25). Using data on manufacturing expenditures, trade shares, tariffs, GDP and total trade deficits, we calculate

$$\gamma_n = \frac{X_n^R + X_n^B - \sum_{i=1}^N \frac{(1-\beta)}{\overline{m}} \left(\pi_{in}^R \frac{X_i^R}{\tau_{in}} + \pi_{in}^B X_i^B \right)}{Y_n^A + D_n^A}, \tag{33}$$

where Y_n^A is the gross domestic product (GDP) of country n. The average value of γ_n is 0.33, and γ_C for China is 0.53.

We calibrate χ such that firms are indifferent with arranging production with regular technology between under ordinary and processing trade regime. Put differently, among values of χ that gives perfect sorting between technology and trade regimes, we pick the lower bound as our calibrated value. We calculate

$$\chi = \left(\frac{P_C^{RO}}{P_C^{RP}} \right)^{1-\beta} = \left(\sum_{i=1}^N \sum_T \pi_{Ci}^{R,T} (\tau_{Ci})^{-\theta} \right)^{-(1-\beta)/\theta}, \tag{34}$$

and we obtain $\chi = 1.0044$.

5.2 Welfare and Trade Effects of Duty Exemption

In the first counterfactual experiment, we quantify effects of duty exemption on trade and welfare. To do so, we move from a counterfactual equilibrium (CE1) in which China does not offer duty exemption to the observed equilibrium of year 2005. We refer to the calibrated model in this counterfactual experiment as the benchmark model.

Effects on Welfare

Duty exemption decreases real income by 1.45% and real wage by 1.26% as shown in Table 5. Decomposing the change of real wage into (i) direct effect and (ii) market size effect using equation (29) demonstrates the dominance of the latter. More importantly, it reveals the importance of the channel by which duty exemption shifts labor from the high DVAS to low DVAS production activities and shrinks the scale of domestic intermediate production. Specifically, the direct effect due to expansion of trade increases real wage by 1.06%, and reduction in the scale of domestic intermediates production, captured by the market size effect, decreases real wage by 2.32% (Table 1).

To understand the dominance of the negative market size effect, it is useful to recall from Section

Table 5: Welfare Effects of Duty Exemption (percent change)

Real Income	-1.45
Real Wage	-1.26
Direct Effect, $\frac{\gamma_C}{\beta\theta} \ln\left(\frac{1}{\hat{\pi}_{CC}^R}\right)$	1.06
Market Size Effect, $(\frac{\gamma_C}{\beta(\sigma-1)} - \frac{\gamma_C}{\beta\theta}) \ln\left(\frac{\hat{X}_C}{\hat{w}_C} \frac{\frac{X_C^{R'}}{X_C'} + \frac{X_C^{B'}}{X_C'} \frac{\pi_{CC}^{B'}}{\pi_{CC}^{R'}}}{\frac{X_C^R}{X_C} + \frac{X_C^B}{X_C} \frac{\pi_{CC}^B}{\pi_{CC}^R}}\right)$	-2.32

Note: Changes are from the counterfactual equilibrium in which China does not offer duty exemption to the observed equilibrium in 2005.

3.1 that it is a product of two things: 1) change in the scale of domestic intermediate production and 2) elasticity of market size effect w.r.t demand for domestic manufactures. Since the latter is determined by parameters that remains constant in this counterfactual experiment, we only need to focus on the former.

Table 6 shows the decomposition of change in the scale of domestic intermediate production into (i) change in total expenditure and (ii) change in relative demand for domestic manufactures. The second and third row of Table 6 indicate that the latter accounts for the majority of the change (-0.19 versus -3.98 in terms of percent change). A further decomposition suggests that reduction in production with regular technology (high DVAS production) is the essential driver of decrease in scale of domestic intermediate production (the last two rows of Table 6). Duty exemption lowers prices of foreign inputs used in production with foreign-inputs-biased technology, inducing expansion of this type of production and simultaneous reduction in production with regular technology. The scale of domestic intermediate production therefore shrinks because production with foreign-inputs-biased technology predominately requires foreign intermediate inputs.

Effects on Trade

The results on trade indicate that duty exemption under China's processing trade regime is a very effective policy instrument to expand trade. Both China's exports and imports increase significantly. Specifically, exports-to-GDP ratio rises from 35.56% to 42.27%, and imports-to-GDP ratio goes up from 14.89% to 21.74% as shown in Table 7. Decomposing exports by production technology and imports by end use shows that the large increase in trade is primarily driven by the increase in exports produced with foreign-inputs-biased technology and increase in imports that used to produce these exports.

The results do not imply that China is actually worse off due to the implementation of duty exemption for processing imports as this paper does not intend to disentangle all underlying mechanisms. What we want to emphasize from the results is that the market size effect triggered by duty exemption contributes negatively to the overall welfare effects, and its magnitude dominates the gains from trade expansion triggered by duty exemption (direct effect). In the next two experiments, we explore how the features of our model affect the (relative) magnitude of the market size effect.

Table 6: Decomposition of the Change in the Scale of Input Production

	CE1	2005	Percent change
	(1)	(2)	(3)
Demand of domestic manufactures	-	-	-4.17
Total expenditure, $\frac{X_C}{w_C}$	-	-	-0.19
Relative demand for domestic manufactures, $\frac{X_C^R}{X_C} + \frac{X_C^B}{X_C}\frac{\pi_{CC}^B}{\pi_{CC}^R}$	0.9498	0.9120	-3.98
Share of X_C^R, $\frac{X_C^R}{X_C}$	0.9360	0.8961	-4.20
Adjusted share of X_C^B, $\frac{X_C^B}{X_C}\frac{\pi_{CC}^B}{\pi_{CC}^R}$	0.0138	0.0159	0.23

Note: Numerical values in column (3) and the last two rows are weighted percent changes. Take the value "0.23" in the last row as an example. "0.23" equals the product of the percent change $\frac{0.0159-0.0138}{0.0138}$ and the weight $\frac{0.0138}{0.0138+0.9360}$.

Table 7: Trade Effects of Duty Exemption (percent)

		CE1[1]	Year 2005
		(1)	(2)
Exports-to-GDP ratio	(1)	35.56	42.27
Processing-exports-to-GDP ratio[2]	(2)	15.17	24.64
Ordinary-exports-to-GDP ratio	(3)	20.39	17.63
Import-to-GDP ratio	(4)	14.89	21.74
Processing-imports-to-GDP ratio[2]	(5)	5.14	9.45
Ordinary-imports-to-GDP ratio	(6)	9.75	12.29

1. CE1 refers to the counterfactual equilibrium in which China does offer duty exemption. Values in column (1) are calculated from solving CE1. Values in column (2) are calculated using the 2005 data.
2. Processing exports in CE1 refers to the exports produced with foreign-inputs-biased technology, and processing imports are imports that are used to produce these exports.

5.3 Effects of Duty Exemption if Treating All Trade as Ordinary Trade

As demonstrated in the first counterfactual exercise, the fact that China's processing exports have much lower DVAS than its ordinary exports and domestic sales underpins the dominance of market size effect.[19] Thus, we are intrigued to find out how large the bias would be for welfare effects of duty exemption if we ignore this fact.

[19] This empirical fact, although pointed out in Koopman et al. (2012) and Kee and Tang (2016), has not been incorporated into previous quantitative works.

To answer this question, first, we construct an alternative model in which foreign-inputs-biased technology aggregates domestic and foreign intermediate inputs almost the same as regular technology (i.e. $\alpha^B_{CC} = 1$ and $\alpha^B_{Ci} = 1 + \epsilon$ for $i \neq C$).[20] We refer to the alternative model as model M2. Second, we calibrate model M2 to the year 2005. We refer to this calibrated equilibrium as M2-calibrated 2005. The M2-calibrated 2005 is identical to the observed equilibrium of year 2005 except that we M2-calibrate trade shares $\pi^{B,R}_{Ci}$ and $\pi^{R,R}_{Ci}$ by forcing them satisfying equilibrium conditions $\frac{\pi^{B,R}_{Ci}}{\pi^{R,R}_{Ci}} = \left(\frac{P^B_C}{P^R_C}\tau_{Ci}\right)^{\sigma-1}$ for each i. After the calibration, processing-imports-to-GDP ratio becomes 2.54% in the M2-calibrated 2005, much lower than the ratio 9.45% in 2005, and ordinary-imports-to-GDP ratio becomes 19.20%, much higher than the ration 12.29% in 2005 as shown in Table 8. Third, we use model M2 and move a counterfactual equilibrium (CE2) in which China does not offer duty exemption to the equilibrium of M2-calibrated 2005, and compare welfare implication of duty exemption from model M2 with that from benchmark model in the first counterfactual experiment.

Table 8: Trade Effects of Duty Exemption in the Model M2 versus the Benchmark (percent)

		CE2[1]	M2-calibrated 2005	CE1	Year 2005
		(1)	(2)	(3)	(4)
Exports-to-GDP ratio	(1)	41.60	42.27	35.56	42.27
Processing-exports-to-GDP ratio[3]	(2)	24.04	24.64	15.17	24.64
Ordinary-exports-to-GDP ratio	(3)	17.56	17.63	20.39	17.63
Import-to-GDP ratio	(4)	21.11	21.74	14.89	21.74
Processing-imports-to-GDP ratio[3]	(5)	2.14	2.54[2]	5.14	9.45
Ordinary-imports-to-GDP ratio	(6)	18.97	19.20[2]	9.75	12.29

1. CE2 refers to the counterfactual equilibrium in which China does offer duty exemption in model M2. Values in column (1) are calculated from solving CE2 in model M2. CE1 refers to the counterfactual equilibrium in which China does offer duty exemption in the benchmark model. Values in column (3) are calculated from solving CE1 in the benchmark model.
2. These two ratios are calibrated according to the assumption that foreign-inputs-biased technology aggregates intermediate inputs almost the same as regular technology.
3. Processing exports in CE2 and CE1 refers to the exports produced with foreign-inputs-biased technology, and processing imports are imports that are used to produce these exports.

Table 9 shows effects of duty exemption on real wage and income according to model M2. We also add results from the benchmark model for comparison. In contrast to the benchmark, duty exemption now has a much smaller impact on welfare. As we can see, the magnitude of change in real income is less than ten percent of that from the benchmark model (-0.14% in model M2 v.s. -1.45% in the benchmark). Decomposing the change in real wage into direct effect and market size effect shows that the latter still dominates, but the much smaller impact on welfare is due to much smaller direct effect and market size effect triggered by duty exemption in model M2.

[20]By assuming that $\alpha^B_{CC} = 1$ and $\alpha^B_{Ci} = 1 + \epsilon$ for $i \neq C$ instead of $\alpha^B_{Ci} = 1$, firms will still choose to produce with foreign-inputs-biased technology under the processing trade regime, and produce with regular technology under the ordinary trade

Table 9: Welfare Effects of Duty Exemption in Model M2 versus the Benchmark (percent change)

	Model M2	Benchmark
	(1)	(2)
Real Income	-0.14	-1.45
Real Wage	-0.03	-1.26
Direct Effect, $\frac{\gamma_C}{\beta\theta}\ln\left(\frac{1}{\hat{\pi}^R_{CC}}\right)$	0.10	1.06
Market Size Effect, $\left(\frac{\gamma_C}{\beta(\sigma-1)}-\frac{\gamma_C}{\beta\theta}\right)\ln\left(\frac{\hat{X}_C}{\hat{w}_C}\frac{\frac{X^{R'}_C}{X'_C}+\frac{X^{B'}_C}{X'_C}\frac{\pi^{B'}_{CC}}{\pi^{R'}_{CC}}}{\frac{X^R_C}{X_C}+\frac{X^B_C}{X_C}\frac{\pi^B_{CC}}{\pi^R_{CC}}}\right)$	-0.13	-2.32

Note: Changes in column (1) are from the counterfactual equilibrium in which China does not offer duty exemption in model M2 to the M2-calibrated equilibrium of year 2005. Changes in column (2) are from the counterfactual equilibrium in which China does not offer duty exemption in the benchmark model to the observed equilibrium in 2005.

The much smaller direct effect is a result of much less trade increase triggered by duty exemption in model M2. As demonstrated in Table 8, exports-to-GDP ratio only increase from 41.60% to 42.27%, and imports-to-GDP ratio from 21.11% to 21.74%. Similar to the benchmark (from CE1 to 2005), the trade growth is still primarily driven by the growth in exports produced with foreign-inputs-biased technology and growth in imports that used to produce these exports. In contrast to the benchmark, exports produced with foreign-inputs-biased technology grows much less as foreign-inputs-biased technology is assumed to be almost the same as regular technology in model M2.

To understand the much smaller market size effect, we also decompose change in scale of domestic intermediate production the same way as we did in the first counterfactual experiment, and the results are shown in Table 10. The change in relative demand for domestic manufactures still accounts for the majority of the change, but the change in relative demand only reduce scale of domestic intermediate production by 0.24%. As discussed in Section 3.1, the change in relative demand depends on two things: 1) the difference of reliance on domestic intermediate inputs between foreign-inputs-biased and regular technologies 2) the change in the composition of total expenditure. The former is assumed to be zero in model M2, and the latter is small as exports produced with foreign-inputs-biased technology grows much less.

In sum, the very different results between the benchmark and model M2 suggests that it is crucial to take account of the fact that China's processing exports have much lower DVAS than its ordinary exports and domestic sales when evaluating effects of duty exemption.

regime.

Table 10: Decomposition of Change in Scale of Domestic Intermediate Production in Model M2

	M2-calibrated 2005	CE2	Percent change
	(1)	(2)	(3)
Demand of domestic manufactures	-	-	-0.24
Total expenditure, $\frac{X_C}{w_C}$	-	-	0.00
Relative demand for domestic manufactures, $\frac{X_C^R}{X_C} + \frac{X_C^B}{X_C}\frac{\pi_{CC}^B}{\pi_{CC}^R}$	1	0.9976	-0.24
Share of X_C^R, $\frac{X_C^R}{X_C}$	0.8985	0.8961	-0.24
Adjusted share of X_C^B, $\frac{X_C^B}{X_C}\frac{\pi_{CC}^B}{\pi_{CC}^R}$	0.1014	0.1014	0.00

Note: Numerical values in column (3) and the last two rows are weighted percent changes. Take the value "-0.24" in the fourth row as an example. "-0.24" equals the product of the percent change $\frac{0.8961-0.8965}{0.8965}$ and the weight $\frac{0.8965}{0.8965+0.1014}$.

5.4 Effects of Duty Exemption under Weaker Economies of Scale

Since the distinctive market size effect triggered by duty exemption arises from increasing returns to scale, we further explore how the strength of increasing returns to scale affect welfare effects of duty exemption by comparing models exhibited varying degrees of increasing return to scale. To do so, first, we start by a model with a σ value that is different from our estimated value 2.94, and we set $\sigma = 4$ which is in the range of estimated (calibrated) value in the literature. We refer to this model as model M3, and model M3 exhibits less degree of increasing returns to scale relative to the benchmark model. Second, we calibrates model M3 to year 2005 with the same manner as calibrating benchmark model to year 2005. We refer to this calibrated equilibrium as the M3-calibrated 2005. Third, we use model M3 and move from a counterfactual equilibrium (CE3) in which China does not duty exemption to the equilibrium of M3-calibrated 2005, and compare welfare effects of duty exemption from model M3 with that from the benchmark model.

Before comparing welfare effects, we want to point out that the parameter σ not only determines the strength of increasing returns to scale, but also affects volume of trade when China allows duty exemption. As shown in Table 11, duty exemption induce less trade growth relative to that in the first counterfactual experiment. Therefore, we focus on comparing the relative magnitude between market size effect and direct effect instead of the absolute values.

Table 12 presents welfare effects of duty exemption from both model M3 and benchmark model. China experiences a 0.45% in real income and 0.14% decrease in real wage from model M3, which are smaller in magnitude than the changes from the benchmark. Decomposing the change in real wage into direct effect and market size effect shows that the magnitude of the latter is 1.5 times larger than the

Table 11: Trade Effects of Duty Exemption in Model M3 (percent)

		CE3[1]	Year 2005
		(1)	(2)
Exports-to-GDP ratio	(1)	39.44	42.27
Processing-exports-to-GDP ratio[2]	(2)	21.21	24.64
Ordinary-exports-to-GDP ratio	(3)	18.23	17.63
Import-to-GDP ratio	(4)	18.91	21.74
Processing-imports-to-GDP ratio[2]	(5)	7.26	9.45
Ordinary-imports-to-GDP ratio	(6)	11.65	12.29

1. CE3 refers to the counterfactual equilibrium in which China does offer duty exemption in model M3. Values in column (1) are calculated from solving CE3 in model M3.
2. Processing exports in CE3 refers to the exports produced with foreign-inputs-biased technology, and processing imports are imports that are used to produce these exports.

Table 12: Welfare Effects of Duty Exemption in Model M3 versus the Benchmark (percent change)

	Model M3	Benchmark
	(1)	(2)
Real Income	-0.47	-1.45
Real Wage	-0.14	-1.26
Direct Effect, $\frac{\gamma_C}{\beta\theta} \ln\left(\frac{1}{\hat{\pi}^O_{CC}}\right)$	0.25	1.06
Market Size Effect, $\left(\frac{\gamma_C}{\beta(\sigma-1)} - \frac{\gamma_C}{\beta\theta}\right) \ln\left(\frac{\hat{X}_C}{\hat{w}_C} \frac{\frac{X^{O\prime}_C}{X^{\prime}_C} + \frac{X^{P\prime}_C}{X^{\prime}_C} \frac{\pi^{P\prime}_{CC}}{\pi^{O\prime}_{CC}}}{\frac{X^O_C}{X_C} + \frac{X^P_C}{X_C} \frac{\pi^P_{CC}}{\pi^O_{CC}}}\right)$	-0.39	-2.32

Note: Changes in column (1) are from the counterfactual equilibrium in which China does not offer duty exemption in model M3 to the M3-calibrated equilibrium of year 2005. Changes in column (2) are from the counterfactual equilibrium in which China does not offer duty exemption in the benchmark model to the observed equilibrium in 2005.

magnitude of the former according to model M3, while it is more than 2 times in the benchmark. We know that market size effect is a product of two things: 1) change in scale of domestic intermediate production and 2) elasticity of market size effect w.r.t demand for domestic manufactures. Therefore, the smaller elasticity induced by a larger value of σ is the main driver for the decrease in relative magnitude of market size effect.

5.5 Uniform Tariff Reduction

One may tend to consider duty exemption with processing trade as a form of partial trade liberalization. The idea that duty exemption is partial because tariffs reduction applies to imported inputs used for producing processing exports, while a more complete trade liberalization should be tariff reductions that applies to all imports. According to the theoretic discussion in Section 3.4, we already know the qualitative difference in welfare effects between duty exemption and uniform tariff reduction. we now quantify welfare effects of uniform tariff reduction from the model of EKK to see how the results is quantitatively different from welfare effects of duty exemption with our model.

To do so, first, we start with the EKK model with our estimates of σ and θ, and calibrate it to a world in which China does not offer the duty exemption. Specifically, we calibrate the EKK model to aggregate bilateral trade shares, total expenditures and gross domestic products from the equilibrium CE1 in the first counterfactual experiment. We refer to this calibrated equilibrium as EKK-calibrated CE1.

Second, we use the EKK model and move from the EKK-calibrated CE1 to a counterfactual experiment in which China implements a uniform tariff reduction, and the level of tariff reduction is chosen so that tariff revenue reduction is equivalent to that triggered by the duty exemption in our benchmark model. Third, we compare welfare effects of this uniform tariff reduction with that of duty exemption from our benchmark model.

Table 13: Welfare Effects of Uniform Tariff Reduction and Duty Exemption (percent change)

	Uniform Tariff Reduction	Duty Exemption
	(1)	(2)
Real Income	0.16	-1.45
Real Wage	0.25	-1.26
Direct Effect	0.24	1.06
Market Size Effect	0.01	-2.32

Note: Changes in column (1) are from the EKK-calibrated CE1 in the model of EKK to a counterfactual equilibrium in which China implements a uniform tariff reduction, and the level of tariff reduction is chosen so that tariff revenue reduction is equivalent to that triggered by duty exemption in the benchmark model. Changes in column (2) are from the counterfactual equilibrium in which China does not offer duty exemption in the benchmark model to the observed equilibrium in 2005.

Table 13 presents welfare effects of the uniform tariff reduction from the EKK model, as well as welfare effects of duty exemption from our benchmark model in Table 13 for comparison. The results show that these two policies moves welfare into opposite directions. Specifically, the uniform tariff reduction increases China's real wage by 0.25% and real income by 0.16%.

Decomposing changes in real wage into direct effects and market size effects shows that the key difference lies in the latter, which is consistent with our theoretic discussion in Section 3.4. Market size effect has almost no impact on the change in real wage for the uniform tariff reduction in the EKK model. This is because the uniform tariff reduction has no impact on the relative demand for domestic manufactures. Moreover, the magnitudes of both effects with the uniform tariff reduction are much smaller than those with duty exemption. This is because the EKK model does not take account of the fact that China's processing exports have much lower DVAS than ordinary exports and domestic sales.

5.6 Sensitivity Analysis for the Share of Labor

There is a concern that processing exporters in China use labor more intensively than ordinary exporters and domestic producers. In this subsection, we consider an alternative calibration in which the share of labor in the foreign-inputs-biased technology differs from that in the regular technology. Let β^B denote the former, and β^R denote the latter. We set β^R equal to our baseline calibrated β, $\beta^R = 0.33$. We calibrate β^B by using equation (26). We calculate

$$\beta^B = 1 - \frac{\overline{m} \sum_{i=1}^{N} M_{Ci}^B}{\sum_{k \neq C} M_{kC}^B \tau_{kC}}, \tag{35}$$

where M_{Ci}^B is China's processing imports from country i, and M_{kC}^B is China's processing exports to country k. We obtain $\beta^B = 0.2927$.

Table 14 presents the results when the two output elasticity of labor differ. We also add the results from the benchmark model in Table 14 for comparison. As we can see, the welfare effects of duty exemption with $\beta^B = 0.2927$ do not differ much from that in the benchmark model. The decrease in real wage is slightly larger with $\beta^B = 0.2927$. This is because duty exemption makes processing exports more competitive in the global market with a smaller output elasticity of labor, triggers larger changes in direct effect and market size effect.

Table 14: Welfare Effects of Duty Exemption with $\beta^R \neq \beta^B$ (percent change)

	$\beta^R \neq \beta^B$	Benchmark
	(1)	(2)
Real Income	-1.44	-1.45
Real Wage	-1.35	-1.26
Direct Effect, $\frac{\gamma_C}{\beta\theta} \ln\left(\frac{1}{\hat{\pi}_{CC}^R}\right)$	1.17	1.06
Market Size Effect, $\left(\frac{\gamma_C}{\beta(\sigma-1)} - \frac{\gamma_C}{\beta\theta}\right) \ln\left(\frac{\hat{X}_C}{\hat{w}_C} \frac{\frac{X_C^{R\prime}}{X_C^\prime} + \frac{X_C^{B\prime}}{X_C^\prime} \frac{\pi_{CC}^{B\prime}}{\pi_{CC}^{R\prime}}}{\frac{X_C^R}{X_C} + \frac{X_C^B}{X_C} \frac{\pi_{CC}^B}{\pi_{CC}^R}}\right)$	-2.52	-2.32

Note: Changes in column (1) are from the counterfactual equilibrium in which China does not offer duty exemption in model with $\beta^R \neq \beta^B$ to the observed equilibrium of 2005. Changes in column (2) are from the counterfactual equilibrium in which China does not offer duty exemption in the benchmark model to the observed equilibrium of 2005.

6 Conclusion

Many developing countries have been encouraging processing trade to stimulate economic growth, but the outcomes are mixed and the underlying mechanisms are not well-understood. In this paper, we build a quantifiable general equilibrium model to understand the costs of duty exemption for processing trade. When intermediate production exhibits increasing returns to scale and the processing exports relies more on foreign intermediates than that of domestic sales and ordinary exports, duty exemption for processing imports would trigger a Dutch disease by shifting labor from producing high DVAS domestic goods and ordinary exports into producing low DVAS processing exports and thereby shrinking the scale of domestic intermediate production. We estimate our model using the Chinese firm-level data and find that the costs of duty exemption outweigh the welfare gains from the expansion of imported input varieties.

Let us close with a remainder that this paper does not intend to disentangle all underlying mechanisms behind duty exemption and processing trade. There are potential mechanisms that are not incorporated into our model, for example, technology spillover and learning from processing trade. Therefore, our quantitative results do not imply that duty exemption *actually* made China worse off. Instead, it offers a cautionary note for such development policies: the costs of duty exemption for processing imports could be quantitatively large and outweigh its benefits from trade expansion.

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A Theory

A.1 Derivation of Equations (19) and (21)

According to equations (3) and (14), we can write the price index of Q_n^R as

$$P_n^R = \left[\int \int \sum_T \sum_i \int_0^{\bar{c}_{ni}^T(\eta)} \alpha f_{ni}^T(\eta, c) \left(\tau_{ni} \overline{m} c\right)^{1-\sigma} d\mu_{ni}^T(c) \, g^T(\alpha, \eta) d\alpha d\eta \right]^{-1/(\sigma-1)}$$

Integrating over cost c and taking both sides to the power of $1-\sigma$, we have

$$\left(P_n^R\right)^{1-\sigma} = (\overline{m})^{1-\sigma} \int \int \alpha \kappa_0 \sum_T \sum_i \left(\tau_{ni}\right)^{1-\sigma} \Phi_{ni}^T \left[\bar{c}_{ni}^T(\eta)\right]^{\theta-(\sigma-1)} g^T(\alpha, \eta) \, d\alpha d\eta,$$

where $\kappa_0 = \frac{\theta}{\theta-(\sigma-1)} - \frac{\theta}{\theta+(\sigma-1)(\lambda-1)}$. Using equation (16), we obtain

$$\left(P_n^R\right)^{1-\sigma} = (\overline{m})^{-\theta} \sum_{i=1}^N \Psi_{ni} \left[A_{ni} \left(\tau_{ni}\right)^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}. \tag{A.1}$$

Similarly, according to equations (5) and (14), the price index of Q_1^B is given by

$$P_1^B = \left[\int \int \sum_T \sum_i \int_0^{\bar{c}_{1i}^T(\eta)} \alpha_{1i}^B \alpha f_{1i}^T(\eta, c) \left(\overline{m} c\right)^{1-\sigma} d\mu_{1i}^T(c) \, g^T(\alpha, \eta) \, d\alpha d\eta \right]^{-1/(\sigma-1)}.$$

Integrating over cost c, taking both sides to the power of $1-\sigma$, and using equation (16) yield

$$\left(P_1^B\right)^{1-\sigma} = (\overline{m})^{-\theta} \sum_{i=1}^N \alpha_{1i}^B \left(\tau_{1i}\right)^{\sigma-1} \Psi_{1i} \left(A_{1i} \left(\tau_{1i}\right)^{(\sigma-1)}\right)^{\theta/(\sigma-1)-1}. \tag{A.2}$$

A.2 Proof of Proposition 1

We start by showing the derivation of equation (28). As real income is comprised of wage, profits and tariff revenue, the change in real income can be written as

$$\frac{\hat{I}_1}{(\hat{w}_1)^{1-\gamma_1}(\hat{P}_1^R)^{\gamma_1}} = \frac{w_1 L_1}{I_1} \frac{\hat{w}_1}{(\hat{w}_1)^{1-\gamma_1}(\hat{P}_1^R)^{\gamma_1}} + \frac{R_1}{I_1} \frac{\hat{R}_1}{(\hat{w}_1)^{1-\gamma_1}(\hat{P}_1^R)^{\gamma_1}} + \frac{\Pi_1}{I_1} \frac{\hat{\Pi}_1}{(\hat{w}_1)^{1-\gamma_1}(\hat{P}_1^R)^{\gamma_1}}.$$

Taking $\left(\frac{\hat{w}_1}{\hat{P}_1^R}\right)^{\gamma_1}$ out, we have

$$\frac{\hat{I}_1}{(\hat{w}_1)^{1-\gamma_1}(\hat{P}_1^R)^{\gamma_1}} = \left(\frac{w_1}{P_1^R}\right)^{\gamma_1} \left(\frac{w_1 L_1}{I_1} + \frac{R_1}{I_1}\frac{\hat{R}_1}{\hat{w}_1} + \frac{\Pi_1}{I_1}\frac{\hat{\Pi}_1}{\hat{w}_1}\right). \tag{A.3}$$

Taking logarithms of both sides of equation (A.3), we obtain equation (28).

We now turn to the derivation of equation (29). From equation (22), the share of X_1^R that is spent on domestic manufacturing goods is

$$\pi_{11}^{R} = \pi_{11}^{R,R} + \pi_{11}^{R,B} = \frac{\Psi_{11}\left(A_{11}\right)^{\theta/(\sigma-1)-1}}{\sum_{k=1}^{N}\Psi_{1k}\left[A_{1k}\left(\tau_{1k}\right)^{(\sigma-1)}\right]^{\theta/(\sigma-1)-1}}. \tag{A.4}$$

The denominator of the fraction is equal to $\overline{m}^{\theta}(P_1^R)^{1-\sigma}$ according to equation (19). We can rewrite equation (A.4) as

$$\pi_{11}^{O} = \frac{1}{\overline{m}^{\theta}}(P_1^R)^{\sigma-1}\Psi_{11}\left(A_{11}\right)^{\theta/(\sigma-1)-1}. \tag{A.5}$$

Using the definition of Ψ_{11} from equation (20), we have

$$\pi_{11}^{R} = \frac{1}{\overline{m}^{\theta}}(P_1^R)^{\sigma-1}\left[\sum_T \kappa_1^T \Phi_{11}^{TM}\left(\frac{1}{\sigma E_{11}^T}\right)^{\theta/(\sigma-1)-1}\right]\left(A_{11}\right)^{\theta/(\sigma-1)-1}.$$

Using the definition of Φ_{11}^T from equation (17), we obtain

$$\pi_{11}^{R} = (\overline{m}Y)^{-\theta}\,T_1\left(\frac{w_1}{P_1^R}\right)^{-\beta\theta}\left[\sum_T \kappa_1^T\left(\frac{1}{\sigma E_{11}^T}\right)^{\theta/(\sigma-1)-1}\right]\left(A_{11}(P_1^R)^{1-\sigma}\right)^{\theta/(\sigma-1)-1}.$$

Rearranging the equation above yields an expression for real wage in country 1

$$\left(\frac{w_1}{P_1^R}\right)^{\gamma_1} = (\overline{m}Y)^{-\frac{\gamma_1}{\beta}}\left(\frac{T_1}{\pi_{11}^R}\right)^{\frac{\gamma_1}{\beta\theta}}\left(\frac{X_1^R + \alpha_{11}^B X_1^B\left(\frac{P_1^B}{P_1^R}\right)^{\sigma-1}}{\sigma E_{11}}\right)^{\frac{\gamma_1}{\beta(\sigma-1)}-\frac{\gamma_1}{\beta\theta}} \tag{A.6}$$

where $E_{11} = \left(\kappa_1^O(E_{11}^O)^{1-\theta/(\sigma-1)} + \kappa_1^P(E_{11}^P)^{1-\theta/(\sigma-1)}\right)^{\frac{\sigma-1}{\sigma-1-\theta}}$.

We now move from an equilibrium in which country 1 the implements duty exemption under processing trade to an equilibrium in which country 1 eliminates the duty exemption. From equation (A.6), the change in real wage of country 1 is given by

$$\left(\frac{\hat{w}_1}{\hat{P}_1^R}\right)^{\gamma_1} = \left(\frac{1}{\hat{\pi}_{11}^R}\right)^{\frac{\gamma_1}{\beta\theta}}\left(\frac{X_1^{R'} + X_1^{B'}\frac{\pi_{11}^{R'}}{\pi_{11}^{R'}}}{X_1^R + X_1^B\frac{\pi_{11}^B}{\pi_1^R}}\frac{1}{\hat{w}_1}\right)^{\frac{\gamma_1}{\beta(\sigma-1)}-\frac{\gamma_1}{\beta\theta}}. \tag{A.7}$$

Taking logarithms of both sides of equation (A.7), we obtain equation (29).

B Data Patterns on Firm Entry and Sales Distributions

In this section, we show the entry patterns and export sales distributions by trade regimes by using the Chinese firm-level data, and that how our model explains these data patterns. These data patterns motivate our model choice, and we also use moments related to these data patterns in our structural estimation.

Pattern 1: Larger markets induce more entry of Chinese firms under both trade regimes.

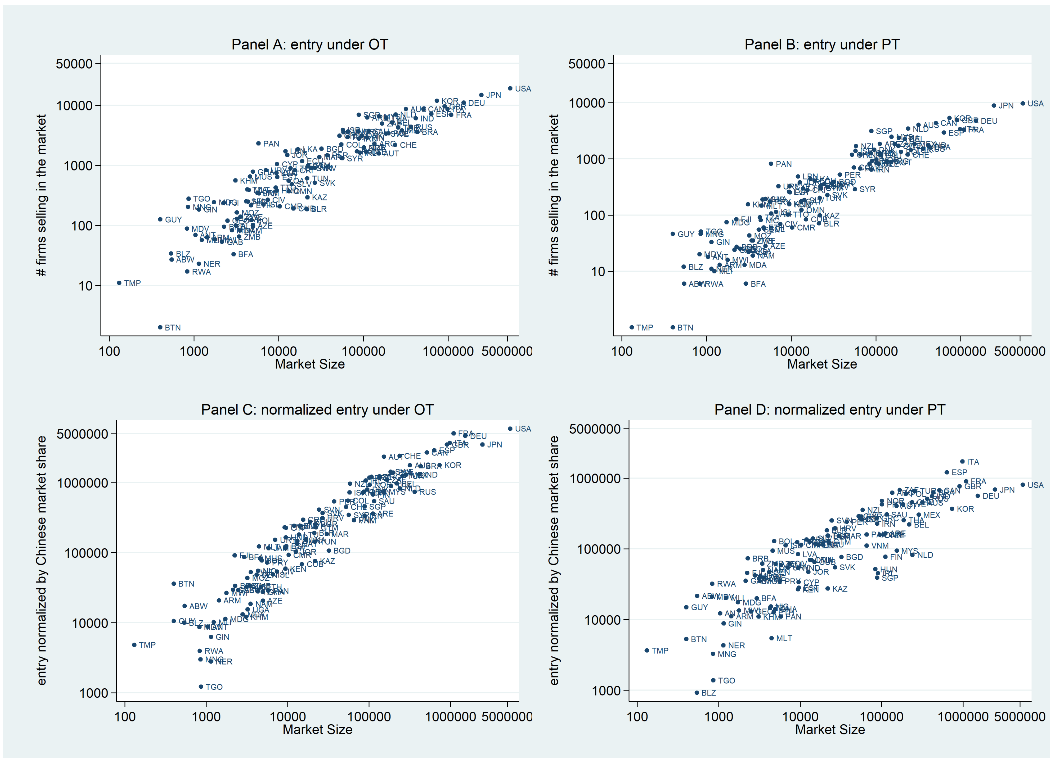

Figure B.1: Entry by Market Size under both Trade Regimes

Figure B.1 shows that larger markets induce more entry of Chinese firms under both trade regimes. In particular, panel A plots the number of Chinese manufacturing firms N^O_{nC} selling to a market under the ordinary trade regime against the total manufacturing absorption X_n in that market.[21] Likewise, Figure 1, panel B, plots the number of Chinese manufacturing firms N^P_{nC} selling to a market under the processing trade regime against total manufacturing absorption X_n. If a firm is observed to have positive sales in a market under both trade regimes, the firms is counted twice, one each for N^O_{nC} and N^P_{nC}, respectively. Under both trade regimes, the number of firms selling to a market tends to increase with the size of the market, although with less entry under processing trade.

[21] The total manufacturing absorption equals the manufacturing output plus imports minus exports. Details about calculation and data source can be found in Appendix 5.1 and D.3.

Moving to Figure B.1, panel C, the x axis is unchanged. The y axis replaces N^O_{nC} with N^O_{nC} divided by China's market share under ordinary trade, calculated by dividing the total exports under ordinary trade of Chinese firms to market n in the sample by its size X_n. The relationship is very tight and linear in logs. Similarly, Figure 1, panel D, displays the number of Chinese manufacturing firms N^P_{nC} selling to a market under processing trade normalized by their market share under processing trade against the market size. The relationship is also linear, although not as tight as that in panel C.

Pattern 2: The distributions of export sales resemble across destination markets and trade regimes.

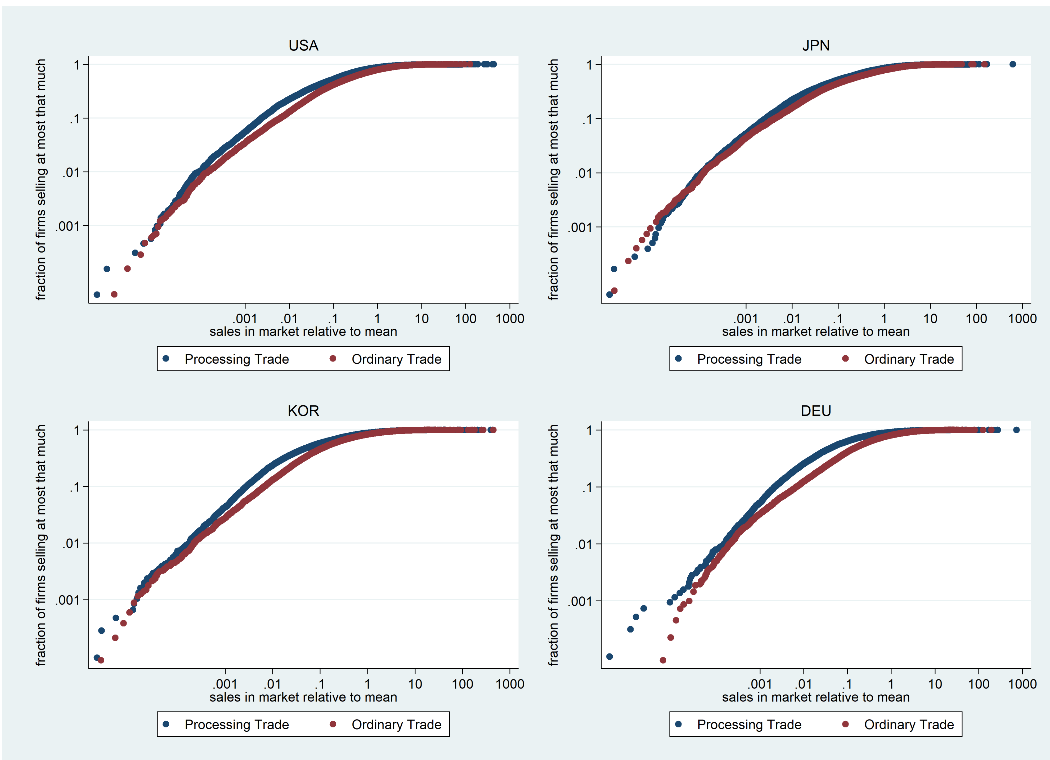

Figure B.2: Distribution of Chinese Firms' Sales across Destinations and Trade Regimes

Figure B.2 indicates that the distributions of export sales of Chinese manufacturing firms are similar across markets and across trade regimes. To be specific, Figure B.2 draws the empirical distributions of firm sales by trade regime within each of China's four top export destinations–the United States, Japan, South Korea, and Germany. Each of the four panels is a plot of the fraction of firms selling in the market that sell at most that much against the sales of in a given market (relative to mean sales). The basic shapes of these distributions resemble each other across the four markets. Another striking feature is that the two trade regimes exhibit nearly identical distributions within each market.

Putting aside the trade regimes, these two data patterns - in entry and sales distributions - are similar to those found in the French data in EKK. These data patterns suggest that extending a model of monopolistic competition with firm heterogeneity, such as the one in EKK, provides a suitable benchmark to study the welfare implication of the duty exemption with China's processing trade.

Connecting the Model to Data Pattern 1

The intuition that the model can rationalize the data pattern of entry is that larger markets have lower entry barriers, thus more firms enter under both trade regimes. Equation (B.1) describes this relationship mathematically: the number of Chinese firms selling in market $n \neq C$ under trade regime TM, N_{nC}^{TM}, equals their total sales divided by the average sales,[22]

$$N_{nC}^{TM} = \begin{cases} \frac{\pi_{nC}^{R,R} X_n}{\frac{\kappa_1^R}{\kappa_2^R}\sigma E_{nC}^R}, & \text{if } TM = O, \\ \frac{\pi_{nC}^{R,B} X_n}{\frac{\kappa_1^B}{\kappa_2^B}\sigma E_{nC}^B}, & \text{if } TM = P. \end{cases} \tag{B.1}$$

where $\kappa_2^T = \int \int \eta^{\theta/(\sigma-1)} g^{TM}(\alpha,\eta) d\alpha d\eta$, $T = R$ or B. Rewriting equation (B.1) yields

$$\frac{N_{nC}^O}{\pi_{nC}^{R,R}} = \frac{\kappa_2^R}{\kappa_1^R}\frac{X_n}{\sigma E_{nC}^R} \text{ and } \frac{N_{nC}^P}{\pi_{nC}^{R,B}} = \frac{\kappa_2^B}{\kappa_1^B}\frac{X_n}{\sigma E_{nC}^B}, \tag{B.2}$$

which represents the normalized numbers of firm entries under both trade regimes. Equation (B.2) thus demonstrates that the number of firms selling to market n under trade regime TM rises with the size of market n.

As displayed in panel C and D of Figure 3, the relationships between the logarithm of the normalized number of entries and the logarithm of market n's size are tight under both trade regimes, with a respective slope of 0.8 and 0.62. Similar to the French firms' case in EKK, these slopes suggest that the entry cost σE_{nC}^T increases with the market size, yet not proportionally. Moreover, the entry cost σE_{nC}^B rises at a faster rate than σE_{nC}^R with the market size.

Connecting the Model to Data Pattern 2

Rewriting equation (18) derives the expression of the sales of Chinese firms selling good ω^T to market n,

$$X_{nC}^T\left(\omega^T\right) = \varepsilon_n\left(\omega^T\right)\left[1 - \left(v_{nC}^T\left(\omega^T\right)\right)^{\lambda/\widetilde{\theta}}\right]\left(v_{nC}^T\left(\omega^T\right)\right)^{-1/\widetilde{\theta}}\sigma E_{nC}^T,$$

where $\widetilde{\theta} = \frac{\theta}{\sigma-1}$, and

$$v_{nC}^T\left(\omega^T\right) = \left(\frac{c\left(\omega^T\right)}{\overline{c}_{nC}^T\left(\eta_n\left(\omega^T\right)\right)}\right)^{\theta}.$$

[22] Here we assume that there is only ordinary trade regime and only one type of technology in country $n \neq C$.

Note that $v_{nC}^{T}\left(\omega^{T}\right)$ is distributed uniformly on $[0,1]$. The entry shock $\varepsilon_{n}\left(\omega^{T}\right)$ is assumed to follow the same distribution across n markets for a given T. These assumptions thus assure that the sales distributions are identical up to a scaling factor σE_{nC}^{T} across all markets for the corresponding trade regime. Additionally, when allowing for similar distributions between $\varepsilon_{n}\left(\omega^{R}\right)$ and $\varepsilon_{n}\left(\omega^{B}\right)$, the model delivers similarity between distributions under the two trade regimes for any given market.

C Estimation

Before describing the step-by-step simulation algorithm, we define the firm's standardized unit cost as

$$u\left(\omega^{T}\right)=T_{C}z_{C}\left(\omega^{T}\right)^{-\theta},$$

and it has a uniform measure that does not depend on any parameter. Associated with the entry hurdles $\bar{c}_{nC}^{T}\left(\eta\right)$ is standardized entry hurdles $\bar{u}_{nC}^{T}\left(\eta\right)$, satisfying

$$\bar{c}_{nC}^{T}\left(\eta\right)=\left(\frac{\bar{u}_{nC}^{T}\left(\eta\right)}{\Phi_{nC}^{T}}\right)^{1/\theta}.$$

A firm selling ω^{T} enters market n if its $u\left(\omega^{T}\right)$ and $\eta_{n}\left(\omega^{T}\right)$ satisfy

$$\begin{aligned}u\left(\omega^{T}\right) &\leq \bar{u}_{nC}^{T}\left(\eta_{n}\left(\omega^{T}\right)\right)\\ &= \bar{u}_{nC}^{T}\left(\eta\right)=\Phi_{nC}^{T}\left(\bar{c}_{nC}^{T}\left(\eta\right)\right),\end{aligned}$$

and we have

$$\bar{u}_{nC}^{R}\left(\eta\right)=\eta^{\widetilde{\theta}}\frac{N_{nC}^{O}}{\kappa_{2}^{R}}\text{ and }\bar{u}_{nC}^{B}\left(\eta\right)=\eta^{\widetilde{\theta}}\frac{N_{nC}^{P}}{\kappa_{2}^{B}}.$$

Conditional on firm ω^{T}'s passing this hurdle, its sales in market n in terms of $u\left(\omega^{T}\right)$ are given by

$$X_{nC}^{T}\left(\omega^{T}\right)=\varepsilon_{n}\left(\omega^{T}\right)\left[1-\left(\frac{u\left(\omega^{T}\right)}{\bar{u}_{nC}^{T}\left(\eta_{n}\left(\omega^{T}\right)\right)}\right)^{\lambda/\widetilde{\theta}}\right]\left(\frac{u\left(\omega^{T}\right)}{\bar{u}_{nC}^{T}\left(\eta_{n}\left(\omega^{T}\right)\right)}\right)^{-(\sigma-1)/\theta}\sigma E_{nC}^{T}.$$

C.1 Simulation Algorithm

We denote an artificial Chinese exporter by s and the number of such exporters by S. Prior to running any simulations, (i) we draw S realizations of $v\left(s\right)$ independently from the uniform distribution $U\left[0,1\right]$, putting them aside to construct the standardized unit cost, and (ii) we draw two sets of $S\times N$ realizations of $a_{n}\left(s\right)$ and $h_{n}\left(s\right)$ independently from $N\left(0,1\right)$, putting them aside to construct $\alpha_{n}^{R}\left(s\right)$ and $\eta_{n}^{R}\left(s\right)$, and $\alpha_{n}^{B}\left(s\right)$ and $\eta_{n}^{B}\left(s\right)$.

A given simulation of the model requires a set of parameters Θ, data for each destination n on average domestic sales or ordinary exports $\overline{X}_{nC}^{O}$ by Chinese ordinary exporters, average processing exports $\overline{X}_{nC}^{P}$ by Chinese processing exporters, and the numbers N_{nC}^{O} and N_{nC}^{P} of Chinese firms selling there via domestic sales or ordinary exports and processing exports, respectively. The simulation involves nine steps:

Step 1 Calculate κ_1^T and κ_2^T

Step 2 Calculate σE_{nC}^T for each destination according to $\sigma E_{nC}^R = \frac{\kappa_2^R}{\kappa_1^R}\overline{X}_{nC}^{O}$ and $\sigma E_{nC}^B = \frac{\kappa_2^B}{\kappa_1^B}\overline{X}_{nC}^{P}$.

Step 3 We use $a_n^T(s)$ and $h_n^T(s)$ to construct $S \times N$ realizations for each $\ln \alpha_n^T(s)$ and $\ln \eta_n^T(s)$ as

$$\begin{bmatrix} \ln \alpha_n^T(s) \\ \ln \eta_n^T(s) \end{bmatrix} = \begin{bmatrix} \sigma_\alpha \sqrt{1-\rho^2} & \sigma_\alpha \rho \\ 0 & \sigma_\eta \end{bmatrix} \begin{bmatrix} a_n^T(s) \\ h_n^T(s) \end{bmatrix}.$$

Step 4 We construct the $S \times N$ entry hurdles for ordinary exports

$$\overline{u}_n^R(s) = \frac{N_{nC}^O}{\kappa_2^R}\eta_n^R(s)^{\widetilde{\theta}},$$

and $S \times N$ entry hurdles for processing exports

$$\overline{u}_n^B(s) = \frac{N_{nC}^P}{\kappa_2^B}\eta_n^B(s)^{\widetilde{\theta}}.$$

Step 5 We calculate

$$\overline{u}(s) = \max_n \left\{ \overline{u}_n^R(s), \overline{u}_n^B(s) \right\},$$

the maximum u consistent with selling somewhere under ordinary or processing trade.

Step 6 To simulate Chinese firms that sell in at least one market, $u(s)$ should be a realization from the uniform distribution over the interval $[0, \overline{u}(s)]$. Therefore, we construct

$$u(s) = v(s)\,\overline{u}(s).$$

Step 7 In the model, a measure of $\overline{u}$ firms have standardized unit cost below $\overline{u}$. Our artificial Chinese exporter s therefore gets an importance weight $\overline{u}(s)$. This importance weight is used to construct statistics on artificial Chinese exporters that relate to statistics on actual Chinese exporters.

Step 8 We calculate $\delta_{nC}^R(s)$, which indicates whether artificial exporters s enters market n producing with regular technology under ordinary trade regime, as determined by the entry hurdles

$$\delta_{nC}^{R}(s) = \begin{cases} 1 & \text{if } u(s) \leq \overline{u}_n^R(s), \\ 0, & \text{otherwise.} \end{cases}$$

Wherever $\delta_{nC}^{R}(s) = 1$, we calculate sales as

$$X_{nC}^{R}(s) = \frac{\alpha_n^R(s)}{\eta_n^R(s)} \left[1 - \left(\frac{u(s)}{\overline{u}_n^R(s)} \right)^{\lambda/\widetilde{\theta}} \right] \left(\frac{u(s)}{\overline{u}_n^R(s)} \right)^{-1/\widetilde{\theta}} \sigma E_{nC}^{R}.$$

Step 9 We calculate $\delta_{nC}^{B}(s)$, which indicates whether artificial exporters s enters market n producing with foreign-inputs-biased technology under processing trade regime, as determined by the entry hurdles

$$\delta_{nC}^{B}(s) = \begin{cases} 1 & \text{if } u(s) \leq \overline{u}_n^B(s), \\ 0, & \text{otherwise.} \end{cases}$$

Wherever $\delta_{nC}^{B}(s) = 1$, we calculate sales as

$$X_{nC}^{B}(s) = \frac{\alpha_n^B(s)}{\eta_n^B(s)} \left[1 - \left(\frac{u(s)}{\overline{u}_n^B(s)} \right)^{\lambda/\widetilde{\theta}} \right] \left(\frac{u(s)}{\overline{u}_n^B(s)} \right)^{-1/\widetilde{\theta}} \sigma E_{nC}^{B}.$$

C.2 Moments

For a candidate value Θ, we use the algorithm above to simulate the sales of S artificial Chinese exporting firms in N markets. From these artificial data, we compute a vector of moments $\widehat{m}(\Theta)$ analogous to particular moments m in the actual data. Here we choose five sets of moments. The first three sets of moments are related to ordinary exports:

- We compute the proportion $\widehat{m}^k(1;\Theta)$ of simulated ordinary exporters selling to each possible combination k of the seven most popular ordinary export destinations. There are 2^7 possible combinations. The corresponding moments from the actual data are simply the proportion $m^k(1)$ of exporters selling to combination k. Stacking these proportions gives us $\widehat{m}(1;\Theta)$ and $m(1)$ with 128 elements (subject to 1 adding up constraint).

- For firms selling in each other $N-1$ export destinations n, we compute the qth percentile of ordinary export sales $s_n^q(2)$ in that market for $q = 50, 75, 95$, from actual data. Using these $s_n^q(2)$, we assign firms that sell in n into four mutually exclusive and exhaustive bins determined by these three ordinary export sales levels. we compute the proportion $\widehat{m}_n(2;\Theta)$ of artificial firms falling into each bin analogous to the actual proportion $m_n(2) = (0.5, 0.25, 0.2, 0.05)'$. Stacking across $N-1$ countries gives us the proportion $\widehat{m}(2;\Theta)$ and $m(2)$, each with $4(N-1)$ elements (subject to $N-1$ adding up constraints).

- For firms selling via ordinary exports in each of the $N-1$ destinations n, we compute the qth percentile of sales $s_n^q(3)$ in China (excluding firms with no sales in China) for $q = 50, 75, 95$, from the actual data. Proceeding as above, we get $\widehat{m}(3;\Theta)$ and $m(3)$, each with $4(N-1)$ elements (subject to $N-1$ adding up constraints).

The last two sets of moments are related to processing exports:

- We compute the proportion $\widehat{m}^k(4;\Theta)$ of simulated processing exporters selling to each possible combination k of the seven most popular processing export destinations. There are 2^7 possible combinations. The corresponding moments from the actual data are simply the proportion $m^k(4)$ of exporters selling to combination k. Stacking these proportions gives us $\widehat{m}(4;\Theta)$ and $m(4)$ with 128 elements (subject to 1 adding up constraint).

- For firms selling in each of the $N-1$ export destinations n, we compute the qth percentile of processing export sales $s_n^q(5)$ in that market for $q = 50, 75, 95$, from actual data. Using these $s_n^q(5)$, we assign firms that sell in n to four mutually exclusive and exhaustive bins determined by these three processing export sales levels. we compute the proportion $\widehat{m}_n(6;\Theta)$ of artificial firms falling into each bin analogous to the actual proportion $m_n(5) = (0.5, 0.25, 0.2, 0.05)'$. Stacking across $N-1$ countries gives us the proportions $\widehat{m}(5;\Theta)$ and $m(5)$, each with $4(N-1)$ elements (subject to $N-1$ adding up constraints).

Stacking the five sets of moments gives us a $(12(N-1)+256)$-element vector of deviations between the moments of the actual and artificial data:

$$y(\Theta) = \begin{bmatrix} m(1) - \widehat{m}(1;\Theta) \\ m(2) - \widehat{m}(2;\Theta) \\ m(3) - \widehat{m}(3;\Theta) \\ m(4) - \widehat{m}(4;\Theta) \\ m(5) - \widehat{m}(5;\Theta) \end{bmatrix}.$$

C.3 Estimation Procedure

We base our estimation procedure on the moment condition

$$\mathbb{E}\left[y(\Theta_0)\right] = 0,$$

where Θ_0 is the true value of Θ. We thus seek a $\widehat{\Theta}$ that achieves

$$\widehat{\Theta} = \arg\min_{\Theta} \left[y(\Theta)' W y(\Theta)\right],$$

where W is an identity matrix.

D Counterfactual

Define tariff structure $\boldsymbol{\tau} = \{\tau_{ni}^{R}, \tau_{ni}^{B}\}$, in which τ_{ni}^{R} denote the ad-valorem tariff for goods from country i imported by country n absorbed in final consumption or production with regular technology, and τ_{ni}^{B} denote the ad-valorem tariff for goods from country i imported by country n used for production with foreign-inputs-biased technology. The counterfactual experiments in this paper all ask what happens moving from policy $\boldsymbol{\tau}$ to $\boldsymbol{\tau}'$. For example, the first counterfactual experiment moves from the counterfactual equilibrium in which China does not offer duty exemption to the observed equilibrium in 2005. It is equivalent to say that the experiment moves $\tau_{Ci}^{B} = \tau_{Ci}^{R}$ to $\tau_{Ci}^{B'} = 1$ for all i, while keeps all other bilateral tariffs unchanged.

In this section, we apply the "exact hat" method developed by Dekle, Eaton, and Kortum (2008) to compute the changes in wages and prices moving from policy $\boldsymbol{\tau}$ to $\boldsymbol{\tau}'$. First, we rewrite the equilibrium equations with the new notation, τ_{ni}^{R} and τ_{ni}^{B}. Second, we define the equilibrium in changes under tariff structure $\boldsymbol{\tau}'$ relative to $\boldsymbol{\tau}$. Third, we describe the data sources for calibration. Fourth, we describe an algorithm to solve the equilibrium in changes.

D.1 A General Representation of the Equilibrium Equations

We begin with the price indices.

$$\left(P_n^R\right)^{1-\sigma} = \overline{m}^{-\theta} \sum_{i=1}^{N} \Psi_{ni} \left(A_{ni} \left(\tau_{ni}^{R}\right)^{\sigma-1}\right)^{\theta/(\sigma-1)-1}, \tag{D.1}$$

and

$$\left(P_n^B\right)^{1-\sigma} = \overline{m}^{-\theta} \sum_{i=1}^{N} \alpha_{ni}^{B} \Psi_{ni} \left(\frac{\tau_{ni}^{R}}{\tau_{ni}^{B}}\right)^{\sigma-1} \left(A_{ni} \left(\tau_{ni}^{R}\right)^{\sigma-1}\right)^{\theta/(\sigma-1)-1}. \tag{D.2}$$

Note that equations (D.1) and (D.2) become equation (19) and (21), respectively, if $\tau_{ni}^{O} = \tau_{ni}$ and $\tau_{ni}^{P} = 1$.

Turning to the trade shares, equation (22) can be written as

$$\pi_{ni}^{R,T} = \frac{\Psi_{ni}^{T} \left(A_{ni} \left(\tau_{ni}^{R}\right)^{\sigma-1}\right)^{\theta/(\sigma-1)-1}}{\sum_{i=1}^{N} \Psi_{ni} \left(A_{ni} \left(\tau_{ni}^{R}\right)^{\sigma-1}\right)^{\theta/(\sigma-1)-1}},$$

and equation (23) is written as

$$\pi_{ni}^{B,T} = \frac{\alpha_{ni}^{B} \Psi_{ni}^{T} \left(\frac{\tau_{ni}^{R}}{\tau_{ni}^{B}}\right)^{\sigma-1} \left(A_{ni} \left(\tau_{ni}^{R}\right)^{\sigma-1}\right)^{\theta/(\sigma-1)-1}}{\sum_{i=1}^{N} \alpha_{ni}^{B} \Psi_{ni} \left(\frac{\tau_{ni}^{R}}{\tau_{ni}^{B}}\right)^{\sigma-1} \left(A_{ni} \left(\tau_{ni}^{R}\right)^{\sigma-1}\right)^{\theta/(\sigma-1)-1}}$$

The total absorption for manufactures in country n is given by

$$X_n^R + X_n^B = \gamma_n I_n + \frac{1-\beta}{\overline{m}} \sum_{i=1}^{N} \left(\frac{\pi_{in}^R}{\tau_{in}^R} X_i^R + \frac{\pi_{in}^B}{\tau_{in}^B} X_i^B \right).$$

I_n is the total income, containing the labor income, tariff revenue and profits. Tariff revenue is given by

$$R_n = \sum_{i=1}^{N} \left(\pi_{ni}^R \frac{\tau_{ni}^R - 1}{\tau_{ni}^R} X_n^R + \pi_{ni}^B \frac{\tau_{ni}^B - 1}{\tau_{ni}^B} X_n^B \right).$$

Profits are given by

$$\Pi_n = \frac{1}{\sigma} \sum_{i=1}^{N} \left(\frac{\pi_{in}^R}{\tau_{ni}^R} X_i^R + \frac{\pi_{in}^B}{\tau_{in}^B} X_n^B \right) - \frac{\theta - (\sigma - 1)}{\sigma\theta} \sum_{i=1}^{N} \left(\pi_{in}^R X_i^R + \pi_{in}^B X_n^B \right).$$

Finally, the trade balance is given by

$$\sum_{i=1}^{N} \left(\frac{\pi_{ni}^R}{\tau_{ni}^R} X_n^R + \frac{\pi_{ni}^B}{\tau_{ni}^B} X_n^B \right) - D_n = \sum_{i=1}^{N} \left(\frac{\pi_{in}^R}{\tau_{in}^R} X_i^R + \frac{\pi_{in}^B}{\tau_{in}^B} X_i^B \right).$$

D.2 Equilibrium in Relative Changes

We now define the equilibrium of the model under policy $\boldsymbol{\tau}'$ relative to a policy $\boldsymbol{\tau}$.

Definition 2: Let $(\mathbf{w}, \mathbf{P}^R, \mathbf{P}^B)$ be an equilibrium under tariff structure $\boldsymbol{\tau}$ and $(\mathbf{w}', \mathbf{P}^{R'}, \mathbf{P}^{B'})$ be an equilibrium under tariff structure $\boldsymbol{\tau}'$. Define $(\hat{\mathbf{w}}, \hat{\mathbf{P}}^R, \hat{\mathbf{P}}^B)$ as an equilibrium under $\boldsymbol{\tau}'$ relative to $\boldsymbol{\tau}$, where a variable with a hat "$\hat{x}$" represents the relative change of the variable, namely $\hat{x} = x'/x$. Using equations (19) (21) (22) (23) (25) (26)and (27), the equilibrium conditions in relative changes satisfy:

- Price indices:

$$\left(\hat{P}_n^R\right)^{-\theta} = \sum_{k=1}^{N} \sum_{T} \pi_{nk}^{R,T} \left(\hat{w}_k\right)^{-\beta\theta} \left(\hat{P}_k^T\right)^{-(1-\beta)\theta} \left(\hat{\tau}_{nk}^R\right)^{-\theta} \left(\frac{X_n^{R'} + X_n^{B'} \frac{\pi_{nk}^{B,R'}}{\pi_{nk}^{R,R'}}}{X_n^R + X_n^B \frac{\pi_{nk}^{B,R}}{\pi_{nk}^{R,R}}} \frac{1}{\hat{w}_n} \right)^{\frac{\theta}{\sigma-1}-1}, \tag{D.3}$$

and

$$\left(\hat{P}_n^B\right)^{-\theta} = \sum_{k=1}^{N} \sum_{T} \pi_{nk}^{B,T} \left(\hat{w}_k\right)^{-\beta\theta} \left(\hat{P}_k^T\right)^{-(1-\beta)\theta} \left(\hat{\tau}_{nk}^B\right)^{-\theta} \left(\frac{X_n^{R'} \frac{\pi_{nk}^{R,R'}}{\pi_{nk}^{B,R'}} + X_n^{B'}}{X_n^R \frac{\pi_{nk}^{R,R}}{\pi_{nk}^{B,R}} + X_n^B} \frac{1}{\hat{w}_n} \right)^{\frac{\theta}{\sigma-1}-1}. \tag{D.4}$$

- Trade shares:

$$\pi_{ni}^{R,T'} = \frac{\pi_{ni}^{R,T}\left(\hat{w}_i\right)^{-\beta\theta}\left(\hat{P}_i^T\right)^{-(1-\beta)\theta}\left(\hat{\tau}_{ni}^R\right)^{-\theta}\left(\frac{X_n^{R'}+X_n^{B'}\frac{\pi_{ni}^{B,R}}{\pi_{ni}^{R,R}}\left(\frac{\hat{P}_n^B}{\hat{P}_n^R}\frac{\hat{\tau}_{ni}^R}{\hat{\tau}_{ni}^B}\right)^{\sigma-1}}{X_n^R+X_n^B\frac{\pi_{ni}^{B,R}}{\pi_{ni}^{R,R}}}\right)^{\frac{\theta}{\sigma-1}-1}}{\sum_{k=1}^N\sum_T\pi_{nk}^{O,T}\left(\hat{w}_k\right)^{-\beta\theta}\left(\hat{P}_k^T\right)^{-(1-\beta)\theta}\left(\hat{\tau}_{nk}^R\right)^{-\theta}\left(\frac{X_n^{R'}+X_n^{B'}\frac{\pi_{nk}^{B,R}}{\pi_{nk}^{R,R}}\left(\frac{\hat{P}_n^B}{\hat{P}_n^R}\frac{\hat{\tau}_{nk}^R}{\hat{\tau}_{nk}^B}\right)^{\sigma-1}}{X_n^R+X_n^B\frac{\pi_{nk}^{B,R}}{\pi_{nk}^{R,R}}}\right)^{\frac{\theta}{\sigma-1}-1}}, \tag{D.5}$$

and

$$\pi_{ni}^{B,T'} = \frac{\pi_{ni}^{B,T}\left(\hat{w}_i\right)^{-\beta\theta}\left(\hat{P}_i^T\right)^{-(1-\beta)\theta}\left(\hat{\tau}_{ni}^R\right)^{-\theta}\left(\frac{\hat{\tau}_{ni}^R}{\hat{\tau}_{ni}^B}\right)^{\sigma-1}\left(\frac{X_n^{R'}+X_n^{B'}\frac{\pi_{ni}^{B,R}}{\pi_{ni}^{R,R}}\left(\frac{\hat{P}_n^B}{\hat{P}_n^R}\frac{\hat{\tau}_{ni}^R}{\hat{\tau}_{ni}^B}\right)^{\sigma-1}}{X_n^R+X_n^B\frac{\pi_{ni}^{B,R}}{\pi_{ni}^{R,R}}}\right)^{\frac{\theta}{\sigma-1}-1}}{\sum_{k=1}^N\sum_T\pi_{nk}^{B,T}\left(\hat{w}_k\right)^{-\beta\theta}\left(\hat{P}_k^T\right)^{-(1-\beta)\theta}\left(\hat{\tau}_{nk}^R\right)^{-\theta}\left(\frac{\hat{\tau}_{nk}^R}{\hat{\tau}_{nk}^B}\right)^{\sigma-1}\left(\frac{X_n^{R'}+X_n^{B'}\frac{\pi_{nk}^{B,R}}{\pi_{nk}^{R,R}}\left(\frac{\hat{P}_n^B}{\hat{P}_n^R}\frac{\hat{\tau}_{nk}^R}{\hat{\tau}_{nk}^B}\right)^{\sigma-1}}{X_n^R+X_n^B\frac{\pi_{nk}^{B,R}}{\pi_{nk}^{R,R}}}\right)^{\frac{\theta}{\sigma-1}-1}}. \tag{D.6}$$

- Total expenditure on manufactures:

$$X_n^{R'} + X_n^{B'} = \gamma_n I_n' + \frac{1-\beta}{\overline{m}}\sum_{i=1}^N\left(\frac{\pi_{in}^{R'}}{\tau_{in}^{R'}}X_i^{R'} + \frac{\pi_{in}^{B'}}{\tau_{in}^{B'}}X_i^{B'}\right). \tag{D.7}$$

- Trade balance:

$$\sum_{i=1}^N\left(\frac{\pi_{ni}^{R'}}{\tau_{ni}^{R'}}X_n^{R'} + \frac{\pi_{ni}^{B'}}{\tau_{ni}^{B'}}X_n^{B'}\right) - D_n = \sum_{i=1}^N\left(\frac{\pi_{in}^{R'}}{\tau_{in}^{R'}}X_i^{R'} + \frac{\pi_{in}^{B'}}{\tau_{in}^{B'}}X_i^{B'}\right), \tag{D.8}$$

where $\pi_{ni}^{R'} = \pi_{ni}^{R,R'} + \pi_{ni}^{R,B'}$, $\pi_{ni}^{B'} = \pi_{ni}^{B,R'} + \pi_{ni}^{B,B'}$, and $I_n' = \hat{w}_n w_n L_n + \sum_{i=1}^N\left(\pi_{ni}^{R'}\frac{\tau_{ni}^{R'}-1}{\tau_{ni}^{R'}}X_n^{R'} + \pi_{ni}^{B'}\frac{\tau_{ni}^{B'}-1}{\tau_{ni}^{B'}}X_n^{B'}\right) + \frac{1}{\sigma}\sum_{i=1}^N\left(\frac{\pi_{in}^{R'}}{\tau_{ni}^{R'}}X_i^{R'} + \frac{\pi_{in}^{B'}}{\tau_{in}^{B'}}X_n^{B'}\right) - \frac{\theta-(\sigma-1)}{\sigma\theta}\sum_{i=1}^N\left(\pi_{in}^{R'}X_i^{R'} + \pi_{in}^{B'}X_n^{B'}\right) + D_n^A$.

To solve the equilibrium in relative changes, we only need two sets of tariff structures ($\boldsymbol{\tau}$ and $\boldsymbol{\tau'}$), data on bilateral trade shares ($\pi_{ni}^{R,T}$ and $\pi_{ni}^{B,T}$), total expenditure ($X_n^R + X_n^B$), total income (I_n), trade elasticity (θ), elasticity of substitution (σ), output elasticity of labor (β), and the share of manufacture consumption (γ_n). Trade elasticity and elasticity of substitution are estimated.

D.3 Data Sources for the Counterfactual Analysis

The following countries and regions are included in the counterfactual analysis: Argentina, Australia, Austria, Bangladesh, Belgium, Brazil, Canada, Chile, China, Taiwan, Colombia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, India, Israel, Italy, Japan, South Korea, Malaysia, Mexico, Morocco the Netherlands, New Zealand, Norway, Pakistan, Peru, Poland, Portugal, Romania, the Russian Federation, Saudi Arabia, the Slovak Republic, Vietnam, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, the United Kingdom, the United States, and the constructed rest of the world. Manufacture includes 2-digit ISIC Rev. 3 industries from 15 to 37.

Bilateral trade flows we use bilateral trade flows for manufactures and 46 countries in 2000 and 2005. Bilateral trade data is from United Nation Statistical Division (UNSD) Commodity Trade (COMTRADE) database. Values are reported in thousands of U.S. dollars at current prices and include cost, insurance and freight (CIF). Commodities are defined using the Harmonized Commodity and Coding System (HS) 1997 and 2002 at the 6-digit level of aggregation and were concorded to 2-digit ISIC Rev. 3.

China's processing and ordinary imports, and processing and ordinary exports We compute the China's processing and ordinary imports for manufactures at the country level. We first aggregate all import transactions at the 6-digit HS code, trade regime and country level by using China's Customs data. We drop data on non-manufactures by concording 6-digit HS code to ISIC Rev. 3, and compute processing and ordinary imports at the country level. Similarly, we compute China's processing and ordinary exports at country level. Export values are reported in freight on board price (FOB). To match the CIF values from COMTRADE database, we scale up China's processing and ordinary exports proportionally to equate the total imports from China for each country in the COMTRADE database. In the Chinese Customs data, we observe transactions that are imports from China under processing and ordinary trade. we treat China's ordinary imports from China as the domestic sales generated from processing production, and China's processing imports from China as the spending on domestic inputs by processing production.

Tariffs We use bilateral tariff data for manufactures and 46 countries in year 2000, 2005, and 2007. The bilateral tariff data are from the UNSD Trade Analysis and Information System (TRAINS). We use the tariff measures that are reported in weighted average effective applied rates at 2-digit ISIC Rev. 3 industries, and obtain the bilateral tariffs for manufactures by calculating the weighted average effective applied rates of all 2-digit ISIC Rev. 3 manufactures industries.

Gross domestic product (GDP), total trade deficit and manufacture output Data on GDP Y_n^A and trade deficits on goods and services are from the World Development Indicators database. Manufacture output is from United Nations Industrial Development Organization Industrial Statistics Database (INDSTAT 4 ISIC Rev.3).

D.4 Algorithm to Compute the Counterfactual Equilibrium

We present a step-by-step procedure to solve the equilibrium.

- Step 1: Guess a vector of wages $\hat{\mathbf{w}}$ and two vectors of price indices $\hat{\mathbf{P}}^R$ and $\hat{\mathbf{P}}^B$. Proceed to Step 2.
- Step 2: Update the price indices by using equation (D.3) and (D.4) and $\hat{\mathbf{w}}$, $\hat{\mathbf{P}}^R$ and $\hat{\mathbf{P}}^B$. Proceed to Step 3.

- Step 3: Calculate the trade shares by using equation (D.5), (D.6) and the updated price indices. Proceed to Step 4.
- Step 4: Calculate the total absorption of manufactures by using equation (D.7) and the bilateral trade shares from step 3. Proceed to Step 5.
- Step 5: Calculate the trade surplus for each country n by using the trade shares from Step 3 and total absorption of manufactures from Step 4. Update each country's wage by using $w_n(1 + c_0 \frac{\text{trade surplus}}{\text{labor income}})$, where c_0 is a constant. Proceed to Step 6.
- Step 6: Proceed to Step 3 if wages do not converge. Proceed to Step 2 if wages converge. Stop when the price indices converge.