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## Article

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## A Quantitative Trade Model with Unemployment\*

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I employ search-and-matching to a multi-country and multi-sector Ricardian model with input-output linkages, trade in intermediate goods, and sectoral heterogeneity, in order to quantify the welfare effects from tariff changes. The paper shows that labor market frictions can be a source of comparative advantage in the sense that better labor market conditions contribute to lower cost in production. Labor market frictions play a critical role in determining the probability of exporting goods to trading partners, and interact with bilateral trade share, price, expenditures, etc. Unemployment and changes in unemployment rates due to tariff reductions contribute welfare changes across countries, implying that welfare effects based on quantitative trade models with full-employment are likely to be biased. I confirm the biased welfare effects by revisiting Caliendo and Parro (2015), who conduct an analysis of the welfare effects from the NAFTA from 1993 to 2005. I show that the welfare gap between theirs and mine has a positive correlation with changes in observed unemployment rates across countries. With the constructed model, I further conduct counterfactual exercises by asking what would happen if China's tariffs remain unchanged from 2006 to 2015. It turns out that there are mild welfare effects to trading partners in the world trading system.

*Keywords:* Quantitative Trade Model, Unemployment, Labor Market Frictions, Welfare, Tariff Reductions

*JEL Classification:* F10, F17, F60

### I. INTRODUCTION

Over the last decade, quantifying the welfare effects from tariff changes has become one of the main challenges among international trade economists. There are a number of quantitative trade models with micro-foundations which emphasize demand-side

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(Anderson and van Wincoop, 2003), supply-side (Eaton and Kortum, 2002), Bertrand competition (Bernard et al., 2003), extensive and intensive margin (Chaney, 2008), etc, and conclude that trade liberalization with tariff reductions leads an economy to reach a higher level of welfare compared to pre-liberalization (Costinot and Rodriguez-Clare, 2014). While elegant, these models inducing gravity equations share the common assumption, a perfect labor market.<sup>1</sup> Quantitative trade models with full-employment developed so far have not taken account of labor market frictions when evaluating the welfare effects from tariff changes. This paper aims to fill the gap in the trade literature by explicitly considering labor market frictions.

I employ search-and-matching to a multi-country and multi-sector Ricardian model with input-output linkages, trade in intermediate goods, and sectoral heterogeneity, in order to quantify the welfare effects from tariff changes. I select to add a simplified one-shot version of search-and-matching into Caliendo and Parro (2015) model.<sup>2</sup> My model is constructed as follows. The world comprises multi-country and multi-sector with input-output linkage and sectoral heterogeneity in the presence of labor market frictions. A generic country produces final output by assembling intermediate goods from domestic and foreign markets. It also produces intermediate goods in perfectly competitive markets and trades them with trading partners. An imperfect labor market plays a role for the production of an intermediate good. Workers and firms producing intermediate goods have to search each other to be matched. The production of an intermediate good requires not only its own material but also materials from other sectors, which reflects input-output linkages across sectors. After the match, an

<sup>1</sup> Quantitative trade models with a perfect labor market seem to be disconnected to reality and trade policy concerning domestic labor market outcomes, and stay mute in topics of international trade and labor market outcomes. In reality, trade liberalization accompanying by tariff reductions across sectors creates displaced workers who experience unemployment. Due to the risk of unemployment, workers and the public often show their fear and worries towards expanding trade liberalization. Policymakers of many countries introduce and implement trade policies such as the so-called trade adjustment assistant program to alleviate the adverse impact of trade liberalization on labor market outcomes.

<sup>2</sup> A notable paper in the literature of macroeconomics is Cacciatore (2014). He examines the effect of labor market frictions on macroeconomic dynamics based on the DSGE-type model with two countries. Though Cacciatore (2014) has more realistic feature (including dynamics) than mine, it is difficult to use the Cacciatore model to understand the effect of tariff changes. While Cacciatore (2014) considers only two countries, my model deals with many countries and sectors and examines the effect of tariff changes (not labor market frictions).

intermediate good can be produced and its surplus created by both a firm and a worker is split by the Nash Bargaining mechanism.

This paper shows several results which cannot be explained in usual quantitative trade models with full-employment. First, the efficiency of matching process in the labor market can be a source of comparative advantage. Labor market frictions play an important role in shaping the unit cost of an intermediate good. My model shows that the unit cost of an intermediate good falls when a country has a flexible labor market where, for instance, searching costs are low for both a firm and a worker. It indicates that labor market frictions interact with many economic variables. Due to the change in the unit cost, labor market frictions affect bilateral trade share, expenditure, price, final output, and thus the overall welfare.

Second, welfare changes due to tariff reductions contain not only changes in wages and prices but also changes in unemployment. In quantitative trade models with full-employment, many authors capture welfare changes by calculating changes in real wages. If the labor market is perfect, there is no change in the total number of employed workers or the labor force. This means that any impact on the labor market would be absorbed by wages and/or price. If we relax full-employment condition, unemployment and changes in unemployment rates play roles to determine welfare changes across countries. This paper shows that quantitative trade models with full-employment are likely to be biased due to the negligence of labor resource reallocations via unemployment.

The constructed trade model in the paper is built on a general equilibrium setting and can be used to answer some counterfactual questions. There are at least two other options such as Arkolakis et al. (2012) and Computational General Equilibrium (CGE) models based on the Armington (1969) type model to conduct counterfactual analysis. A key difference between Arkolakis et al. (2012) and CGE models is parsimony. The former only requires the trade elasticity to obtain welfare changes, whereas CGE models need more than 13,000 structural parameters (Adao et al., 2017). My model is located in between those two since it requires more than one parameter for analysis.

Third, with the constructed model, I conduct two counterfactual analyses by revisiting Caliendo and Parro (2015) and studying the welfare effect of China's tariff reductions.<sup>3</sup> In a revisit to Caliendo and Parro (2015), I first duplicate their model by

<sup>3</sup> The constructed model of the paper enables us to conduct counterfactual analysis evaluating the welfare effects from tariff changes, taking into account labor market frictions. Several authors have developed their own quantitative trade models with full-employment, including Dekle et al. (2008),

calculating welfare effects from the NAFTA given world tariffs changes from 1993 to 2005. Next, I use my model to examine the NAFTA's welfare effects and compare these to that of Caliendo and Parro (2015). I find that welfare effects from tariff reductions can be biased, overstated or understated, depending on changes in unemployment. The welfare gap between theirs and mine has a positive correlation with changes in observed unemployment rates for the same period. For an analysis on the welfare effect of China's tariff reductions, I ask what would happen if China's tariff structure remains unchanged since 2006. To answer the question, I use the World Input-Output Database (WIOD) released in 2016 and construct tariff schedules among countries and sectors from 2006 and 2015 using the World Integrated Trade Solution (WITS). I find that China's unchanged tariffs have a mild welfare impact on trading partners.

This paper contributes to the relatively new literature on international trade and unemployment in a quantitative framework. As many international trade theorists extended the HO model and Melitz (2003) model by adding labor market frictions,<sup>4</sup> several other authors began to extend quantitative trade models with full-employment by relaxing the labor market assumption. Two pioneering papers are detected: Heid and Larch (2016) and Carrere et al. (2016). Heid and Larch (2016) added search-and-matching to the Armington model whereas Carrere et al. (2016) employed search-and-matching into Costinot et al. (2012). My model builds search-and-matching into a multi-country and multi-sector Ricardian model of Caliendo and Parro (2015) with sectoral linkage and trade in intermediate goods. The constructed model of the paper can be regarded as a generalization of Caliendo and Parro (2015) but it should be noted that labor market frictions generate non-trivial outcomes in the model.

This paper is closely related to Heid and Larch (2016), who also use a simplified one-shot version of search-and-matching mechanism to consider labor market frictions. Both Heid and Larch (2016) and mine point out the role of unemployment and underscore the necessity to modify the calculation of welfare changes. However, there

Caliendo and Parro (2015), Costinot and Rodriguez-Clare (2014), Hsieh and Ossa (2016), and others, in order to do counterfactual predictions. Unlike theirs, my model allows changes in unemployment rates in evaluating the welfare effects of tariff reductions.

<sup>4</sup> In the trade literature, many theoretical papers have dealt with international trade and unemployment. For example, many authors have developed intra-industry trade models with various sources of equilibrium unemployment such as search-and-matching (Felbermayr et al., 2011; Helpman et al., 2010; Davidson and Matusz, 2012), efficiency wages (Davis and Harrigan, 2011), fair wages (Egger and Kreickemeier, 2009), and minimum wage (Egger et al., 2012).

are distinctive differences between theirs and mine. A key difference between their model and mine comes from structures of international trade. My model is built on a multi-country and multi-sector Ricardian model with sectoral linkages and trade in intermediate goods, whereas their model is constructed on the Armington model. In other words, their model has the single sector nature of homogeneous firm framework, thus the total output (total sales) is determined by its output price times the number of employed workers. Unlike Heid and Larch (2016), my model allows sectoral heterogeneity and trade in goods at sectoral levels so that labor market frictions play an important role even in shaping the unit cost of an intermediate good.

The remainder of the paper is structured as follows. Section II describes the quantitative trade model with unemployment. Section III describes world trading equilibrium and derives changes in the equilibrium. Section IV provides counterfactual analysis based on the model. Section V concludes the paper.

## II. THE MODEL

I build a simplified one-shot version of search-and-matching into a multi-country and multisector Ricardian model. The Ricardian world economy comprises  $N$  countries and  $J$  sectors. Denote a particular sector by  $j, k \in \{1, 2, \dots, J\}$  and a particular country by  $n, i \in \{1, 2, \dots, N\}$ . Sectors are of two types, either tradable or non-tradable. Each country consists of households and firms. Households play the roles of consumers as well as workers. Firms produce either intermediate goods or final outputs and compete perfectly in their own market. A final output is produced by assembling intermediate goods from domestic and foreign markets. An intermediate good in a generic sector requires not only its own material but materials from other sectors. Labor market is imperfect. Firms producing the intermediate good have to search for workers, and workers also have to search for firms to be matched. Once a single worker-firm matching is created, the worker can produce intermediate goods using materials from other sectors. The net surplus created in production is shared by a firm and a worker through the Nash Bargaining solution. Labor is mobile across sectors and immobile across countries. Lastly, trade is balanced.<sup>5</sup>

<sup>5</sup> This assumption can be relaxed as considered in Caliendo and Parro (2015), Costinot and Rodriguez-Clare (2014), Dekle et al. (2008) among many others. For the sake of simplicity, I keep this assumption in the main body of the paper.

### 1. Consumer

The representative consumer in each country  $n \in \{1, 2, \dots, N\}$  maximizes his/her utility:

$$\max_{\{x_n^j\}_{j=1}^J} \prod_{j=1}^J (x_n^j)^{\alpha_n^j} \quad (1)$$

where  $x_n^j$  is consumption of final output produced at sector  $j$  in country  $n$  and  $\alpha_n^j$  is the share of consumption over final output  $x_n^j$ . The utility follows Cobb-Douglas with homothetic of degree one. It thus holds  $\sum_{j=1}^J \alpha_n^j = 1$  for any country  $n$ . As we will see later, final output is composite intermediate goods. It implies that consumers consume all sectors' composite goods with different weights  $\alpha_n^j$ . Denote  $p_n^j$  as the corresponding prices to the purchase of  $x_n^j$  in sectors  $j \in \{1, 2, \dots, J\}$ .

Consumers are also workers who have to search for a job. Workers who are successfully matched with firms create surplus and get paid wage income from the matched firm. With total income  $I_n$  and given prices  $\{p_n^j\}$  for final goods, the consumer maximizes his/her utility (1) subject to the budget constraint  $\sum_{j=1}^J p_n^j x_n^j = I_n$ .<sup>6</sup> The optimal consumption choices over the final goods can be summarized as the total demand of final good  $j$  in country  $n$ ,  $p_n^j x_n^j = \alpha_n^j I_n$ . Its corresponding ideal price index in country  $n$  is calculated by  $P_n = (p_n^j / \alpha_n^j)^{\alpha_n^j}$ .

### 2. Firm

The paper allows input-output linkage across sectors. Assume that composite intermediate goods in each sector can be yielded using only intermediate goods available from that specific sector. A fraction of composite intermediate goods (or final goods) are consumed by consumers and the rest are used in the production of intermediate goods. Countries have different productivity in producing intermediate

<sup>6</sup> Total income consists of wage income and lump-sum transfer from the country to which consumers belong. At this stage, only total income matters in deriving the optimal consumption basket.

goods, which follows the spirit of the Ricardian model. Firms are identical within sector  $j$  in country  $n$ . The markets for both final goods and intermediate goods are perfectly competitive.

### 1) Intermediate goods

Firms in a generic sector  $j$  of country  $n$  produce a continuum of varieties of intermediate goods.<sup>7</sup> Firms producing intermediate goods differ in their productivity level  $z_n^j$  which is drawn randomly from a Frechet distribution. The one-worker production function  $y_n^j(z_n^j)$  for intermediate goods is obtained given the realization of productivity level  $z_n^j$  at intermediate good sector  $j$  in country  $n$ :

$$y_n^j(z_n^j) = z_n^j \prod_{k=1}^J m_n^{k,j}(z_n^j)^{\gamma_n^{k,j}} \quad (2)$$

where  $m_n^{k,j}(z_n^j)$  is the demand for composite intermediate goods by firms in sector  $j$  from sector  $k$  and  $\gamma_n^{k,j} \geq 0$  is the share of composite intermediate goods from sector  $k$  in the production of sector  $j$ . This structure of production technology is closely related to the input-output matrix for each economy.

The efficiency of production of intermediate goods differs across sectors and countries. Let  $z^j = (z_1^j, z_2^j, \dots, z_N^j)$  be the vectors of productivity draws for any given intermediate good  $j$  for the  $N$  countries. The productivity vectors are independent random variables indicating efficiency following Eaton and Kortum (2002) and Caliendo and Parro (2015). The Frechet distribution is  $F_n^j(z) = e^{-\lambda_n^j z^{-\theta^j}}$  where  $\lambda_n^j$  is location parameter varying by country and sector and  $\theta^j > \sigma^j - 1$  is shape parameter by sector but is the same across countries. Its corresponding probability density function is  $f_n^j(z) = \lambda_n^j e^{-\lambda_n^j z^{-\theta^j}}$ .

<sup>7</sup> A continuum of varieties is needed to generate heterogeneity across countries. Since firms are identical within a generic sector, varieties will be indexed by sector and traced by productivity at the sectoral level.



## 2) Final goods

Firms in a generic sector  $j$  of country  $n$  produce final output  $Q_n^j$  by assembling intermediate goods. So, final output production needs no value-added. The final output  $Q_n^j$  can be seen as the composite intermediate good or a bundle of intermediate goods in  $(n, j)$ . This bundle cannot be generated by assembling intermediate goods from different sectors other than sector  $j$ . The assembling technology following Ethier (1982) is for any sector  $j$  and any country  $n$ :

$$Q_n^j = \left( \int_{R_+^N} d_n^j(z_n^j)^{1-1/\sigma_n^j} \phi^j(z^j) dz^j \right)^{\sigma_n^j/(\sigma_n^j-1)}, \quad (3)$$

where  $d_n^j(z_n^j)$  is the demand of intermediate goods from lowest cost supplier with  $z_n^j$ .  $\phi^j(z^j)$  denotes the cumulative density function  $(\prod_{n=1}^N \lambda_n^j) e^{\{-\sum_{n=1}^N \lambda_n^j z_n^j - \theta^j\}}$  for the vector  $z^j$  is the elasticity of substitution across intermediate goods within sector  $j$  and assume that  $\sigma_n^j$  is same across countries but is sector-specific, e.g.,  $\sigma^j = \sigma_n^j$  for all countries.

Let  $p_n^j(z_n^j)$  denote the unit price of composite intermediate goods in sector  $j$ . Using (3), firms producing final goods solve the problem:  $\max_{\{d_n^j(z^j)\}} P_n^j Q_n^j - \int p_n^j(z^j) d_n^j(z^j) \phi^j(z^j) dz^j$ . The demand function for the intermediate goods  $d_n^j(z^j)$  is obtained by

$$d_n^j(z^j) = \left( \frac{p_n^j(z^j)}{P_n^j} \right)^{-\sigma^j} Q_n^j$$

where  $P_n^j = \left( \int p_n^j(z^j)^{1-\sigma^j} \phi^j(z^j) dz^j \right)^{1/(1-\sigma^j)}$  by using the property of final output technology. Free entry to the perfectly competitive final output market implies zero profit.

### 3. Labor market and production

Unlike the usual quantitative trade models with full-employment, I adopt a simplified one-shot version of search-and-matching model for the imperfect labor market for the sake of analytical tractability.<sup>8</sup>

#### 1) Search-and-matching

Firms and workers have to search each other to be matched in the labor market. It is costly for firms to find a worker. A firm that wishes to produce an intermediate good has to post a vacancy by spending  $e_n^j P_n$  measured in terms of the final good at country  $n$ . A worker who wishes to earn income has to search for a job first. Assume that there are potentially  $L_n$  number of workers and  $V_n$  number of job postings in country  $n$ . Matches in the labor market arise through matching technology.

Define the successful number of matches between firms and workers:

$$M_n(L_n, V_n) = \bar{m}_n L_n^{\chi_n} V_n^{1-\chi_n} \quad (4)$$

where  $\bar{m}_n$  denotes overall matching efficiency and  $\chi_n \in (0,1)$  is elasticity of the matching function in country  $n$ .

Let  $\zeta_n (= V_n/L_n)$  be the degree of labor market tightness in country  $n$ . The fraction of open vacancies filled in country  $n$  is  $M_n/V_n$  whereas the fraction of all workers who will find jobs is  $M_n/L_n$ . Using the degree of labor market tightness and equation (4), we can express  $M_n/V_n = \bar{m}_n \zeta_n^{-\chi_n} \equiv m_n(\zeta_n)$  and  $M_n/L_n = \bar{m}_n \zeta_n^{1-\chi_n} \equiv \zeta_n m_n(\zeta_n)$ . From the perspective of the firm,  $m_n(\zeta_n)$  means the probability of filling a vacancy. The fraction of all workers who will find jobs is interpreted as the employment rate, which implies that the unemployment rate in country  $n$  is calculated as

$$u_n = 1 - \bar{m}_n \zeta_n^{1-\chi_n}, \quad (5)$$

<sup>8</sup> For the survey paper of search-and-matching, see Rogerson et al. (2005).

where the overall matching efficiency should be sufficiently low to guarantee the unemployment rate being in between zero and unity.

## 2) Wage determination

As noted earlier, it is costly for a firm to hire a worker. In equilibrium, posting costs  $e_n^j P_n$  should cover at least expected net profit  $E\pi_n^j$  where  $E$  is an expectation operator. Regardless of the size of wage, the firm should pay costs for intermediate goods in production. Notice that first order condition with respect to intermediate goods for demand implies that the condition  $m_n^{k,j}(z_n^j) = (1 - \sum_{k=1}^J \gamma_n^{k,j}) p_n^j(z_n^j) y_n^j(z_n^j) / p_n^k(z_n^j)$  must hold. Such an optimality condition states that marginal cost of intermediate goods bundles equal marginal product of those bundles in sector  $j$  and country  $n$ . Applying the condition results in  $\pi_n^j(z_n^j) = (1 - \sum_{k=1}^J \gamma_n^{k,j}) p_n^j(z_n^j) y_n^j(z_n^j) - w_n^j$  where  $w_n^j$  is the worker's wage. Since a worker-firm encounters  $m_n(\zeta_n)$  probability of filling a vacancy, the expected profit becomes  $E\pi_n^j = \pi_n^j m_n(\zeta_n)$ .

The so-called job creation curve is obtained from  $e_n^j P_n = \pi_n^j m_n(\zeta_n)$ ,

$$w_n^j = (1 - \sum_{k=1}^J \gamma_n^{k,j}) p_n^j(z_n^j) y_n^j(z_n^j) - \frac{e_n^j P_n}{m_n(\zeta_n)}. \quad (6)$$

Total match surplus is split by the Nash Bargaining process. It should be clear about the size of total surplus created by a worker-firm production. The firm creates net profit from the match whereas the worker gains wage minus reservation wage. Let  $\beta_n$  indicate the worker's bargaining power and  $r_n$  represent reservation wage. As usual in the standard search-and-matching literature, the Nash Bargaining solution is obtained by choosing wages to maximize  $[w_n^j - r_n]^{\beta_n} [(1 - \sum_{k=1}^J \gamma_n^{k,j}) p_n^j(z_n^j) y_n^j(z_n^j) - w_n^j]^{(1-\beta_n)}$ .

The so-called wage equation is obtained from the outcome of the Nash Bargaining

$$w_n^j = \beta_n (1 - \sum_{k=1}^J \gamma_n^{k,j}) p_n^j(z_n^j) y_n^j(z_n^j) \quad (7)$$

which assumes that workers have zero reservation wage for simplicity. Note that a worker receives wages, a fraction  $\beta_n$  of the net profit or the total surplus. Manipulating (6) and (7) renders wage equation  $w_n^j = \beta_n e_n^j P_n / (1 - \beta_n) m_n(\zeta_n)$  expressed in terms of bargaining power  $\beta_n$ , posting costs  $e_n^j P_n$ , and a firm's matching probability and also provides revenue equation  $p_n^j(z_n^j) y_n^j(z_n^j) = e_n^j P_n / (1 - \beta_n) (1 - \sum_{k=1}^J \gamma_n^{k,j}) m_n(\zeta_n)$ . The wage and revenue equation become useful in deriving unit cost of intermediate goods firms.

## 2) Unit cost

The market structure of the intermediate goods is perfect competition. So, a firm's optimal pricing equals unit cost divided by its own productivity, that is  $p_n^j(z_n^j) = c_n^j(z_n^j) / z_n^j$ . Before moving on to international trade, we should be able to derive optimal unit cost for the intermediate goods firm. Unit cost plays a critical role since a final goods firm compares prices of intermediate goods from domestic and foreign markets before buying and assembling them for the production of the final good. Of course, we will take into account trade costs but still unit costs matter.

Manipulating equation (2) together with the wage and revenue equation derived above provides unit cost in country  $n$  and sector  $j$ ,

$$c_n^j(z^j; \bar{m}_n) = A_n^j \underbrace{\left( \frac{e_n^j P_n}{(1 - \beta_n) m_n(\zeta_n)} \right)^{(1 - \sum_{k=1}^J \gamma_n^{k,j})}}_{\text{frictions}} \underbrace{\prod_{k=1}^J p_n^k(z_n^k)^{\gamma_n^{k,j}}}_{\text{sectoral linkage}} \quad (8)$$

where  $A_n^j$  is constant.<sup>9</sup>

Two distinct features from the unit cost (8) can be summarized as follows. First, notice that labor market frictions play an important role in generating the unit cost in all countries and sectors. The unit cost in (8) shows that as the posting cost to search for a worker increases, the unit cost in production increases. As a worker's bargaining power increases, the unit cost also increases. As a firm finds it easier to find a worker, the unit cost in production decreases. In sum, the firm's unit cost is affected by not

<sup>9</sup>  $A_n^j$  consists of parameters such as  $(1 - \sum_{k=1}^J \gamma_n^{k,j})^{-(1 - \sum_{k=1}^J \gamma_n^{k,j})} \prod (\gamma_n^{k,j})^{-\gamma_n^{k,j}}$ .

only the sector-specific price of composite intermediate goods, but also labor market conditions. Second, country-specific labor market conditions can contribute to form a comparative advantage. A country with low search costs and better matching would generate a low unit cost of the intermediate goods, which implies higher probability of exporting intermediate goods in the international trade relative to that with high search costs and inferior matching technology. This result brings to mind the key message by Cuñat and Melitz (2012). They provide empirical evidence that different labor market institutions generate a new source of comparative advantage across countries.

The aforementioned result of the paper is sharply contrasted with a quantitative trade model with perfect labor market as in Caliendo and Parro (2015). The quantitative trade model with full-employment cannot illustrate how changes in one country's labor market conditions affect its unit cost and thus comparative advantage. The result of the paper is also unlike Heid and Larch (2016). A notable distinction between Heid and Larch (2016) and mine is that labor market frictions can affect the unit cost in my model while not in their model. The main reason why the unit cost is unchanged by labor market frictions in Heid and Larch's (2016) model is that their model considers neither intermediate goods, nor sectoral input-output linkage. Further, they treat cost function as given whereas the cost function in my model is endogenously determined.

#### 4. International trade

Trade in intermediate goods is costly. In order for a firm to export one unit of any intermediate good in sector  $j$  from country  $n$  to  $i$ , the firm should produce and export  $\tau_{ni}^j \geq 1 (i \neq n)$  times larger units of the intermediate good due to iceberg trade costs in tradable sectors. For domestic trade costs in tradable sectors,  $\tau_{nn}^j = 1$  for all countries and, in non-tradable sectors,  $\tau_{ni}^j = \infty$  for all countries. The paper mainly considers ad-valorem tariff as trade costs.

*Price competition:* Final good firms demand intermediate goods from domestic and foreign markets. These firms search for the lowest price of intermediate goods together with trade costs. In tradable sectors, intermediate goods firms have a price as a result of the following minimization problem:  $p_n^j(z^j; \bar{m}_n) = \min_i \{c_i^j(z_i^j; \bar{m}_i) \tau_{ni}^j / z_i^j\}$  where the resulting price  $p_n^j(z^j; \bar{m}_n)$  paid for an intermediate good with vector of productivity draws  $z^j$  is obtained by the minimum of unit costs adjusted by trade

costs. Since labor market conditions affect the unit cost, they can also affect prices of intermediate goods across countries. In non-tradable sectors,  $p_n^j(z_n^j; \bar{m}_n) = c_n^j(z_n^j; \bar{m}_n)/z_n^j$ . Using the property of the Frechet distribution and optimal prices from all sellers in all countries, the price of the composite intermediate good is obtained by

$$P_n^j = \Gamma(\xi_n^j)^{1/(1-\sigma_n^j)} \left[ \sum_{i=1}^N \lambda_i^j (c_i^j(z^j; \bar{m}_n) \tau_{ni}^j)^{-\theta^j} \right]^{-1/\theta^j} \quad (9)$$

for all sectors and countries.<sup>10</sup>

*Bilateral trade share:* Bilateral trade share  $\pi_{ni}^j$  between country  $n$  and country  $i$  in sector  $j$  is given by  $\pi_{ni}^j = X_{ni}^j / X_n^j$  where  $X_n^j$  is total expenditure on sector  $j$  in country  $n$  and  $X_{ni}^j$  is the expenditure in country  $n$  of sector  $j$  goods from country  $i$ . So,  $X_n^j = \sum_i X_{ni}^j$ . Mathematically,  $\pi_{ni}^j = X_{ni}^j / \sum_i X_{ni}^j = \Pr\{c_i^j \tau_{ni}^j / z_i^j \leq c_h^j \tau_{nh}^j / z_h^j\}$ . Again, using the property of the Frechet distribution, simple algebra provides bilateral trade share,

$$\pi_{ni}^j = \frac{\lambda_i^j (c_i^j(z^j; \bar{m}_i) \tau_{ni}^j)^{-\theta^j}}{\sum_{h=1}^N \lambda_h^j (c_h^j(z^j; \bar{m}_h) \tau_{nh}^j)^{-\theta^j}} \quad (10)$$

where location parameter  $\lambda$ , shape parameter  $\theta$  in the Frechet distribution, unit cost  $c$  in the production of intermediate good, and bilateral trade cost  $\tau$  are involved. Of course, trade costs affect bilateral trade share heavily. However, it is worth noting that the unit cost plays an important role in the determination of bilateral trade share. As shown in equation (8), country-specific labor market frictions affect the unit cost  $c_n^j$  for all countries and sectors. This implies that a country's labor market condition can also affect bilateral trade shares.

<sup>10</sup>  $\Gamma(\xi_n^j)$  is the Gamma function evaluated at  $\xi_n^j = 1 + \frac{1-\sigma_n^j}{\theta^j}$ . For non-tradables,  $P_n^j = A_n^j \lambda_i^{j-1/\theta^j} c_n^j$  since  $\tau_{in}^j = \infty$ .

*Total expenditure:* Employed workers receive wages from firms in every country  $n$ . The employed workers  $E_n$  are a fraction of the total labor force  $L_n$ . Their total wage incomes are  $w_n E_n$ . Assume that the country imposing tariffs on imported goods redistributes tariff revenues to its households. We ignore the trade deficit or surplus since we assume that trade is balanced.<sup>11</sup> The consumer's budget becomes  $I_n = w_n E_n + R_n$  where tariff revenues  $R_n = \sum_j \sum_i \tau_{ni}^j M_{ni}^j$ .

The total expenditure of country  $n$  from sector  $j$  can be derived as

$$X_n^j = \sum_{k=1}^J \gamma_n^{j,k} \sum_{i=1}^N \pi_{in}^k X_i^k / (1 + \tau_{in}^k) + \alpha_n^j I_n \quad (11)$$

where recall that a fraction of composite intermediate goods or final goods are consumed by consumers.

### III. EQUILIBRIUM

On the equilibrium: Total labor force is the sum of the total number of employed workers and unemployed workers,  $L_n = E_n + U_n$ . Unemployed workers are the total number of labor force subtracting the number of workers who are successfully matched with firms,  $U_n = u_n L_n = L_n - \zeta_n m_n(\zeta_n) L_n = L_n - \bar{m}_n \zeta_n^{1-\chi_n} L_n$  with unemployment rate  $u_n$  in country  $n$ . Employed workers are the sum of all employed workers across all sectors including tradable and non-tradable for a generic country

$$E_n = \sum_j E_n^j = \sum_j \int E_n^j(z_n^j) \lambda_n^j e^{-\lambda_n^j z_n^j} dz_n^j.$$

Given total labor force  $L_n$ , exogenous parameters from the Frechet distribution  $\{\lambda_n^j, \theta^j\}$ , and matching efficiency and elasticity of matching function  $\{\bar{m}_n, \chi_n\}$ , an equilibrium in the world economy under tariff structure  $\tau$  is labor market tightness and series of prices  $\{\zeta \in \mathbb{R}^N, \{p_n^j\}_{j \in N}\}$  that solves (5), (8), (9), (10), and (11) for all  $N$  countries and  $J$  sectors.

<sup>11</sup> As Caliendo and Parro (2015) did, we can further consider trade deficit or surplus by employing lump-sum transfer  $D_n = \sum_{k=1}^J D_n^k$ . This creates unnecessary complexity to the main expression of the paper. Even if we consider the fact that trade is unbalanced, the qualitative results would not change.

Changes in equilibrium: Let labor market tightness and series of prices  $\{\zeta \in R^N, \{p_n^j\}_{j=N}\}$  be the initial equilibrium under  $\tau$ . Similarly, let labor market tightness and series of prices  $\{\zeta' \in R^N, \{(p_n^j)'\}_{j=N}\}$  be the new equilibrium under  $\tau'$  where prime indicates values after the change in tariff. Define the system of equations including (12), (13), (14), (15), and (16) be an equilibrium under  $\tau'$  relative to  $\tau$ . Hat indicates the ratio of values of a variable, e.g.,  $\hat{\tau} = \tau'/\tau$  in accordance with Dekle et al. (2008).

Unit cost ( $N \times J$  equations):

$$\hat{c}_n^j = \hat{\zeta}_n^{\chi_n(1-\sum_k \gamma_n^{k,j})} \prod_{k=1}^J (\hat{p}_n^k)^{\gamma_n^{k,j}}. \quad (12)$$

Price index ( $N \times J$  equations):

$$\hat{p}_n^j = \left[ \sum_{i=1}^N \pi_{ni}^j (\hat{c}_n^j \hat{\tau}_{ni}^j)^{-\theta^j} \right]^{-1/\theta^j}. \quad (13)$$

Bilateral trade shares ( $N \times N \times J$  equations):

$$\hat{\pi}_{ni}^j = [\hat{c}_n^j \hat{\tau}_{ni}^j]^{-\theta^j} [\hat{p}_n^j]^{\theta^j}. \quad (14)$$

Total expenditure ( $N \times J$  equations):

$$\hat{X}_n^j X_n^j = \sum_{k=1}^J \gamma_n^{j,k} \sum_{i=1}^N \pi_{in}^k \frac{\hat{X}_i^k X_i^k}{1 + \hat{\tau}_{in}^k \tau_{in}^k} + \alpha_n^j \hat{I}_n I_n. \quad (15)$$

Labor market tightness ( $N$  equations):

$$\hat{\zeta}_n^{1-\chi_n} = \frac{1 - \hat{u}_n u_n}{1 - u_n}. \quad (16)$$

There are  $3(N \times J) + N \times N \times J + N$  number of unknown variables for  $\{\hat{c}, \hat{p}, \hat{\pi}, \hat{X}, \hat{\zeta}\}$  in the system of equations. Since there are the same number  $3(N \times J) + N \times N \times J + N$  of equations, all values are endogenously determined within the quantitative trade model constructed in the present paper. With known values at hand, welfare changes from tariff reductions can be measured by changes in



real income:  $\hat{W}_n = \hat{I}_n / (\prod_{j=1}^J \hat{p}_n^j)^{\alpha^j}$ . The welfare changes can be presented by the following equation:

$$d \ln W_n = \frac{w_n E_n}{I_n} d \ln w_n + \frac{R_n}{I_n} d \ln R_n - d \ln P_n - \frac{w_n U_n}{I_n} d \ln u_n \quad (17)$$

where  $\ln$  denotes logarithm. The first term on the right hand-side in (17) captures changes in wage incomes. The second term shows changes in tariff revenues and the third term represents changes in price level. The first two terms on the right-hand side in (17) contribute positively to changes in welfare, whereas the third term lowers welfare. Applying no unemployment  $u_n = 0$  and labor force equating to employed workers  $L_n = E_n$  in (17) returns Caliendo and Parro (2015). In the presence of labor market frictions, any changes in tariff structure can induce changes in unemployment in the labor market, affecting welfare changes in a country. Equation (17) shows that changes in unemployment rates appearing in the last term on the right hand-side further adjust welfare effects across countries. This implies that welfare effects from tariff reductions are likely to be biased, overstated or understated, in quantitative trade models with perfect labor market because the last term on the right-hand side in (17) is neglected. A similar comment can be found Heid and Larch (2016), who introduce search-and-matching into the Armington model.

Solution algorithm: Consider a change in tariff structure from  $\tau$  to  $\tau'$  captured by  $\hat{\tau}$ . To solve the system of equations from (12) to (16), parameter values including  $\alpha_n^j$ ,  $\gamma_n^j$ , and  $\gamma_n^{k,j}$  are calculated from the WIOD data and the sectoral dispersion of productivity  $\theta^j$  are adopted from the estimation by Caliendo and Parro (2015). I also refer Heid and Larch (2016) for parameter values relating to labor market frictions and assume that there is no change in matching efficiency, that is  $\hat{m}_n$  for all countries.<sup>1213</sup>

<sup>12</sup> See also pages 77-78 in Heid and Larch (2016).

<sup>13</sup> One may want to pursue to calibrate parameter values relating to labor market frictions to match them in the base year. As usual exercises done in labor economics, matched parameter values can be used to analyze the effect of labor market frictions on welfare changes. However, the main purpose of the paper is not to see the welfare effect of labor market frictions, but to examine the welfare effect of tariff changes. I take labor market frictions as given in conducting counterfactual analysis throughout the paper. For the sake of computational simplicity and due to the paucity of

As an initial guess for a vector of labor market tightness, I use  $\hat{\zeta}_n = 1$  for all countries. That is, there is no change in labor market tightness in all countries. Given the vector of labor market tightness,  $(N \times J)$  equations at (12) and  $(N \times J)$  equations at (13) can be solved. With the corresponding unit costs and prices for all countries and sectors,  $(N \times N \times J)$  equations at (14) for bilateral trade shares can be derived. Using unit costs, prices, and bilateral trade shares together with initial values of parameters,  $(N \times J)$  equations at (15) give values corresponding to the initial guess. Of course, at this stage, equation (16) is automatically satisfied. Since I assume that trade is balanced, all resulting values from equations from (12) to (16) can be used to check if the balanced trade condition holds. If not, the initial guess for the vector of labor market tightness is updated to narrow the gap to converge to the condition for balanced trade.

#### IV. COUNTERFACTUAL ANALYSIS BASED ON THE MODEL

This section conducts counterfactual analysis based on the constructed quantitative trade model with labor market frictions. Two counterfactual exercises are selected: revisiting Caliendo and Parro (2015) and examining welfare effects from China's tariff reductions.

##### 1. *A revisit to Caliendo and Parro (2015)*

The purpose of revisiting Caliendo and Parro (2015) is to compare main results for welfare effects from the North American Free Trade Agreement (NAFTA) with mine. To highlight the importance of labor market frictions, I compare the magnitude of changes in welfare effects across countries depending on the labor market assumption.

Caliendo and Parro (2015) extend the Eaton and Kortum (2002) model by adding input-output linkage and trade in intermediate goods. They take the quantitative trade model to quantify welfare effects from the NAFTA and conclude that the U.S.'s

data, changes in parameter values relating to labor market frictions are set to the unity regardless of the initial level of parameter values of those. Although there is no change in matching efficiency and efficiency in matching technology, all possible adjustments due to tariff changes are absorbed by not only wages and prices, but unemployment changes via labor market tightness as shown in equation (16) and (17).

welfare increases by 0.08%, Mexico's welfare increases by 1.31%, and Canada's welfare falls by 0.06%. The methodology that they developed contains state-of-the-art techniques and their main results are appealing. Their model is, however, built on the assumption of full-employment. There is still room for further refinement in the developed model. My model in the paper can fill the gap in the literature. To show the validity of my model, I take three steps. First, I duplicate the main result for welfare effects from the NAFTA as in Caliendo and Parro (2015). Second, I conduct the same analysis done in the first step, using the quantitative trade model constructed above. Lastly, I compare the welfare effects from the NAFTA depending on labor market frictions. Table 1 shows the outcomes derived from each step described above.

Table 1. Welfare Effects from the NAFTA Depending on Labor Market Frictions

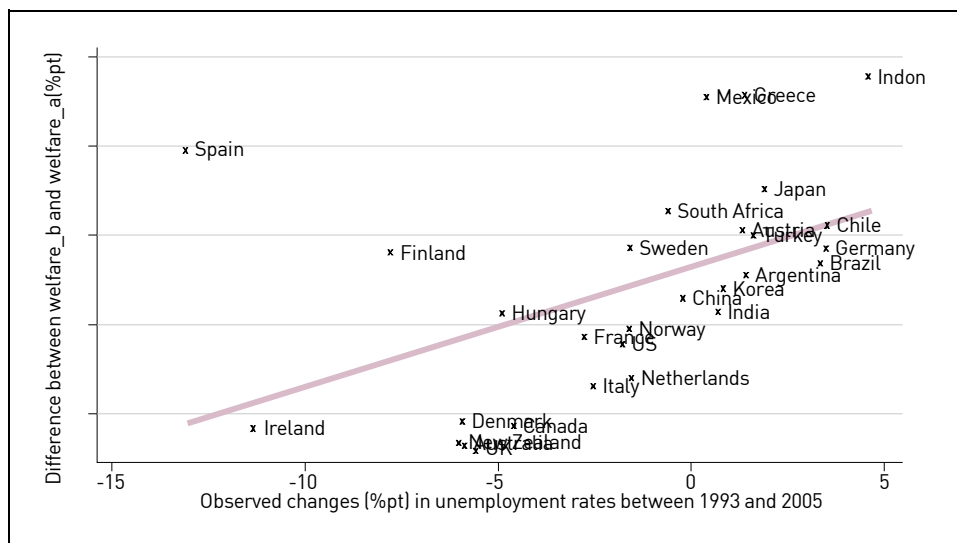
Country	Welfare <sub>a</sub>	Welfare <sub>b</sub>	Diff.	Country	Welfare <sub>a</sub>	Welfare <sub>b</sub>	Diff.
Argentina	0.58%	0.30%	0.28%p	Ireland	0.19%	0.77%	-0.58%p
Australia	0.30%	0.98%	-0.68%p	Italy	0.10%	0.44%	-0.34%p
Austria	2.02%	1.49%	0.53%p	Japan	0.21%	-0.57%	0.77%p
Brazil	0.32%	-0.03%	0.35%p	Korea	0.20%	-0.01%	0.20%p
Canada	0.10%	0.66%	-0.56%p	Mexico	1.36%	0.08%	1.28%p
Chile	0.26%	-0.30%	0.56%p	Netherlands	0.10%	0.41%	-0.31%p
China	13.90%	13.76%	0.14%p	New Zealand	0.71%	1.37%	-0.66%p
Denmark	0.08%	0.63%	-0.55%p	Norway	0.54%	0.56%	-0.02%p
Finland	0.78%	0.37%	0.41%p	Portugal	12.70%	2.69%	10.00%p
France	0.25%	0.32%	-0.07%p	South Africa	1.87%	1.23%	0.64%p
Germany	0.12%	-0.30%	0.42%p	Spain	0.67%	-0.32%	0.99%p
Greece	1.15%	-0.14%	1.29%p	Sweden	0.84%	0.40%	0.44%p
Hungary	1.63%	1.56%	0.07%p	Turkey	0.53%	0.02%	0.51%p
India	3.64%	3.56%	0.08%p	U.S.	0.22%	0.32%	-0.10%p
Indonesia	1.91%	0.52%	1.40%p	U.K.	0.04%	0.76%	-0.71%p
				ROW	2.83%	3.18%	-0.35%p

Remark: Caliendo and Parro (2015) calculates Welfare<sub>a</sub> based on their quantitative model with full-employment and provides the result for welfare effects in Table 7 of the paper. The present paper calculates Welfare<sub>b</sub> based on the constructed model with the system of equations (12)-(17). Diff. indicates the difference between Welfare<sub>a</sub> and Welfare<sub>b</sub>.

Table 1 shows the welfare effects for the 31 countries depending on the consideration of labor market frictions. Caliendo and Parro (2015) calculates  $\text{Welfare}_a$  based on their model with full-employment. Welfare effects by their model indicate welfare changes from NAFTA's tariff reductions given world tariff changes from 1993 and 2005. As can be seen, the largest winner is China with 13.9% welfare increases. Korea is also a winner with a welfare gain of 0.20%. Welfare changes for other countries are provided in columns of  $\text{Welfare}_a$ .  $\text{Welfare}_b$  in Table 1 covers the same number of countries and sectors and conducts the same scenario used in generating  $\text{Welfare}_a$ . Unlike  $\text{Welfare}_a$ ,  $\text{Welfare}_b$  is calculated based on the quantitative trade model with unemployment as in the system of equations from (12) to (17). It turns out that welfare changes for all countries in the sample are biased. Some countries including Argentina, Austria, and others have lower welfare changes relative to those in  $\text{Welfare}_a$  while still other countries including Australia, Canada, and others have higher welfare changes relative to those in  $\text{Welfare}_a$ .

In an attempt to explain the welfare gap between  $\text{Welfare}_a$  and  $\text{Welfare}_b$ , recall that unemployment and changes in unemployment rates (derived within the model) play key roles in adjusting welfare effects from tariff reductions as aforementioned in equation (17). From the World Bank database, I collect data for the observed unemployment rate for 1993 and 2005. In Figure 1, the horizontal axis shows the observed unemployment rate gap between 2005 and 1993. The vertical axis represents the difference between welfare changes derived from Caliendo and Parro (2015) and those calculated from my model. As seen in Figure 1, the welfare gap is positively correlated with the observed unemployment gap. Under the structure of the model with input-output linkage, trade in intermediate goods, and sectoral heterogeneity, unemployment seems to play a role in adjusting welfare effects in the quantitative trade model. A caveat is that changes in unemployment due to tariff changes are not the only factor to explain welfare changes across countries as can be seen in equation (17) and the difference in welfare changes between the two models can be understood from the perspective of the present model. In addition, it is difficult to keep track of how unemployment and changes in unemployment rates affect welfares across countries due to the dimensionality of the system with many countries and sectors.

Figure 1. Correlation Between Unemployment Changes and Welfare Differences



Remark: The change in unemployment rates is calculated from the observed 2005 unemployment rate minus the 1993 unemployment rate for every country. The difference between  $Welfare_a$  and  $Welfare_b$  comes from Table 1.

## 2. The welfare effect of China's tariff reductions

Recently, many scholars have paid much attention to the economic effects of China to the rest of the world.<sup>14</sup> In turn, China also benefits from world tariff reductions. The author of the paper further wonders about the welfare effect from world tariff reductions to China and other countries after 2005.<sup>15</sup> This paper asks what would happen if China's tariff schedules remain unchanged after 2005. To answer the question based on the constructed model in the paper, I set 2006 as the base year. I introduce the change in the world tariff structure from that in 2006 to the actual tariff structure in a generic year  $t$  from 2006 to 2015 into the model. Given China's tariff structure and its trading partners remain the 'same' as in 2006, I solve for the

<sup>14</sup> See, for example, Autor et al. (2013, 2016) and Hsieh and Ossa (2016) among many others. I borrow the term "China shock" from the title of the paper by Autor et al. (2016), reflecting China's appearance as a great economic power.

<sup>15</sup> A majority of FTAs that China have effectuated are after 2005.

equilibrium in relative changes from the world tariff structure in 2006 to the tariff structure in a generic year  $t$  from 2006 to 2015. To be concrete, let tariff changes be  $\hat{\tau}_{ni,t}^j = 1$  for  $n$  or  $i$  is China and all tradable sectors  $j$  and all year  $t$  from 2006 and 2015. Of course,  $\hat{\tau}_{ni,t}^j = \tau_{ni,t}^j / \tau_{ni,2006}^j$  for otherwise.

To conduct counterfactual analysis, I use two data sources: the World Integrated Trade Solution (WITS) and World Input-Output Database (WIOD). I use the weighted average of tariffs for all years from 2006 to 2015. Trade and input-output data are from the WIOD, as released in 2016, which covers 44 regions: 43 countries and the Rest of the World (ROW). I aggregate all 28 European countries as EU, thus we have 16 countries and the 17th region is an aggregate of the ROW (see Appendix A). The WIOD covers 56 sectors; I re-group them into 40 sectors (see Appendix B).

The WIOD data contains information for changes in inventories. Inventories are not positive always, but sometimes show negative signs. To deal with this issue, I follow the treatment by Costinot and Rodriguez-Clare (2014). If inventory is treated as a part of the final demand, this leads some entries in the final demand to be negative. This situation can be avoided by treating changes in inventories in two ways. If entry of inventory shows positive, then it is added to a part of the final demand. If not (showing negative), I interpret negative inventory as output produced in the previous period, stored and consumed in the current period. Since my model is static, I put the absolute value of the negative inventory as a part of the final demand in the current period. After this treatment, I build trade flows, final demand, value-added share, expenditures, etc, at the country-sector level.

Table 2 shows two results of counterfactual analysis. The upper table gives results of welfare changes when we allow changes in tariffs of all countries including China, which can be considered the benchmark. The lower table renders results of welfare effects for all 17 countries (with the ROW) when China's tariffs and its trading partners' tariffs against China do not change since 2006, but all other countries' tariffs change from 2006 to 2015. It turns out that, first, Korea is the country that benefits most from world tariff reductions regardless of changes in China's tariffs. Second, China would be hurt if its tariffs remain the same as in 2006. Lastly, China's unchanged tariffs tend to lower welfares for all other countries. However, its unchanged tariffs exert 'mild' welfare effects in terms of magnitudes.

Table 2. Welfare Effects from China's Tariff Changes from 2006 to 2015

<b>Welfare effects from world tariff reductions (relative to 2006)</b>										
Country	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Australia	0%	-.01%	.03%	.06%	.13%	.17%	.25%	.26%	.30%	.06%
Brazil	0%	-.01%	.02%	.02%	.06%	.11%	.04%	.07%	.01%	.13%
Canada	0%	.01%	.09%	.05%	.08%	.07%	.11%	.15%	.13%	-.02%
China	0%	.07%	.10%	.20%	.22%	.17%	.20%	.18%	.05%	.25%
European Union	0%	.03%	.03%	.02%	.03%	.03%	.05%	.05%	.06%	.11%
India	0%	.06%	2.23%	.80%	1.17%	1.12%	.68%	.52%	.89%	1.49%
Indonesia	0%	.08%	.16%	.17%	.18%	.21%	.19%	.21%	.28%	.45%
Japan	0%	-.01%	-.01%	.10%	.18%	.15%	.29%	.33%	.38%	.22%
Korea	0%	.36%	.20%	1.01%	2.46%	3.89%	2.88%	8.35%	9.95%	11.57%
Mexico	0%	.28%	.34%	.36%	.66%	.70%	.69%	.69%	.34%	.35%
Russia	0%	-.02%	.04%	.02%	.07%	.04%	.04%	.04%	-.00%	-.02%
Turkey	0%	.17%	.40%	.13%	.39%	.90%	.89%	.95%	.73%	.39%
Taiwan	0%	.04%	.01%	.01%	-.03%	.04%	.03%	.07%	.06%	.12%
United States	0%	-.00%	.03%	.05%	.02%	.01%	.04%	.06%	.09%	.02%
ROW	0%	.25%	.35%	.40%	.33%	.37%	.39%	.39%	.36%	.40%
Average	0%	.09%	.27%	.23%	.40%	.53%	.45%	.82%	.91%	1.04%
<b>Eliminating China's tariff changes given world tariffs change (relative to 2006)</b>										
Country	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Australia	0%	-.02%	.01%	.05%	.09%	.13%	.22%	.23%	.22%	.00%
Brazil	0%	-.01%	.02%	.02%	.07%	.12%	.06%	.07%	.03%	.17%
Canada	0%	.01%	.08%	.03%	.08%	.06%	.10%	.13%	.12%	-.02%
China	0%	-.02%	-.02%	-.02%	-.02%	-.04%	-.04%	-.02%	-.04%	.17%
European Union	0%	.03%	.03%	.57%	.03%	.03%	.05%	.05%	.06%	.10%
India	0%	.04%	2.18%	.16%	.94%	.97%	.53%	.35%	.79%	1.38%
Indonesia	0%	.08%	.15%	.10%	.16%	.14%	.12%	.14%	.20%	.32%
Japan	0%	.05%	.04%	.90%	.26%	.24%	.39%	.43%	.43%	.26%
Korea	0%	.47%	.13%	.33%	2.14%	4.17%	2.21%	8.55%	10.02%	11.60%
Mexico	0%	.27%	.32%	.00%	.63%	.65%	.64%	.64%	.30%	.30%
Russia	0%	-.01%	.03%	.06%	.04%	.02%	.01%	.02%	-.02%	-.03%
Turkey	0%	.06%	.26%	.00%	.21%	.45%	.44%	.47%	.31%	.41%
Taiwan	0%	.04%	.01%	.03%	-.03%	.03%	.03%	.07%	.05%	.11%
United States	0%	-.00%	.02%	.34%	-.01%	-.01%	.01%	.03%	.07%	.01%
ROW	0%	.25%	.31%	.17%	.26%	.27%	.29%	.30%	.26%	.30%
Average	0%	.08%	.24%	.40%	.32%	.48%	.34%	.76%	.85%	1.01%

Remark: All calculations are based on the system of equations from (12) to (17).

## V. CONCLUSION

This paper emphasizes the role of labor market frictions, which is largely neglected in quantitative trade models that usually assume full-employment. Labor market frictions can contribute to a source of comparative advantage, thus affecting trade share, price, expenditure, etc. Unemployment and changes in unemployment rates play a key role in the calculation of changes in welfare. This paper highlights that quantitative trade models with full-employment can provide biased welfare effects from tariff changes relative to the present model with labor market frictions.

There are several ways to use my model. First, the model can be used to evaluate if a change in one country's labor market conditions affect its trading partners through international trade in intermediate goods. Related empirical results are mixed so far and quantitative trade models with full-employment are not suitable to study how a change in one country's labor market conditions affect its trading partners (or vice versa). Second, the model offers a basic framework to quantify how enhancement in a country's matching efficiency affect its own country and trading partners. As the internet and information and communication technology progress, the job matching process has been enhanced due to a fall in search costs.

There are several ways to extend my model. First, some might want to introduce different kinds of labor market frictions rather than search-and-matching. For example, one could think of efficiency wage, minimum wage, fair wage, etc. Second, the model can be extended by adding heterogeneous workers, high-skilled and low-skilled. This setup can lead to the topic of (for example) wage inequality and income distribution. I leave these avenues for future research.



## Appendix A. List of Country

No	Country in the paper	WIOD 2014 (released 2016)
1	AUS	AUS
2	BRA	BRA
3	CAN	CAN
4	CHE	CHE
5	CHN	CHN
6	IDN	IDN
7	IND	IND
8	JPN	JPN
9	KOR	KOR
10	MEX	MEX
11	NOR	NOR
12	RUS	RUS
13	TUR	TUR
14	TWN	TWN
15	USA	USA
16	EU	AUT, BEL, BGR, CYP, CZE, DEU, DNK, ESP, EST, FIN, FRA,GBR, GRC, HRV, HUN, IRL, ITA, LTU, LUX, LVA, MLT, NLD, POL, PRT, ROM, SVK, SVN, SWE
17	ROW	ROW

## Appendix B. List of sectors

No	Tradable Industry	Description
1	Agriculture	Agriculture plus mining
2	Food	Food products, beverage and tobacco
3	Textile	Textiles, textile products, leather and footwear
4	Wood	Wood and products of wood and cork
5	Petroleum	Coke refined petroleum and nuclear fuel
6	Chemicals	Chemicals
7	Plastic	Rubber and plastics products
8	Minerals	Other nonmetallic mineral products
9	Basic Metal	Basic metals
10	Machinery	Machinery and equipment
11	Electrical	Electrical machinery and apparatus
12	Communication	Radio, television and optical instruments
13	Medical	Medical, precision and optical instruments
14	Auto	Motor vehicles trailers and semi-trailers
15	Other	Manufacturing nec. and recycling

Non-tradable includes service sectors that cover (in short) ‘Electricity(D35)’, ‘Water collection(E36)’, ‘Sewerage(E37-E39)’, ‘Construction(F)’, ‘Wholesale and retail trade(G45-G47)’, ‘Land transport(H49)’, ‘Water transport(H50)’, ‘Air transport(H51)’, ‘Warehousing(H52)’, ‘Postal activities(H53)’, ‘Accommodation(I)’, ‘Publishing and broadcasting(J58-J60)’, ‘Telecommunications(J61)’, ‘Computer programming(J62-J63)’, ‘Financial service(K64)’, ‘Insurance(K65-K66)’, ‘Real estate activities(L68)’, ‘Legal and accounting (M69-M70)’, ‘Architectural and engineering(M71)’, ‘Scientific research and development(M72)’, ‘Advertising and market research(M73-M75)’, ‘Support service(N)’, ‘Public administration(O84)’, ‘Education(P85)’, ‘Human health(Q)’, ‘Other service activities(R-S)’ and T, U are partly included

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