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## The Dynamic and Distributional Aspects of Import Tariffs

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**THE DYNAMIC AND DISTRIBUTIONAL ASPECTS OF IMPORT TARIFFS\***BY WOLFGANG LECHTHALER<sup>1</sup>  AND MARIYA MILEVA *Kiel Institute for the World Economy, Germany ; California State University, U.S.A.  
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We use a dynamic trade model with two sectors and two types of workers to analyze the optimal setting of income-generating tariffs. We study dynamic and distributional aspects focusing on the time horizon of policy-makers and workers. The level of tariffs preferred by workers depends on the sector where they are employed as well as their skill class, with the relative weight of both aspects determined by the time horizon of the workers. Unskilled workers in the unskilled-intensive sector are the ones most in favor of protectionism and might even benefit from a trade war.

## 1. INTRODUCTION

Motivated by the surge in protectionist tendencies on campaign trails all over developed countries, we take a fresh look at the optimal setting of income-generating tariffs. To do so, we use a dynamic model with two countries, two factors of production, two sectors, endogenous firm entry, and firm heterogeneity. This allows us to draw a rich picture of the dynamic distributional aspects of import tariffs.<sup>2</sup> We find that the level of tariffs preferred by a specific worker depends on the sector where the worker is employed as well as her skill class, with the relative weight of both aspects determined by the time perspective of the worker. For a worker who is more concerned about the immediate future, the sector of employment is more important, for a worker who is more concerned about long-run outcomes, the skill-class is more relevant. The workers most in favor of tariffs are the unskilled workers in the unskilled-intensive sector.

The analysis of the setting of optimal tariffs has a long tradition in the trade literature. One shortcoming of this literature is that it is typically based on static models. This is a shortcoming for at least two reasons. On the one hand, adjustment dynamics are ignored. On the other hand, tariffs are typically set by elected politicians who tend to care more about the next couple of years than the infinite future (the new steady state). So, focusing on purely static models might yield implausible policy conclusions.

Two recent papers (Larch and Lechthaler 2013; Lechthaler 2017) try to close this gap by analyzing the setting of tariffs in a dynamic version of the Melitz (2003) model. Both papers consistently find that a shorter time horizon implies lower optimal tariffs because the short-run effects of higher tariffs are worse than the long-run effects.<sup>3</sup> However, in both papers, distributional aspects are missing because they rely on the representative agent framework

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<sup>2</sup> Previous papers (Costinot et al., 2016; Demidova and Rodriguez-Clare 2009; Felbermayr et al., 2013; Lechthaler 2017) have shown that including firm heterogeneity is important for understanding the effects of import tariffs. None of these papers, however, has looked at the dynamic distributional aspects of tariffs that are the focus of this study.

<sup>3</sup> For a more general discussion of the short-run and long-run effects of structural reforms and related political economy issues, see Rodrik (1996).

of the Melitz model. Thus there is only one sector and only one factor of production and each worker is affected equally by changing tariffs. This is at odds with recent evidence showing that workers employed in import-competing sectors were especially adversely affected by trade liberalization with China (see, e.g., Autor et al., 2013; Dauth et al., 2014; Ebenstein et al., 2009; Pierce and Schott 2016).

To be able to capture this differential exposure of workers to international trade as well as the sluggish adjustment of an economy after a trade shock and the potential short-sightedness of policymakers, we use the dynamic version of the model of Bernard et al. (2007) developed in Lechthaler and Mileva (2019), augmented by income-generating tariffs. The model features two factors of production, skilled and unskilled workers, two sectors that use both factors with different intensities, and two countries with different endowments of skilled versus unskilled workers. The model is calibrated to broadly match important features of the two economies of the United States and China.

Following Ossa (2014), we first analyze unilaterally optimal tariffs, that is, the optimal U.S. tariff under the assumption that the Chinese tariff does not change.<sup>4</sup> In response to an increase in the U.S. tariff, aggregate U.S.-consumption increases permanently, but due to enhanced firm investment, the increase is very sluggish. Thus, as in Larch and Lechthaler (2013) and Lechthaler (2017), a policymaker who is interested in maximizing aggregate consumption sets a lower tariff the shorter his time horizon.

However, workers are very differently affected by the tariff increase. In the short run, workers in the skill-intensive sector lose because an increase in tariffs partially unwinds the economy's specialization in its comparative advantage sector while workers in the unskilled-intensive sector gain (the United States has a comparative advantage in skill-intensive production because it has relatively more skilled workers than China). In the long run, skilled workers lose while unskilled workers gain, because the unwinding of specialization reduces the relative demand for skilled workers.

These effects, of course, perfectly resemble the well-known Stolper–Samuelson and Ricardo–Viner theorems. However, we combine both aspects in a unified framework and bring them together with preferences for trade protection and a worker's time perspective. Thus it is neither solely the skill class of a worker nor the sector where she is employed that determines her preference for tariffs, but rather a combination of both, with the time perspective of the worker determining their respective weights.

Thus a skilled worker in the unskilled-intensive sector might prefer free trade if she has a long-term perspective but favor tariffs if she has a sufficiently short-term perspective. In contrast, an unskilled worker in the skill-intensive sector favors lower tariffs when she has a short-term perspective but a higher tariff when she has a long-term perspective. As expected, unskilled workers in the unskilled-intensive sector are the ones most in favor of tariffs and even more so if they have a short-term perspective.

It is often argued that the fear of retaliation prevents policymakers from raising tariffs because in a trade war in which both countries raise their tariff both countries would suffer lower welfare. Although from an aggregate perspective this is still true in our model, our analysis adds a nuance to this outcome. In the Nash-equilibrium of a noncooperative game, aggregate consumption and the consumption of most worker groups are lower than in the status quo but this is not true for the unskilled workers in the unskilled-intensive sector. Although their consumption in the new steady state with higher tariffs is basically the same as in the old steady state, during the transition period they enjoy substantial, albeit temporary gains in consumption. Thus even though the economy as whole would suffer from a trade war, some workers still gain and are thus willing to support an increase in tariffs even in the face of potential retaliation.

<sup>4</sup> For most of our analysis, we assume that the tariff is the same for both sectors but in Section 6 we allow for different tariffs across sectors.

Our article connects to three different strands of the literature. First, the large literature on the setting of Nash-equilibrium and optimal tariffs, see, for example, Johnson (1953), Gros (1987), Krugman (1991), Bond and Syropoulos (1996), Bagwell and Staiger (1999), Yi (2000), Ornelas (2005), Demidova and Rodriguez-Clare (2009), Felbermayr et al. (2013), Ossa (2014), or Nicita et al. (2018). Second, the literature that analyzes the effects of trade with China, for example, Autor et al. (2013), Dauth et al. (2014), Ebenstein et al. (2009), Pierce and Schott (2016), Amiti et al. (2019), or Fajgelbaum et al. (2019). And finally, the relatively young but growing literature on the dynamic adjustment to trade shocks, see, for example, Alessandria and Choi (2014), Melitz and Burstein (2011), Cacciatore (2014), Cacciatore and Ghironi (2020), Coşar (2013), Dix-Carneiro (2014) or Kambourov (2009). None of these papers, however, has considered the joint analysis of tariffs in a dynamic setting with inter-industry trade.

The rest of the article is structured as follows. Section 2 describes the model. Section 3 discusses the dynamic adjustment of aggregate variables in response to an increase in tariffs, and the role of the policymaker's planning horizon for the optimal unilateral tariff. Section 4 analyzes the dynamic adjustment of worker-specific variables and worker-specific preferences for tariffs. Section 5 discusses Nash-equilibrium tariffs ("trade wars"), Section 6 discusses sector-specific tariffs, and Section 7 concludes.

## 2. THEORETICAL MODEL

Our model economy consists of two countries, Home (H) and Foreign (F). Each country produces two goods, good  $S$  and good  $U$ . The production of each good requires two inputs, skilled and unskilled labor. The sector that produces good  $S$  is skill-intensive, that is, the production of good  $S$  requires relatively more skilled labor than the production of good  $U$ . Country H has a comparative advantage in producing good  $S$  because it has a higher relative endowment of skilled labor. Similarly, F has a comparative advantage in sector  $U$  because it has a higher relative endowment of unskilled labor. We assume that unskilled labor is more abundant than skilled labor in both countries in order to generate a positive skill premium.<sup>5</sup> We also assume that incumbent firms and workers are immobile across sectors, that is, they have to stick to the sector where they have entered. Reallocation across sectors is modeled via retiring firms and workers that are replaced by new entrants. These new entrants can choose their sector upon entry.<sup>6</sup> In the following, we describe all the decision problems in H; equivalent equations hold for F.

*2.1. Households.* In our model, workers are organized within households, where households are defined by the skill class and the sector of employment of its members, that is, each member of a household belongs to the same skill class and works in the same sector. Due to the structure of our model, this implies that in each country there are four types of households, one consisting of skilled workers employed in sector  $S$ , one consisting of skilled workers employed in sector  $U$ , and likewise, one consisting of unskilled workers employed in sector  $S$  and another one consisting of unskilled workers employed in sector  $U$ .

Workers are retiring at an exogenous rate  $s$  and get replaced by newly entering workers. These newly entering workers inherit their skill class but are free to choose their sector of employment based on labor demand (Section 2.2), and stay in that sector for the rest of their working life. By choosing a sector of employment, they automatically get assigned to the corresponding household. The entry decision of newly entering workers thus endogenously determines the size of each household. We assume that consumption and saving decisions are done by the household not by individual workers, but letting workers decide would yield

<sup>5</sup> What matters for comparative advantage are relative endowments, so skilled labor can be scarce in both countries.

<sup>6</sup> In the Appendix, we consider the case of perfect labor mobility across sectors as well as the case of endogenous skill formation.

equivalent Euler equations. Deviating from the assumption of a single representative household common in the macroeconomic literature allows for a more meaningful analysis of inequality. In the following, we describe the problem of the households of skilled workers, but equivalent equations hold for unskilled workers (refer to Table 1 for a list of the equations pertaining to unskilled workers).

The household of skilled workers employed in sector  $i = S, U$  maximizes the present discounted value of utility derived from consumption:

$$(1) \quad E_t \left\{ \sum_{k=0}^{\infty} \gamma^k \log(C_{it+k}^s) S_{it+k} \right\},$$

where  $C_{it+k}^s$  is the consumption per worker of the aggregate consumption bundle,  $\gamma$  is the subjective discount factor, and  $S_{it+k}$  is the number of workers in the household.

The household faces the following intertemporal budget constraint:<sup>7</sup>

$$(2) \quad \begin{aligned} B_{it+1}^s + \frac{\eta}{2} (B_{it+1}^s)^2 + Q_t B_{*,it+1}^s + Q_t \frac{\eta}{2} (B_{*,it+1}^s)^2 + C_{it}^s S_{it} \\ = (1 + r_t) B_{it}^s + Q_t (1 + r_t^*) B_{*,it}^s + w_{it}^s S_{it} + \Pi_t S_{it} + T_{it}^s + T_t^t S_{it}, \end{aligned}$$

where  $B_{it}^s$  are household holdings of domestic bonds,  $B_{*,it}^s$  are household holdings of foreign bonds,  $\eta$  is the cost of adjusting bond holdings,  $Q_t$  is the real exchange rate,  $r_t$  is the real interest rate,  $w_{it}^s$  is the real wage,  $\Pi_t$  are the transfers of a mutual fund to be described further below, and  $T_t^t$  is the tariff income per worker that the government transfers to domestic workers in a lump-sum fashion. The cost of adjusting bond holdings is used to pin down steady state bonds to zero and to get a well-defined steady state.<sup>8</sup> As is standard, the costs of adjusting bond holdings are assumed to be reimbursed to the households ( $T_{it}^s$ ) and  $\eta$  is set to a small enough level so that adjustment dynamics are not affected.<sup>9</sup>

To keep the model tractable, we need to either restrict worker heterogeneity, worker mobility, or worker savings. We assume that workers are heterogeneous and save but restrict their mobility, that is, once they choose a sector of employment upon entry, they have to stay there and cannot switch sectors (households) anymore. This allows for simple aggregation because if workers were allowed to switch households after entry, then the bond level of a worker would depend on her employment history. If she changes her sector of employment, then her incentives to save change. Thus, her desired savings would differ from the savings of workers employed in her old sector. But her current bond holdings are determined by her old sector and, thus, are different from the bond holdings of workers in her new sector. In the transition, savings histories of workers who switch would depend on the time of the switch. This would imply the necessity to keep track of the whole employment history of workers.

To avoid this problem, the macro-literature often assumes that workers pool their income within large households (see, e.g., Andolfatto 1996). Then the consumption of a worker no longer depends on her wage earnings and the whole economy can be characterized by one representative household. However, since the focus of our analysis is precisely on optimal tariffs and their welfare implications for various types of workers, we do not want to aggregate

<sup>7</sup> We make the assumption that the household chooses total saving but this is isomorphic to a model where the household picks the saving for each worker. This would involve a reformulation of the household budget constraint where bond holdings refer to those of individual workers:  $B_{it+1}^s S_{it} + S_{it} \frac{\eta}{2} (B_{it+1}^s)^2 + Q_t B_{*,it+1}^s S_{it} + S_{it} Q_t \frac{\eta}{2} (B_{*,it+1}^s)^2 + C_{it}^s S_{it} = (1 + r_t) B_{it}^s S_{it} + Q_t (1 + r_t^*) B_{*,it}^s S_{it} + w_{it}^s S_{it} + \Pi_t S_{it} + T_{it}^s S_{it} + T_t^t S_{it}$ . The optimal Euler equations determining saving would remain unchanged.

<sup>8</sup> See, for example, Ghironi and Melitz (2005) for more details.

<sup>9</sup> This implies that  $T_{it}^s = \frac{\eta}{2} (B_{it+1}^s)^2 + Q_t \frac{\eta}{2} (B_{*,it+1}^s)^2$ .

TABLE 1  
MODEL SUMMARY

|                              | Sector-Specific Equations  |
|------------------------------|--|
| Price index                  | $\psi_{it}^{1-\theta} = N_{d,it}(\tilde{\rho}_{d,it})^{1-\theta} + N_{x,it}^*(\tilde{\rho}_{x,it}^*)^{1-\theta}$   |
| Domestic price               | $\tilde{\rho}_{d,it} = \frac{\theta}{\theta-1} \frac{(w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}}{\bar{z}_{d,it}}$   |
| Export price                 | $\tilde{\rho}_{x,it} = \frac{\tau_{it}^*}{Q_t} \frac{\theta}{\theta-1} \frac{(w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}}{\bar{z}_{x,it}}$   |
| Average profit               | $\bar{d}_{it} = \bar{d}_{d,it} + \frac{N_{x,it}}{N_{d,it}} \bar{d}_{x,it}$   |
| Average domestic profit      | $\bar{d}_{d,it} = \frac{1}{\theta} \left( \frac{\tilde{\rho}_{d,it}}{\psi_{it}} \right)^{1-\theta} \alpha_i C_t$   |
| Average export profit        | $\bar{d}_{x,it} = \frac{Q_t}{\theta \tau_{it}^*} \left( \frac{\tilde{\rho}_{x,it}}{\psi_{it}^*} \right)^{1-\theta} \alpha_i C_t^* - f_x(w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}$  |
| Free entry                   | $\bar{v}_{it} = f_e(w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}$  |
| Export cutoff                | $\bar{d}_{x,it} = \left( \frac{\theta-1}{k-(\theta-1)} \right) f_x(w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}$   |
| Share of exporting firms     | $\frac{N_{x,it}}{N_{d,it}} = \left( \frac{\bar{z}_{d,it}}{\bar{z}_{x,it}} \right)^k$   |
| Number of firms              | $N_{d,it} = (1-\delta)(N_{d,it-1} + N_{e,t-1})$  |
| Average firm value           | $\bar{v}_{it} = \gamma(1-\delta)E_t \left[ \left( \frac{C_{t+1}}{C_t} \right)^{-1} (\bar{v}_{it+1} + \bar{d}_{it+1}) \right]$  |
| Sector accounting            | $N_{d,it} \left( \frac{\tilde{\rho}_{d,it}}{\psi_{it}} \right)^{1-\theta} \alpha_i C_t + \frac{Q_t}{\tau_{it}^*} N_{x,it} \left( \frac{\tilde{\rho}_{x,it}}{\psi_{it}^*} \right)^{1-\theta} \alpha_i C_t^* + \bar{v}_{it} N_{e,it} = w_{it}^s S_{it} + w_{it}^l L_{it} + \bar{d}_{it} N_{d,it}$  |
| Relative demand for labor    | $\frac{w_{it}^s}{w_{it}^l} = \frac{\beta_i}{1-\beta_i} \frac{L_{it}}{S_{it}}$  |
| Household budget constraints | $B_{it+1}^s + \frac{\eta}{2} (B_{it+1}^s)^2 + Q_t B_{*,it+1}^s + Q_t \frac{\eta}{2} (B_{*,it+1}^s)^2 + C_{it}^s S_{it} = (1+r_t)B_{it}^s + Q_t(1+r_t^*)B_{*,it}^s + w_{it}^s S_{it} + \Pi_t S_{it} + T_{it}^s + T_{it}^l S_{it}$<br>$B_{it+1}^l + \frac{\eta}{2} (B_{it+1}^l)^2 + Q_t B_{*,it+1}^l + Q_t \frac{\eta}{2} (B_{*,it+1}^l)^2 + C_{it}^l L_{it} = (1+r_t)B_{it}^l + Q_t(1+r_t^*)B_{*,it}^l + w_{it}^l L_{it} + \Pi_t L_{it} + T_{it}^l + T_{it}^s L_{it}$ |
| Bond cost reimbursement      | $T_{it}^s = \frac{\eta}{2} (B_{it+1}^s)^2 + Q_t \frac{\eta}{2} (B_{*,it+1}^s)^2$<br>$T_{it}^l = \frac{\eta}{2} (B_{it+1}^l)^2 + Q_t \frac{\eta}{2} (B_{*,it+1}^l)^2$   |
| Euler equations              | $(C_{it}^s)^{-1} (1 + \eta B_{it+1}^s) = \gamma E_t [(C_{it+1}^s)^{-1} (1 + r_{t+1})]$<br>$(C_{it}^s)^{-1} (1 + \eta B_{*,it+1}^s) = \gamma E_t [(C_{it+1}^s)^{-1} (1 + r_{t+1}^* \frac{Q_{t+1}}{Q_t})]$<br>$(C_{it}^l)^{-1} (1 + \eta B_{it+1}^l) = \gamma E_t [(C_{it+1}^l)^{-1} (1 + r_{t+1})]$<br>$(C_{it}^l)^{-1} (1 + \eta B_{*,it+1}^l) = \gamma E_t [(C_{it+1}^l)^{-1} (1 + r_{t+1}^* \frac{Q_{t+1}}{Q_t})]$   |
| Worker value functions       | $V_{it}^s = E_t [\log(C_{it}^s) + \gamma(1-s)V_{it+1}^s]$<br>$V_{it}^l = E_t [\log(C_{it}^l) + \gamma(1-s)V_{it+1}^l]$   |
| Worker flows                 | $S_{it} = (1-s)S_{it-1} + S_{e,it}$<br>$L_{it} = (1-s)L_{it-1} + L_{e,it}$   |
| Worker entry                 | <b>Nonsector-Specific Equations</b><br>$\bar{\varepsilon}_t^S = V_{Ut}^S - V_{St}^S$<br>$\frac{S_{e,St}}{sS} = 1 - J(\bar{\varepsilon}_t^S)$<br>$\bar{\varepsilon}_t^L = V_{Ut}^L - V_{St}^L$<br>$\frac{L_{e,St}}{sL} = 1 - J(\bar{\varepsilon}_t^L)$<br>$sS = S_{e,St} + S_{e,Ut}$<br>$sL = L_{e,St} + L_{e,Ut}$  |
| Aggregate price index        | $\left( \frac{\psi_{St}}{\alpha_S} \right)^{\alpha_S} \left( \frac{\psi_{Ut}}{\alpha_U} \right)^{\alpha_U} = 1$  |

(Continued)

TABLE 1  
CONTINUED

| Sector-Specific Equations |  |
|---------------------------|--|
| Bond aggregation          | $B_t \equiv (B_{St}^s + B_{Ut}^s + B_{St}^l + B_{Ut}^l)$ $B_{*,t} \equiv (B_{*,St}^s + B_{*,Ut}^s + B_{*,St}^l + B_{*,Ut}^l)$  |
| Tariff revenue            | $T_t^t(S + L) = \frac{t_{St}^{-1}}{t_{St}} N_{x,St}^* \left( \frac{\hat{p}_{x,St}^*}{\hat{\psi}_{St}} \right)^{1-\theta} \alpha_S C_t + \frac{t_{Ut}^{-1}}{t_{Ut}} N_{x,Ut}^* \left( \frac{\hat{p}_{x,Ut}^*}{\hat{\psi}_{Ut}} \right)^{1-\theta} \alpha_U C_t$ |
| Firm transfers            | $\Pi_t(S + L) = \tilde{d}_{St} N_{d,St} + \tilde{d}_{Ut} N_{d,Ut} - \tilde{v}_{St} N_{e,St} - \tilde{v}_{Ut} N_{e,Ut}$   |
| Trade balance             | $tb = \sum_{i=S,U} [Q_t \frac{1}{t_{it}^*} N_{x,it}^* \left( \frac{\hat{p}_{x,it}^*}{\hat{\psi}_{it}^*} \right)^{1-\theta} \alpha_i C_t^* - \frac{1}{t_{it}^*} N_{x,it}^* \left( \frac{\hat{p}_{x,it}^*}{\hat{\psi}_{it}^*} \right)^{1-\theta} \alpha_i C_t]$  |
| Net foreign assets        | $B_t + Q_t B_{*,t} = (1 + r_{t-1}) B_{t-1} + (1 + r_{t-1}^*) B_{*,t-1} Q_t + tb_t$   |
| Bond clearing             | $B_t + B_t^* = 0$ $B_{*,t} + B_{*,t}^* = 0$  |

NOTES: The equations above hold for sector  $i = S, U$  for country H. An equivalent set of equations holds for country F, excluding the trade balance, net foreign assets, and the bond clearing conditions. Variables with an asterisk pertain to country F. Note that due to the absence of fixed costs of production  $\bar{z}_d = (k/k - (\theta - 1))^{\frac{1}{\theta-1}} z_{\min}$  is given exogenously.

workers into one single household. Instead, disallowing workers to switch sectors allows us to model worker heterogeneity and worker saving at the same time.<sup>10</sup>

The household chooses  $C_{it}^s, B_{it+1}^s$ , and  $B_{*,it+1}^s$ . The first-order conditions yield:

$$(3) \quad \begin{aligned} (C_{it}^s)^{-1} (1 + \eta B_{it+1}^s) &= \gamma E_t \left[ (C_{it+1}^s)^{-1} (1 + r_{t+1}) \right], \\ (C_{it}^s)^{-1} (1 + \eta B_{*,it+1}^s) &= \gamma E_t \left[ (C_{it+1}^s)^{-1} \left( 1 + r_{t+1}^* \frac{Q_{t+1}}{Q_t} \right) \right], \end{aligned}$$

which are standard consumption Euler equations (for domestic and foreign bonds, respectively).

The composition of the aggregate consumption bundle is the same for all households; only the quantity of consumed goods differs across households. Therefore, in the following description, we omit the indices for the household to avoid cumbersome notation. The aggregate consumption bundle  $C_t$  is a Cobb–Douglas composite of the goods produced in the two sectors:

$$(4) \quad C_t = C_{St}^{\alpha_S} C_{Ut}^{\alpha_U},$$

where  $\alpha_S$  is the share of good  $S$  in the consumption bundle for both H and F and  $\alpha_U = 1 - \alpha_S$ . We can obtain relative demand functions for each good from the expenditure minimization problem of the household. The implied demand functions are

$$(5) \quad C_{St} = \alpha_S \frac{P_t}{P_{St}} C_t \quad \text{and} \quad C_{Ut} = \alpha_U \frac{P_t}{P_{Ut}} C_t,$$

where  $P_t = (P_{St}/\alpha_S)^{\alpha_S} (P_{Ut}/\alpha_U)^{\alpha_U}$  is the price index that buys one unit of the aggregate consumption bundle  $C_t$ .

<sup>10</sup> A third option would be to allow for heterogeneity and mobility, but disallow workers to save, see Lechthaler and Mileva (2019) or the Appendix of this article.

Goods  $S$  and  $U$  are consumption bundles defined over a continuum of varieties  $\Omega_i$ :

$$(6) \quad C_{it} = \left[ \int_{\omega \in \Omega_i} c_{it}(\omega)^{\frac{\theta-1}{\theta}} d\omega \right]^{\frac{\theta}{\theta-1}},$$

where  $\theta > 1$  is the elasticity of substitution between varieties. Varieties are internationally traded. Thus a variety can either be produced at home or imported. At any given time, only a subset of varieties  $\Omega_{it} \in \Omega_i$  is available in each sector. The consumption-based price index for each sector is  $P_{it} = \left[ \int_{\omega \in \Omega_{it}} p_{it}(\omega)^{1-\theta} d\omega \right]^{\frac{1}{1-\theta}}$  and the household demand for each variety is  $c_{it} = (p_{it}/P_{it})^{-\theta} C_{it}$ . It is useful to redefine these in terms of aggregate consumption units. Let us define  $\rho_{it} \equiv p_{it}/P_t$  and  $\psi_{it} \equiv P_{it}/P_t$  as the relative prices for individual varieties and for the sector bundles, respectively. Then, we can rewrite the demand functions for varieties and sector bundles as  $c_{it} = (\rho_{it}/\psi_{it})^{-\theta} C_{it}$  and  $C_{it} = \alpha_i \psi_{it}^{-1} C_t$ , respectively.

*2.2. Worker Allocation.* Recent empirical evidence indicates that incumbent workers are very immobile across sectors in response to trade shocks (see, e.g., Autor et al., 2013; Wacziarg and Wallack 2004; Autor et al., 2014; and Dix-Carneiro 2014). Therefore, we assume that incumbent workers have to stick to their sector of employment.<sup>11</sup> However, to nevertheless allow for worker reallocation, we assume that incumbent workers retire at an exogenous rate  $s$  and are replaced by an equal number of newly entering workers that are allowed to choose their sector of occupation. This occupational choice will be influenced by wage differentials across sectors implying that the workforce will grow in the expanding sector (more workers are entering this sector than leaving it), while the workforce will contract in the shrinking sector.

Although we allow for reallocation of the labor input across sectors, in our baseline setting we do not allow for changes in the skill composition, that is, we assume that each retiring skilled worker gets replaced by a newly entering skilled worker and that each retiring unskilled worker gets replaced by a newly entering unskilled worker. Thus the total number of skilled and unskilled workers is exogenously given and remains constant over time:<sup>12</sup>  $sS = S_{e,S,t} + S_{e,U,t}$  and  $sL = L_{e,S,t} + L_{e,U,t}$ , where  $S$  and  $L$  are the exogenously given number of skilled and unskilled workers in country H, and  $S_{e,it}$  and  $L_{e,it}$  are newly entering skilled and unskilled workers in sector  $i = S, U$ .

The main factor influencing a worker's choice of sector is the wage differential. Naturally, workers tend to prefer the sector that pays the higher wage.<sup>13</sup> However, we also allow a worker's choice of sector to be affected by preferences: upon entering the workforce each worker draws her sector preference from a symmetric random distribution. This is in line with evidence by Dix-Carneiro (2014), Heckman and Sedlacek (1985), and Heckman and Sedlacek (1990) who, after controlling for worker heterogeneity such as age, education, and gender, provide evidence for self-selection into sectors based on nonpecuniary preferences and show that this is an important ingredient to explaining the wage differential across sectors. We also assume random sector preferences due to numerical reasons.<sup>14</sup>

We denote the sector preference by  $\varepsilon^S$  for skilled workers and by  $\varepsilon^L$  for unskilled workers, with a positive number meaning that the worker prefers sector  $S$  and a negative number

<sup>11</sup> In the Appendix, we also consider the case of mobility of incumbent workers across sectors.

<sup>12</sup> In the Appendix, we consider a version of the model where the supply of skilled and unskilled workers is endogenous and newly entering workers have access to a training technology and can choose their skill class. However, the results do not change significantly and we choose the simpler version of the model as our benchmark.

<sup>13</sup> This assumption is in line with empirical evidence in, for example, Ryoo and Rosen (2004) who find that the fraction of college graduates who are engineers is closely related to a measure of relative earnings prospects in engineering.

<sup>14</sup> Without these sector preferences there would be no mechanism assuring that the steady state is hit, potentially implying overshooting and oscillatory dynamics.



meaning that the worker prefers sector  $U$ . Every newly entering skilled worker draws her relative sector preference from a random distribution with cumulative distribution function  $J(\varepsilon^S)$  and support on  $(-\infty, \infty)$  (unskilled workers draw their relative sector preference  $\varepsilon^L$  from the random distribution  $J(\varepsilon^L)$ ).

In the following, we will describe the choice of sector of skilled workers only but the entry problem of unskilled workers is equivalent (refer to Table 1 for a list of the equations pertaining to unskilled workers). An entering skilled worker will choose to enter sector  $S$  if

$$(7) \quad V_{St}^s + \varepsilon_t > V_{Ut}^s,$$

where  $V_{it}^s = E_t[\log(C_{it}^s) + \gamma(1 - s)V_{it+1}^s]$  is the present discounted value of consumption utility of a skilled worker in sector  $i$ . Equation (7) defines a threshold value  $\overline{\varepsilon^S}$ , for which a worker is indifferent between both sectors:

$$(8) \quad \overline{\varepsilon_t^S} = V_{Ut}^s - V_{St}^s,$$

and the share of the newly entering skilled workers that choose sector  $S$  is  $1 - J(\overline{\varepsilon_t^S})$  while the rest of the workers will enter sector  $U$ :  $S_{e,Ut} = sS - S_{e,St}$ . Workers are immobile between sectors. That implies that worker' wages are different across sectors: wages are higher in the sector that experiences higher demand (after an increase in tariffs this will be the unskilled-intensive sector). Consequently, the value of a worker is also higher in the sector that experiences higher demand. This uniquely pins down the entry threshold via Equation (8), and thus the share of workers entering a specific sector. The resulting law of motion for skilled workers in sector  $i$  is

$$(9) \quad S_{it} = (1 - s)S_{it-1} + S_{e,it}.$$

During transition the sector with the higher wage will attract a relatively larger number of entrants, implying that the wage differential across sectors becomes smaller over time. At the new steady state, the number of workers in each sector will be stationary, that is, the number of workers entering the sector equals the number of workers leaving the sector. Sector preferences still imply a wage differential, but we will calibrate the relative sector preference distribution such that the wage differential is negligible in steady state.

**2.3. Production.** There are two sectors of production in each country. In the spirit of Melitz (2003), an endogenous number of firms with heterogeneous productivity operates in each sector.<sup>15</sup> To avoid cumbersome notation, we omit a firm-specific index in the following description of production. The production technology is assumed to be Cobb–Douglas in the two inputs of production:

$$(10) \quad Y_{it} = zS_{it}^{\beta_i}L_{it}^{(1-\beta_i)},$$

where  $z$  is firm-specific productivity, while  $S_{it}$  and  $L_{it}$  is the amount of skilled and unskilled labor used by a firm.  $\beta_i$  is the share of skilled labor required to produce one unit of output  $Y_i$  in

<sup>15</sup> Since Melitz (2003), endogenous firm entry and firm heterogeneity are standard features in models of international trade. Ghironi and Melitz (2005) have shown that both features are also important for macroeconomic dynamics. More specifically, Felbermayr et al. (2013) have shown in a static model that including firm heterogeneity is crucial when analyzing optimal tariffs because the restriction to homogenous goods shuts off an important channel. In a dynamic context, Lechthaler (2017) has shown that firm entry and firm heterogeneity have important effects on the dynamic adjustment after changes in import tariffs and thereby on the optimal setting of tariffs.

sector  $i$ . Sector  $S$  is assumed to be skill intensive and sector  $U$  unskilled intensive, which implies that  $1 > \beta_S > \beta_U > 0$ . The labor market is assumed to be perfectly competitive, implying that the real wage of both skilled and unskilled workers equals the values of their marginal products of labor. In addition, workers are perfectly mobile across all firms in a specific sector. That implies that all firms within a sector pay the same wage. Consequently, relative labor demand can be described by the following condition:

$$(11) \quad \frac{w_{it}^s}{w_{it}^l} = \frac{\beta_i}{1 - \beta_i} \frac{L_{it}}{S_{it}},$$

which says that the ratio of the skilled real wage  $w_{it}^s$  to the unskilled real wage  $w_{it}^l$  for sector  $i$  is equal to the ratio of the marginal contribution of each factor in producing one additional unit of output. Note that this condition implies that relative demand for labor is the same across all firms within a sector. Since relative demand for labor is independent of firm-specific productivity, Equation (11) also holds at the sector level, that is, relative labor demand per sector is entirely determined by the relative wages paid by firms in that sector. This condition is valid for both sectors.

As in Melitz (2003), incumbent firms are heterogeneous in terms of their productivity  $z$ , which is constant for the whole existence of the firm. The productivity differences across firms translate into differences in the marginal cost of production. Measured in the units of the aggregate consumption bundle, the marginal cost of production is  $(w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i} / z$ .

Prior to entry, firms are identical and face a sunk entry cost  $f_e$ , which is produced by skilled and unskilled labor, equal to  $f_e (w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}$  units of aggregate H consumption (for a discussion of the entry decision, see Subsection 2.3.2). Note that entry costs can differ between sectors due to different factor intensities and due to inter-sectoral wage differentials. Upon entry firms draw their productivity level  $z$  from a common distribution  $G(z)$  with support on  $[z_{\min}, \infty)$ . This firm productivity remains fixed thereafter. As in Ghironi and Melitz (2005), there are no fixed costs of production, so that all firms produce each period until they are hit by an exit shock, which occurs with probability  $\delta \in (0, 1)$  each period. This exit shock is independent of the firm's productivity level, so  $G(z)$  also represents the productivity distribution of all producing firms.

Exporting goods to F is costly and involves an iceberg trade cost  $\tau^* \geq 1$ , an import tariff  $t_{it}^* \geq 1$  as well as a fixed cost  $f_x$ , again measured in units of effective skilled and unskilled labor. In real terms, these costs are  $f_x (w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}$ . The fixed cost of exporting implies that not all firms find it profitable to export.

All firms face a residual demand curve with constant elasticity in both H and F. They are monopolistically competitive and set prices as a proportional markup  $\theta / (\theta - 1)$  over marginal cost. Let  $p_{d,it}(z)$  and  $p_{x,it}(z)$  denote the nominal domestic and export prices of an H firm in sector  $i$ . We assume that the export prices are denominated in the currency of the export market. Prices in real terms, relative to the price index in the destination market, are then given by

$$(12) \quad \rho_{d,it}(z) = \frac{p_{d,it}(z)}{P_t} = \frac{\theta}{\theta - 1} \frac{(w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}}{z}, \quad \rho_{x,it}(z) = \frac{p_{x,it}(z)}{P_t^*} = \frac{1}{Q_t} \tau^* t_{it}^* \rho_{d,it}(z).$$

Profits, expressed in units of the aggregate consumption bundle of the firm's location are  $d_{it}(z) = d_{d,it}(z) + d_{x,it}(z)$ , where

$$(13) \quad d_{d,it}(z) = \frac{1}{\theta} \left( \frac{\rho_{d,it}(z)}{\psi_{it}} \right)^{1-\theta} \alpha_i C_t$$

$$(14) \quad d_{x,it}(z) = \begin{cases} \frac{Q_t}{\theta \rho_{it}^*} \left( \frac{\rho_{x,it}(z)}{\psi_{it}^*} \right)^{1-\theta} \alpha_i C_t^* - f_x(w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}, & \text{if firm } z \text{ exports} \\ 0 & \text{otherwise.} \end{cases}$$

A firm will export if and only if it earns nonnegative profits from doing so. For H firms, this will be the case if their productivity draw  $z$  is above some cutoff level  $z_{x,it} = \inf\{z : d_{x,it} > 0\}$ . We assume that the lower bound productivity  $z_{\min}$  is identical for both sectors and low enough relative to the fixed cost of exporting so that  $z_{x,it}$  is above  $z_{\min}$ . Firms with productivity between  $z_{\min}$  and  $z_{x,it}$  serve only their domestic market.

2.3.1. *Firm Averages.* In every period, a mass  $N_{d,it}$  of firms produces in sector  $i$  of country H. These firms have a distribution of productivity levels over  $[z_{\min}, \infty)$  given by  $G(z)$ , which is identical for both sectors and both countries. The number of exporters is  $N_{x,it} = [1 - G(z_{x,it})]N_{d,it}$ , which might differ across sectors. It is useful to define two average productivity levels, an average  $\bar{z}_{d,it}$  for all producing firms in sector  $i$  of country H and an average  $\bar{z}_{x,it}$  for all exporters in sector  $i$  of country H:

$$\bar{z}_{d,it} = \left[ \int_{z_{\min}}^{\infty} z^{\theta-1} dG(z) \right]^{\frac{1}{(\theta-1)}}, \quad \bar{z}_{x,it} = \left[ \int_{z_{x,it}}^{\infty} z^{\theta-1} dG(z) \right]^{\frac{1}{(\theta-1)}}.$$

As in Melitz (2003), these average productivity levels summarize all the necessary information about the productivity distributions of firms.

We can redefine all the prices and profits in terms of these average productivity levels. The average nominal price of H firms in the domestic market is  $\bar{p}_{d,it} = p_{d,it}(\bar{z}_{d,it})$  and in the foreign market is  $\bar{p}_{x,it} = p_{x,it}(\bar{z}_{x,it})$ . The price index for sector  $i$  in H reflects prices for the  $N_{d,it}$  home firms and F's exporters to H. Then, the price index for sector  $i$  in H can be written as  $P_{it}^{1-\theta} = [N_{d,it}(\bar{p}_{d,it})^{1-\theta} + N_{x,it}(\bar{p}_{x,it})^{1-\theta}]$ . Written in real terms of aggregate consumption units, this becomes  $\psi_{it}^{1-\theta} = [N_{d,it}(\bar{\rho}_{d,it})^{1-\theta} + N_{x,it}(\bar{\rho}_{x,it})^{1-\theta}]$ , where  $\bar{\rho}_{d,it} = \rho_{d,it}(\bar{z}_{d,it})$  and  $\bar{\rho}_{x,it} = \rho_{x,it}(\bar{z}_{x,it})$  are the average relative prices of H's producers and F's exporters.

Similarly we can define  $\bar{d}_{d,it} = d_{d,it}(\bar{z}_{d,it})$  and  $\bar{d}_{x,it} = d_{x,it}(\bar{z}_{x,it})$  such that  $\bar{d}_{it} = \bar{d}_{d,it} + [1 - G(z_{x,it})]\bar{d}_{x,it}$  are average total profits of H firms in sector  $i$ .

2.3.2. *Firm Entry and Exit.* Firms are owned by a mutual fund that invests in new firms, collects all the profits, and distributes any surplus in a lump-sum fashion to the households. The mutual fund acts on behalf of the whole population and therefore uses the stochastic discount factor  $\gamma^{s-t}(1 - \delta)^{s-t}(C_s/C_t)^{-1}$  to discount between periods  $s$  and  $t$ . This way of modeling firm entry allows to separate firm entry from household heterogeneity.

As in Melitz (2003), firm entry is free in the sense that every period there is an unbounded mass of prospective new firms in both sectors and both countries. To become active, however, firms have to pay a sunk entry cost. We assume that entrants at time  $t$  only start producing at time  $t + 1$ , which introduces a one-period time-to-build lag in the model. The exogenous exit shock occurs at the end of each period, after entry and production. Thus a proportion  $\delta$  of new entrants will never produce. The mutual fund is forward looking and computes the expected post-entry value of a firm entering sector  $i$  in period  $t$  as the present discounted value of its expected stream of profits  $\{\bar{d}_{is}\}_{s=t+1}^{\infty}$ ,

$$(15) \quad \bar{v}_{it} = E_t \sum_{s=t+1}^{\infty} \left[ \gamma^{s-t}(1 - \delta)^{s-t} \left( \frac{C_s}{C_t} \right)^{-1} \bar{d}_{is} \right].$$

This also corresponds to the average value of incumbent firms after production has occurred. The mutual fund discounts future profits using the aggregate stochastic discount factor

adjusted for the probability of firm survival  $(1 - \delta)$ . Note that Equation (15) can be written in recursive form as

$$(16) \quad \tilde{v}_{it} = \gamma(1 - \delta)E_t \left[ \left( \frac{C_{t+1}}{C_t} \right)^{-1} (\tilde{v}_{it+1} + \tilde{d}_{it+1}) \right].$$

Entry occurs until the average firm value is equal to the entry cost, which implies the following free entry condition that determines the number of newly entering firms and thereby the mass of active firms in each sector:

$$(17) \quad \tilde{v}_{it} = f_e(w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}.$$

If the value of a firm was larger than the cost of entry, new firms would be created, increasing competition and thus lowering the profits of all firms and thus the value of a firm. This process continues until the value of a firm equals the cost of entry. The surplus of the mutual fund is distributed in a lump-sum fashion to the households:

$$(18) \quad \Pi_t(S + L) = \tilde{d}_{St}N_{d,St} + \tilde{d}_{Ut}N_{d,Ut} - \tilde{v}_{St}N_{e,St} - \tilde{v}_{Ut}N_{e,Ut}.$$

Finally, the number of firms evolves according to:

$$(19) \quad N_{d,it} = (1 - \delta)(N_{d,it-1} + N_{e,t-1}).$$

**2.3.3. Productivity distribution of firms.** Productivity  $z$  follows a Pareto distribution with lower bound  $z_{\min}$  and shape parameter  $k > \theta - 1$ :  $G(z) = 1 - (z_{\min}/z)^k$ . Let  $\nu = \{k/[k - (\theta - 1)]\}^{\frac{1}{\theta-1}}$ , then average productivities are

$$(20) \quad \tilde{z}_{d,it} = \nu z_{\min} \quad \text{and} \quad \tilde{z}_{x,it} = \nu z_{x,it}.$$

The share of exporting firms in sector  $i$  in H is

$$(21) \quad \frac{N_{x,it}}{N_{d,it}} = 1 - G(z_{x,it}) = \left( \frac{\nu z_{\min}}{\tilde{z}_{x,it}} \right)^k.$$

Together with the zero export profit condition for the cutoff firm,  $d_{x,it}(z_{x,it}) = 0$ , this implies that average export profits must satisfy

$$(22) \quad \tilde{d}_{x,it} = (\theta - 1) \left( \frac{\nu^{\theta-1}}{k} \right) f_x(w_{it}^s)^{\beta_i} (w_{it}^l)^{1-\beta_i}.$$

**2.4. Market Clearing Conditions, Aggregate Accounting, and Trade.** Market clearing requires that total production in each sector must equal total income so that:

$$(23) \quad N_{d,it} \left( \frac{\tilde{\rho}_{d,it}}{\psi_{it}} \right)^{1-\theta} \alpha_i C_t + Q_t \frac{1}{t_{it}^*} N_{x,it} \left( \frac{\tilde{\rho}_{x,it}}{\psi_{it}^*} \right)^{1-\theta} \alpha_i C_t^* + \tilde{v}_{it} N_{e,it} = w_{it}^s S_{it} + w_{it}^l L_{it} + \tilde{d}_{it} N_{d,it}.$$

Total production of the sector (on the left-hand side) includes the production of the aggregate consumption bundle (both for the domestic market and the foreign market) and the production of new firms. Total income generated by the sector (on the right-hand side) includes wage earnings and profits.

The trade balance is defined as exports minus imports in both sectors:<sup>16</sup>

$$(24) \quad tb_t = \sum_{i=S,U} \left[ Q_t \frac{1}{t_{it}^*} N_{x,it} \left( \frac{\tilde{\rho}_{x,it}}{\psi_{it}^*} \right)^{1-\theta} \alpha_i C_t^* - \frac{1}{t_{it}} N_{x,it} \left( \frac{\tilde{\rho}_{x,it}^*}{\psi_{it}} \right)^{1-\theta} \alpha_i C_t \right]$$

Let us define aggregate bond holdings in H as  $B_t \equiv (B_{St}^s + B_{Ut}^s + B_{St}^l + B_{Ut}^l)$  and  $B_{*,t} \equiv (B_{*,St}^s + B_{*,Ut}^s + B_{*,St}^l + B_{*,Ut}^l)$  and similarly for aggregate bond holdings in F. In equilibrium, the international net supply of bonds is zero for H bonds, such that  $B_t + B_t^* = 0$  and for F bonds, such that  $B_{*,t} + B_{*,t}^* = 0$ . Then net foreign assets evolve according to the following law of motion:

$$(25) \quad B_t + Q_t B_{*,t} = (1 + r_{t-1}) B_{t-1} + (1 + r_{t-1}^*) B_{*,t-1} Q_t + tb_t.$$

**2.5. Summary.** Table 1 summarizes the equations of the model that define the equilibrium. The equations in the table constitute a system of 126 equations in 126 endogenous variables. The system includes 25 sector-specific equations for sector  $i = S, U$  for H, with an equivalent set holding for F, making 100 sector-specific equations in total, and 11 nonsector specific equations for H and equivalent for F, 26 nonsector specific equations in total including the trade balance, net foreign assets, and the bond clearing conditions. The sector-specific endogenous variables for H include:  $\tilde{d}_{it}, \tilde{d}_{d,it}, \tilde{d}_{x,it}, N_{e,it}, N_{d,it}, N_{x,it}, \tilde{z}_{x,it}, \tilde{v}_{it}, \tilde{\rho}_{d,it}, \tilde{\rho}_{x,it}, \psi_{it}, w_{it}^s, w_{it}^l, C_{it}^s, C_{it}^l, V_{it}^s, V_{it}^l, S_{it}, L_{it}, S_{e,it}, L_{e,it}, B_{it}^s, B_{*,it}^s, B_{it}^l, B_{*,it}^l, T_{it}^s, T_{it}^l$ , 27 for each sector and 54 in total for H, with another 54 equivalent variables describing F. The nonsector specific variables for H are eight and include:  $C_t, B_t, B_{*,t}, T_t^l, \Pi_t, r_t, \bar{\varepsilon}_t^S, \bar{\varepsilon}_t^L$  with equivalent eight relevant for F. Thus, we have 62 variables for H and 62 for F, and adding the real exchange rate  $Q_t$ , and the trade balance  $tb_t$ , makes a total of 126. The model also features four exogenous policy variables: the import tariffs paid by H to F in sector  $i$ ,  $t_{it}^*$  and the import tariffs paid by F to H in sector  $i$ ,  $t_{it}$ , which the policymaker chooses optimally when maximizing the welfare of various households.

Throughout the text we have imposed the following parameter restrictions on our model:  $0 < \beta_U < \beta_S < 1$ ,  $0 < \alpha_S < 1$ ,  $0 < \gamma < 1$ ,  $0 < s < 1$ ,  $0 < \delta < 1$ ,  $f_e > 0$ ,  $f_e^* > 0$ ,  $f_x > 0$ ,  $f_x^* > 0$ ,  $k > 0$ ,  $z_{\min} > 0$ ,  $\theta > 1$ ,  $k > \theta - 1$ ,  $S > 0$ ,  $L > 0$ ,  $S^* > 0$ ,  $L^* > 0$ . They are necessary to hold for the model to have a unique and stable solution. These parameter restrictions are also necessary to ensure the existence and uniqueness of our steady state. Appendix A.7 gives a formal proof that our model has a unique steady state and discusses the implications of different parameter restrictions.

**2.6. Parametrization.** This section describes the parametrization of the model that we use for our analysis of optimal tariffs. Table 2 summarizes our parameter choices. In most aspects, we follow Ghironi and Melitz (2005), interpreting the home country as the United States. Furthermore, we assume that both economies are symmetric except for their relative endowments of skilled/unskilled workers and the steady state tariffs they charge. To calibrate these variables, we interpret the foreign country as China. We take this approach because it is not our goal to provide a precise quantitative assessment of optimal tariffs but rather to highlight the role of comparative advantage, distributional aspects, and dynamic adjustment. To this end, we want to keep the asymmetries across countries at a minimum.

We interpret each period as a quarter and set the household discount rate  $\gamma$  to 0.99, which targets a four-percent annual real interest rate and is the standard choice for quarterly dynamic models. We set the elasticity of substitution between varieties to  $\theta = 3.8$ , based on the

<sup>16</sup> Assuming international trade in bonds allows for unbalanced trade. Ruling out international trade, and thus assuming that trade is balanced at all times, would not change our results qualitatively (see Ghironi and Melitz 2005), but allowing for unbalanced trade is certainly the more general approach, and therefore we prefer to do so.

TABLE 2  
PARAMETRIZATION

| Parameter     | Description  | Value  | Calibration Target   |
|---------------|--|--------|--|
| $\gamma$      | Discount factor                                    | 0.99   | U.S. annual real interest rate 4%  |
| $\alpha_S$    | Weight of skill-intensive good in household basket | 0.6    | Revenue share of comparative advantage sectors 62.7%, average over period 1980–2009  |
| $\theta$      | Substitution elasticity                            | 3.8    | based on U.S. plant and macro data from Bernard et al. (2003)  |
| $k$           | Pareto distribution shape                          | 3.4    | Standard deviation of log U.S. plant sales $1/(k - \theta + 1) = 1.67\%$ from Bernard et al. (2003)                          |
| $z_{min}$     | Pareto distribution scale                          | 1      | Normalized parameter   |
| $f_e$         | Fixed entry cost                                   | 1      | Normalized parameter   |
| $\delta$      | Firm exit rate                                     | 0.025  | U.S. annual job destruction rate 10%   |
| $f_x$         | Fixed export cost                                  | 0.0085 | 23.5% of the per period amortized value of the entry cost $([1 - \gamma(1 - \delta)]/[\gamma(1 - \delta)]f_e)$ , based on GM |
| $\tau/\tau^*$ | Iceberg trade cost                                 | 1.71   | China trade share in manufacturing value added 20.6%, average over period 1994–2014  |
| $\beta_S$     | Skill intensity in skill-intensive sector          | 0.45   | Wage share of production workers in comparative advantage sectors, average over period 1980–2009                             |
| $\beta_U$     | Skill intensity in the unskilled-intensive sector  | 0.32   | Wage share of production workers in comparative disadvantage sectors, average over period 1980–2009                          |
| $S$           | Number of skilled workers for H                    | 444    | U.S. production workers to managers ratio 3.5 to 1, average over 1990 and 2005   |
| $L$           | Number of unskilled workers for H                  | 1556   | U.S. production workers to managers ratio 3.5 to 1, average over 1990 and 2005   |
| $S^*$         | Number of skilled workers for F                    | 191    | China production workers to managers ratio 9.5 to 1, average over 1990 and 2005  |
| $L^*$         | Number of unskilled workers for F                  | 1809   | China production workers to managers ratio 9.5 to 1, average over 1990 and 2005  |
| $s$           | Retirement rate of workers                         | 0.005  | Separation rate due to retirement of 2.5%  |
| $sd$          | Standard deviation of entry cost distribution      | 0.1    | Narrow distribution  |
| $t$           | Import tariff charged by H                         | 3%     | Import tariff of United States on China, average over period 1994–2014   |
| $t^*$         | Import tariff charged by F                         | 6%     | Import tariff of China on United States, average over period 1994–2014   |

estimates from plant-level U.S. manufacturing data in Bernard et al. (2003). We set the parameters of the Pareto distribution to  $z_{min} = 1$  and  $k = 3.4$ , respectively. This choice satisfies the condition for finite variance of log productivity:  $k > \theta - 1$ .

Changing the sunk cost of firm entry  $f_e$  only rescales the mass of firms in an industry. Thus without loss of generality, we can normalize it so that  $f_e = 1$ . We set the fixed cost of exporting  $f_x$  to 23.5% of the per-period, amortized flow value of the sunk entry costs,  $[1 - \gamma(1 - \delta)]/[\gamma(1 - \delta)]f_e$ . We set the size of the exogenous firm exit probability to  $\delta = 0.025$ , to match the level of 10% job destruction per year in the United States. These choices of parameter values are based on Ghironi and Melitz (2005).

To focus on comparative advantage, we assume that all industry parameters are the same across industries and countries except factor intensity ( $\beta_i$ ). The reason that we assume identical values across the two countries is because we want to focus on the role of comparative-advantage-driven trade on determining optimal import tariffs. If we were to assume different parameters for the developing country, given the complicated structure of our model, it would

be difficult to determine what drives the tariffs preferred by different workers and to isolate the impact of comparative advantage. Furthermore, industry and firm-level data on China is not freely available and it would be difficult to calibrate these parameters for China.

We calibrate ( $\beta_i$ ) based on our own calculations using the NBER-CES Manufacturing Industry Database<sup>17</sup> that provides annual industry-level data from 1958 to 2009 on output, employment, payroll and other input costs, investment, capital stocks, TFP, and various industry-specific price indices. We aggregate the data set to feature 19 3-digit NAICS industries and then classify these industries based on their revealed comparative advantage. To distinguish between comparative advantage and comparative disadvantage sectors, we use a measure of revealed comparative advantage (*RCA*) that takes account of exports and imports at the sector level. *RCA* is defined as the ratio of the export share of the sector in total manufacturing exports over the import share of the sector in total manufacturing imports ( $RCA = (Ex_{it}/Ex_{manuf,t})/(Im_{it}/Im_{manuf,t})$ ), with  $RCA > 1$  referring to comparative advantage sectors and  $RCA < 1$  referring to comparative disadvantage sectors.<sup>18</sup> To calibrate factor intensities of each sector, we calculate the wage share of production workers in total payroll for comparative advantage sectors and comparative disadvantage sectors, where production workers are defined as blue-collar, unskilled workers. We take the period average from 1980 to 2009 and find that the implied wage share for skilled workers in comparative advantage sectors is  $\beta_S = 0.45$  and in comparative disadvantage sectors is  $\beta_U = 0.32$ . Similarly, we calculate the average share of comparative advantage sectors in total sector revenue to be 0.627 for 1980–2009. We use it to calibrate  $\alpha_S = 0.6$  and  $\alpha_U = 0.4$ .

Given the definition of skilled workers and unskilled workers in the NBER-CES data, we calibrate the endowments based on the ratio of production workers to managers in Figure 4 in Ebenstein et al. (2012). For the United States, this ratio is 4 to 1 in 1990 and 3 to 1 in 2005. For China, the ratio is 8 to 1 in 1990 and 11 to 1 in 2005. Taking the average over the two available years and for a total population of 2,000 workers, these ratios imply that  $S = 444$  and  $L = 1,556$  for the Home country and  $S^* = 191$  and  $L^* = 1,809$  for the Foreign country. These endowments imply that the United States has a higher relative endowment of skilled workers than China and thus a comparative advantage in producing skill-intensive goods.

According to data from the World Trade Organization (WTO), there is a significant difference in the tariffs both economies charge (see <https://tao.wto.org/>). Over the past 10 years, the United States charged on average a tariff of 3% for imports from China, while China charged on average a tariff close to 6% for imports from the United States. We set tariffs in the initial steady state (the status quo) accordingly.

Iceberg trade costs are calibrated to deliver a share of U.S. trade with China to U.S. GDP of 0.206. This corresponds to the average share of United States–China manufacturing trade and manufacturing value added for the United States over the period 1994–2014. Assuming symmetric trade costs, this share implies trade costs of  $\tau = \tau^* = 1.71$ .

To calibrate the retirement rate  $s$ , we use data from the Job Openings and Labor Turnover Survey. According to this source, workers exited the manufacturing sector at an average rate of 2.5% per year between 2000 and 2018. This includes retirements, transfers to other locations, deaths, and separations due to employee disability.<sup>19</sup> Since the retirement rate is a bit smaller than this exit rate, we assume that workers in our model retire at an exogenous rate of 2% per year that corresponds to  $s = 0.5\%$  at quarterly frequency. Regarding worker entry, we assume that the entering worker's relative sector preference follows a normal

<sup>17</sup> The data can be accessed at <http://www.nber.org/nberces/>.

<sup>18</sup> We prefer this measure over the more traditional measure of revealed comparative advantage introduced by Balassa because it not only takes account of the export structure of the sector but also of its import structure. In addition, data on U.S. exports and imports at the NAICS industry classification is readily available at Peter Schott's Web site. In contrast, the Balassa measure of *RCA* requires data on world export shares at the NAICS level that has to be converted from other industry classification systems.

<sup>19</sup> Source is the Job Openings and Labor Turnover Survey and data on the separation due to retirement only are not provided.

TABLE 3  
MODEL VERSUS DATA

|  | Model at the Steady State | Data for the U.S.<br>Manufacturing |
|--|---------------------------|------------------------------------|
| Skill premium                              | 1.34                      | 0.67                               |
| Gini index                                 | 0.18                      | 0.13                               |
| Share of sector S in total trade           | 0.58                      | 0.60                               |
| Trade share in sector revenue for sector S | 0.19                      | 0.19                               |
| Trade share in sector revenue for sector U | 0.24                      | 0.22                               |
| Share of unskilled workers in sector S     | 0.74                      | 0.67                               |
| Share of unskilled workers in sector U     | 0.84                      | 0.78                               |

distribution with a mean of zero and a standard deviation of  $sd = 0.1$ . We have set the standard deviation parameter in order to ensure a very narrow distribution so that the entry decision of a worker regarding sector entry is mostly determined by sectoral wage differentials instead of sector preferences. This assumption is in line with empirical evidence in Ryoo and Rosen (2004) who find that the fraction of college graduates who are engineers is closely related to a measure of relative earnings prospects in engineering. Dix-Carneiro (2010) also finds that nonpecuniary preference parameters play a relatively small but significant role for the choice of employment sector.

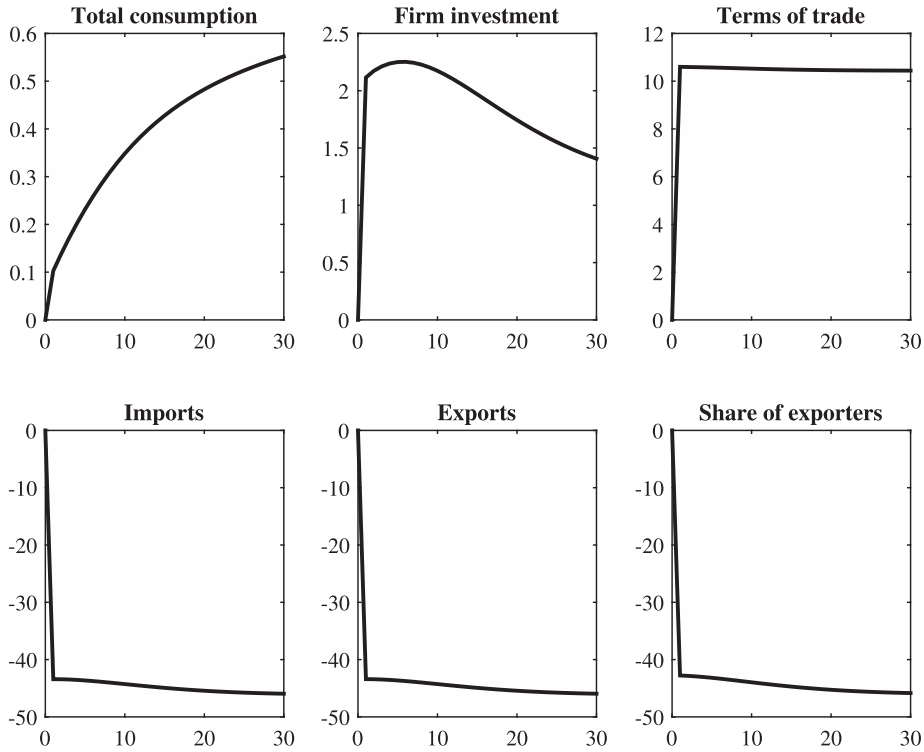
To further check the performance of our model, Table 3 compares the steady state values of key variables that we have not targeted directly against their corresponding values in the data. The table shows averages over the period 1980–2009 that are based on the NBER-CES database, except for the trade shares, which are averaged over the period 1989–2005 due to limitations in the data on exports and imports. The skill premium and the Gini index are constructed based on average wages per worker instead of hourly wages, so that the data measure is closer to our model that does not include an intensive margin of labor. As the table shows, the model fits the data very well: there is evidence of specialization both in the model and in the data, for example, the comparative advantage (net exporting) sector tends to be more skill intensive and larger, as it has a lower share of production workers and a higher share in total trade both in the model and in the data. However, the model is overestimating the share of unskilled workers in employment and as a result it is overestimating the skill premium and the Gini index. Concerning dynamic adjustment, Lechthaler and Mileva (2019) have already shown that a version of the model without import tariffs does a good job in replicating the dynamic adjustment to liberalizing trade with China including the slow reallocation of workers in response to the “China-shock.”

### 3. OPTIMAL ECONOMY-WIDE TARIFFS

*3.1. The Dynamic Adjustment after an Increase in Tariffs.* This section discusses the setting of unilaterally optimal tariffs under the assumption that the same tariff is set for both sectors. As in Ossa (2014), we assume that for this experiment the tariff of the other country is held constant. In later sections, we will relax this assumption and discuss Nash-equilibrium tariffs (or trade wars). Later we will also consider sector-specific tariffs.

It is a well-established result in the trade literature that due to the terms of trade externality, and starting from a low tariff, a permanent unilateral increase in the tariff yields a permanent increase in the consumption of the country that imposes the higher tariff. Basically, there are two counteracting effects. On the one hand, a positive tariff drives a wedge between the consumer price and the producer price and thus creates an inefficiency. On the other hand, since the tariff is partly born by foreign producers, whereas the ensuing income is solely distributed to domestic consumers, income is redistributed from foreign producers to domestic consumers. Starting from a low tariff, the second effect dominates and raising the tariff





NOTES: Quarters on the horizontal axis, percent (point) deviations from the old steady state on the vertical axis.

FIGURE 1

EFFECTS OF AN INCREASE IN THE U.S. TARIFF FROM 3% TO 32.5%

increases domestic consumption (as long as there is no retaliation). The higher the tariff gets, the stronger the distortion becomes so that for high tariffs the first effect can dominate. This reasoning implies that there exists a tariff that maximizes consumption.

Following the traditional approach in the trade literature that is based on a static analysis and ignores dynamic adjustment, our model yields an optimal tariff for the United States of 32.5% that maximizes aggregate U.S.-consumption in steady state given the observed tariff of China. Figure 1 shows the dynamic adjustment of selected aggregate variables in response to a permanent increase of the U.S. tariff from 3%, the status quo, to this static optimum, 32.5%.<sup>20,21</sup> Obviously, aggregate U.S. consumption does not jump immediately to its new long-run equilibrium, but rather takes a long time to converge. This implies that the short-term gains from raising tariffs are actually much smaller than a purely static analysis would suggest. Consequently, the optimal tariff of a dynamic analysis is expected to be smaller than the optimal tariff of a static analysis. We will come back to the optimal tariff later, but first let us discuss the dynamic adjustment in a bit more detail.

The main reason for the sluggish increase in aggregate consumption is the surge in firm investment. An increase in the import tariff implies lower competition for domestic firms. This implies that the number of firms in the new steady state must be higher than the number

<sup>20</sup> In Lechthaler and Mileva (2019), we have shown that a version of the model without import tariffs does a good job in replicating the dynamic adjustment to liberalizing trade with China including the slow reallocation of workers in response to the “China-shock.” The paper also shows that trade with China can explain a reasonable share of the increase in wage inequality in the United States. Thus we are confident that the model can also capture well the dynamic adjustment in response to tariff hikes.

<sup>21</sup> We use DYNARE to simulate the dynamic adjustment between the two steady states. The rank condition is satisfied suggesting a stable equilibrium and a unique adjustment path.

for firms in the old steady state (as is standard in the Melitz model). During the adjustment period, the stock of firms must be built up, which implies especially high investment in firms. Enhanced investment in new firms reduces consumption, so that the short-run gain in consumption is considerably smaller than the long-run gain.

In contrast to the adjustment of aggregate consumption, imports and exports adjust very quickly. The increase in the tariff immediately makes imports more expensive, so that imports drop by more than 40% on impact. However, the reduced demand for foreign products and the less efficient mix of domestic varieties and foreign varieties in the United States induce a sharp increase in the U.S. TOT, defined as the price of exports relative to the price of imports (and the U.S. real exchange rate appreciates). This partly offsets the decreased demand for Chinese imports and at the same time reduces the demand for U.S. exports. As a consequence, the trade balance (not depicted) does not move much, which is in line with empirical evidence (see, for example, Gagnon 2017). The reduced export demand is also visible in the significant reduction in the number of exporting firms. Note that this reduction in the number of exporting firms also corresponds to less efficient production because exporting firms are more productive than firms that solely serve the domestic market.

*3.2. Optimal Tariffs and The Planning Horizon.* Taking account of adjustment dynamics has two major advantages. First, the adjustment process is not ignored. Second, it allows us to analyze the optimal behavior of policymakers who might be more interested in the next couple of years than the infinite future. As discussed above, the slow adjustment in aggregate consumption implies that a dynamic analysis yields smaller gains from raising tariffs than a static analysis. Taking account of this adjustment, we determine the optimal tariff  $t_T^{\text{opt}}$  as the tariff that maximizes the present discounted value of aggregate consumption in the next  $T$  periods:<sup>22</sup>

$$(26) \quad t_T^{\text{opt}} = \operatorname{argmax} \left( \sum_{k=0}^T \beta^k C_{t+k} \right)$$

Further assuming for the moment that the policymaker is so forward looking that she cares about all future generations, that is,  $T = \infty$ , yields an optimal tariff of 30.5%, not much but still noticeably less than the 32.5% of the static analysis.

Because of the slow adjustment of consumption, policymakers tend to set lower tariffs the shorter their planning horizon.<sup>23</sup> This is illustrated in Figure 2. Similarly to Larch and Lechthaler (2013) and Lechthaler (2017), this figure shows the optimal U.S. tariff in dependence of the planning horizon of the U.S. policymaker. By planning horizon, we mean that the policymaker does not care about the infinite future but rather about the next  $x$  periods where  $x$  is measured along the horizontal axis. Formally, the tariff shown in Figure 2 solves the policymaker's problem in Equation (26) for  $T = x$ , that is, it maximizes the discounted present value of consumption of all periods up to  $T = x$ . As an example, the figure illustrates that for a policymaker who cares about the next four years, a common term of office, the optimal tariff is just 24%.

So far this perfectly resembles the results in Larch and Lechthaler (2013) and Lechthaler (2017). However, the use of a model with comparative advantage and inter-industry trade

<sup>22</sup> We assume that the policymaker focuses on consumption because it is more readily observable than utility, but maximizing utility instead of consumption would not change our results (compare the left panel of Figure A4 in the Appendix, in which the optimal tariff is based on maximizing utility instead of consumption, to Figure 2).

<sup>23</sup> Conconi et al. (2014) have recently shown that politicians close to reelection tend to be more protectionist than other politicians. This might seem at odds with our result that politicians with a shorter time horizon should be in favor of smaller tariffs. Note, however, that even the optimal tariff for politicians with a very short time horizon is with around 20% much higher than the status quo of 3%. So no matter how long the planning horizon of a policymaker is, if she faces reelection, our model suggests that she should favor an increase in tariffs.

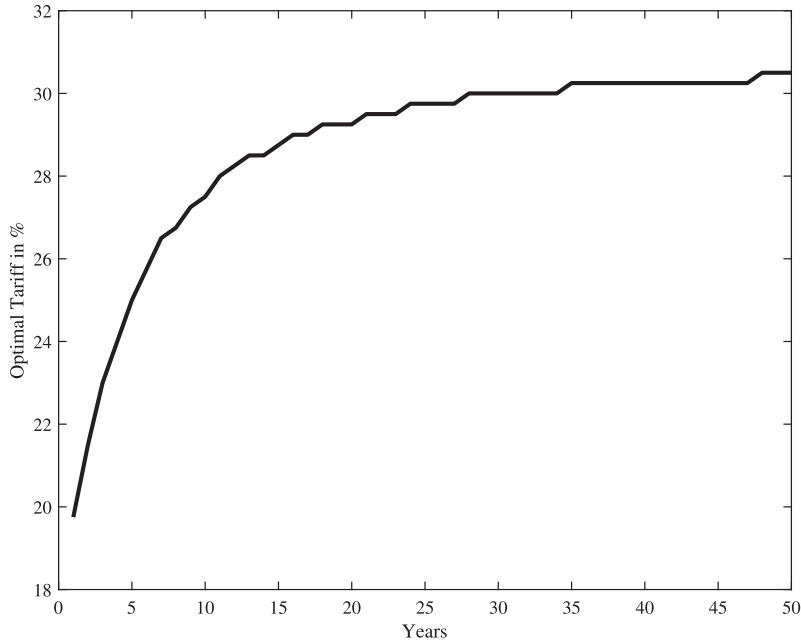


FIGURE 2

OPTIMAL TARIFF IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON

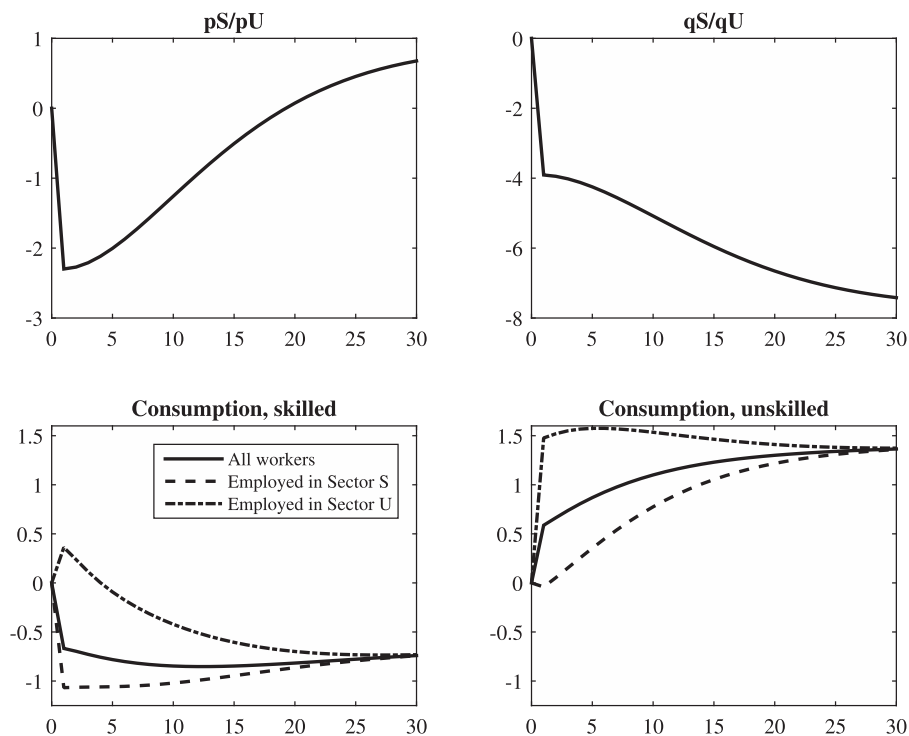
allows for a broader perspective, with the potential to put more weight on specific worker groups or to charge different tariffs for different sectors. In the following discussion, we will concentrate on the first of these aspects, analyzing cases where the policymaker might care more for certain groups of workers than for others.

#### 4. TARIFFS AND SPECIFIC WORKERS GROUPS

4.1. *Worker-Specific Effects of Tariffs.* So far we have concentrated on the adjustment of aggregate variables. In this section, we take a closer look at the experience of specific worker groups and their preferences for tariffs. Going back to the scenario where the United States raises the tariff to 32.5%, we see from Figure 3 that the experience of different types of workers diverges a lot.

The economy is very much specialized in the production of the sector where it has its comparative advantage. Since the United States has a relatively large share of skilled workers, it specializes more in the production of the skill-intensive sector, sector S. Raising import tariffs partially reverses this specialization. Imports from China become more expensive and thus it becomes profitable for the United States to increase its production in the unskilled-intensive sector, sector U.

In the short run, this implies that the price of sector U,  $p_U$  rises relative to sector S and consequently the wages of workers employed in sector U rise relative to the wages of workers in sector S, irrespective of the skill class of the worker. In the longer run, both firms and workers migrate from sector S to sector U. This not only tends to reduce the differential between wages across sectors but also has the implication that the skill mix changes in both sectors, making unskilled workers relatively more productive. Put differently, the reduced importance of the skill-intensive sector puts downward pressure on the wage of skilled workers but this effect takes time to fully materialize because production factors need to reallocate.



NOTES: Quarters on the horizontal axis, percent deviations from the old steady state on the vertical axis.

FIGURE 3

EFFECTS OF AN INCREASE IN THE U.S. TARIFF FROM 3% TO 32.5%

As seen in Figure 3, the described adjustment implies very diverse developments in the consumption of different types of workers. Skilled workers in the unskilled-intensive sector gain in the short run due to the increased importance of sector U but lose in the long run due to the lower demand for skills. In contrast, unskilled workers in the skill-intensive sector lose a bit in the short run due to the decreased importance of their sector but gain in the long run due to the increased demand for unskilled workers. Skilled workers in skill-intensive sector are worst off, losing both in the long run and even more in the short run. The biggest winners of the increase in tariff are the unskilled workers in the unskilled-intensive sector, gaining both in the short run and in the long run with the short-run gains even overshooting the long-run equilibrium.

*4.2. Worker-Specific Preferences for Tariffs.* Naturally, these diverse developments imply very different preferences for trade policy. This is illustrated in the left-hand panel of Figure 4 that shows the tariff that maximizes the present discounted value of consumption of specific workers up to period  $x$ , where  $x$  is measured on the horizontal axis.<sup>24</sup> Skilled workers in the skill-intensive sector always prefer zero-tariffs, whereas skilled workers in the unskilled-intensive sector might vote for tariffs as high as 30% if they have a short-run perspective, but also prefer zero tariffs when having a long-run perspective. Although unskilled workers tend to prefer higher tariffs, it is not generally true that they always want higher tariffs than skilled workers. If their horizon is sufficiently short run, unskilled workers in the skill-intensive sector actually prefer lower tariffs than skilled workers in the unskilled-intensive sector. As expected, unskilled workers in the unskilled-intensive sector

<sup>24</sup> For this exercise, aggregate consumption in Equation (26) is replaced by the consumption of a specific worker.

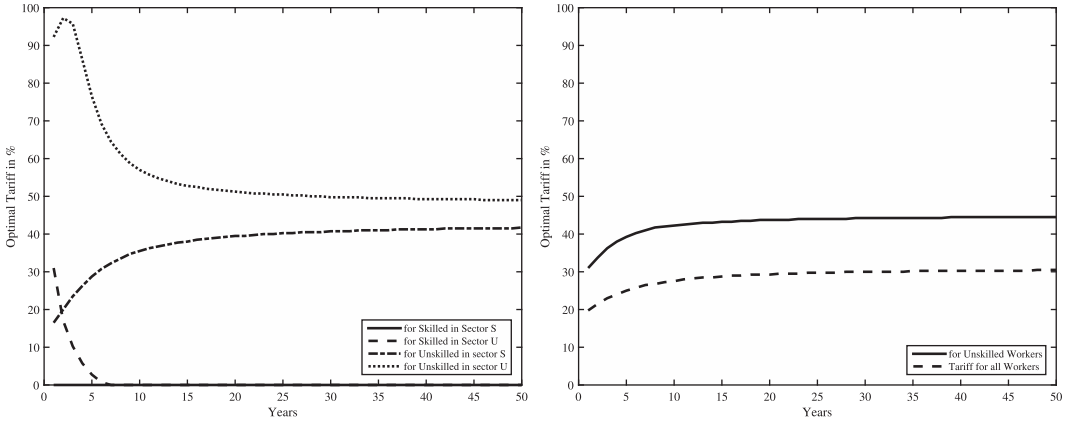


FIGURE 4

OPTIMAL TARIFF IN DEPENDENCE OF THE WORKER'S PLANNING HORIZON

are the most in favor of protectionism, especially (but not only) when they have a short-run perspective.<sup>25</sup>

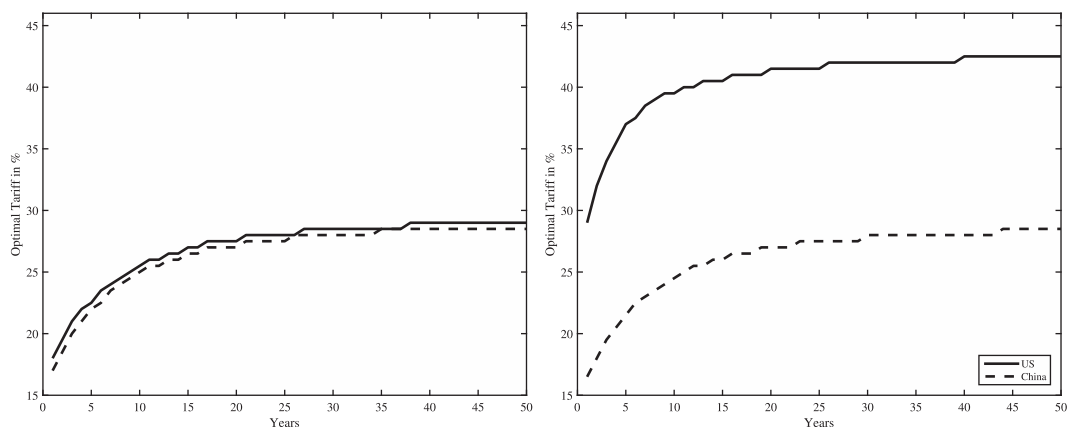
Thus, Figure 4 paints a rich picture of trade protection preferences and powerfully demonstrates the important role of the dynamic adjustment in response to trade shocks and the time-perspective of policymakers and voters. It is neither solely the skill-class of a worker nor the skill-intensity of the sector in which the worker is employed that determines her preferences for trade protection. It is rather a combination of both aspects that matters with the time perspective importantly affecting the relative weight of both.

The potential preference of voters with a short-run perspective for higher tariffs is in stark contrast with the analysis in Larch and Lechthaler (2013) and Lechthaler (2017) where a shorter perspective robustly implies a preference for lower tariffs. Given these previous results, it is a bit of a puzzle that politicians nevertheless often promote protectionism on their campaigns and that indeed many voters tend to favor protectionism. Figures 3 and 4 provide an explanation for this result showing that specific worker groups benefit more in the very short run and might thus support protectionism even more strongly if they have a shorter time perspective.

Finally, this section presents an alternative approach to determine the political economy equilibrium: the tariff chosen by a coalition of unskilled workers. Our model features four different types of workers, depending on the skill class of the workers and the sector where they are employed. According to our calibration none of these groups is in absolute majority, but, in line with the data, unskilled workers have a majority over skilled workers. Since unskilled workers are affected similarly by tariffs, at least in the medium and long run, it is natural for these workers to form a coalition.

The solid line in the right-hand panel of Figure 4 illustrates the tariff chosen by such a coalition (along with the tariff of the benchmark case where aggregate consumption is maximized). As discussed above, an import-tariff benefits unskilled workers since it increases the relative demand for the unskilled-intensive sector and thereby the relative wage and consumption of unskilled workers. Therefore, such a coalition would choose a higher tariff than the tariff that maximizes overall consumption irrespective of the time perspective.

<sup>25</sup> These results are broadly in line with the empirical evidence that finds that unskilled workers and workers in comparative disadvantage sectors tend to favor protectionism, see, for example, Beaulieu (2002), Mayda and Rodrik (2005), Sanz and Martinez i Coma (2008), and Scheve and Slaughter (2001).



NOTES: Left panel: United States maximizes consumption of all workers; right panel: United States maximizes consumption of unskilled workers.

FIGURE 5

NASH-EQUILIBRIUM TARIFFS IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON

### 5. NASH-EQUILIBRIUM ECONOMY-WIDE TARIFFS

So far we have analyzed unilaterally optimal tariffs, that is, we have assumed that the United States can set its tariffs as it likes while Chinese tariffs stay at their old level. As the trade dispute between the United States and China, which started in early 2018, has shown, China would not just accept the increase in U.S. tariffs, but would rather retaliate by increasing tariffs on its own. In fact, the same argument as for raising U.S. tariffs (the terms of trade externality) applies, of course, also for the Chinese tariff: By increasing its tariff, China can raise its own consumption (given a certain U.S. tariff).

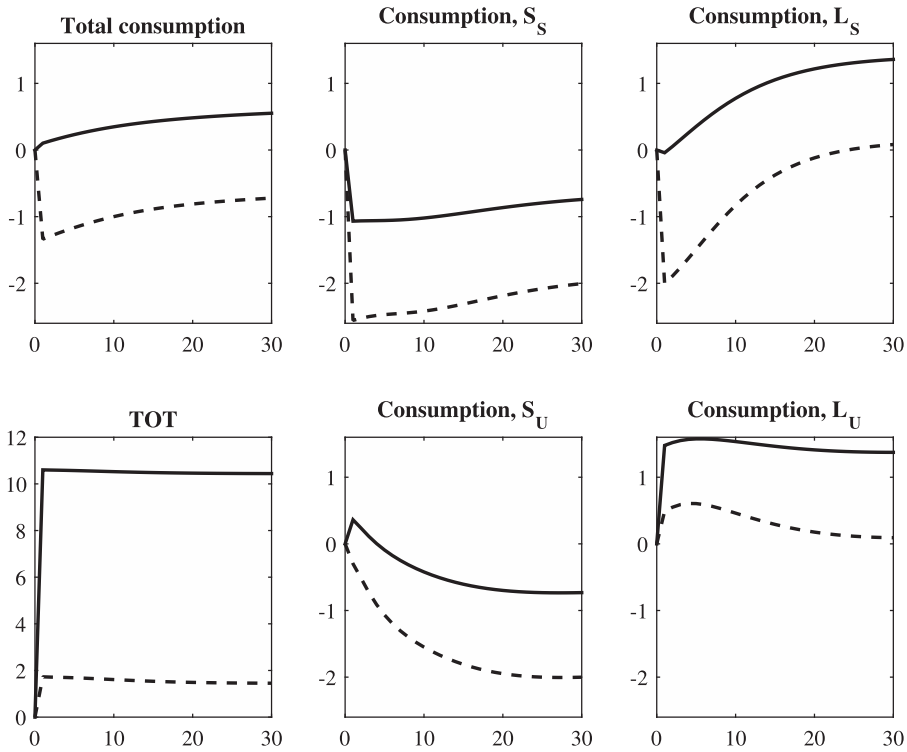
Therefore, in this section we consider what Ossa (2014) calls a trade war, a noncooperative game between two countries. The equilibrium of this game is a Nash-equilibrium that is defined as the combination of U.S. tariff and Chinese tariff from which neither country has an incentive to deviate.

To determine the Nash-equilibrium, we compute the best-response function for both countries, that is, for a wide range of tariffs for the United States, we calculate the optimal tariff of China and vice versa. The intersection of both best-response functions is the Nash-equilibrium. No country has an incentive to deviate from this equilibrium because consumption is already maximized, given the tariff of the other country.

Figure 5 shows the resulting Nash-equilibrium tariff for both countries, for different planning horizons of the policymaker and under two different assumptions of whose consumption is maximized. In the left-hand panel, policymakers of both countries maximize aggregate consumption, whereas for the right-hand panel it is assumed that in the U.S. policy is determined by a coalition of unskilled workers (whereas Chinese policy still maximizes China's aggregate consumption).

The same basic pattern applies as before. Concentrating on a short time horizon implies lower tariffs and concentrating on unskilled workers implies higher tariffs.<sup>26</sup> When both country's policymakers maximize their respective country's aggregate consumption, China sets a slightly lower tariff, because it gains more from international trade. When policymakers in the United States maximize the consumption of unskilled workers only, then the two countries charge very different tariffs with the gap lying around 15 percentage points.

<sup>26</sup> Note that the optimal tariff for policymakers with a long time horizon is slightly below 30%. This is very close to the results in Nicita et al. (2018) who find that in a trade war tariffs would increase on average by 32% (and for U.S. exporters by 27%).



NOTES: Quarters on the horizontal axis, percent deviations from the old steady state on the vertical axis. Solid line: benchmark of unilateral tariff; dashed line: trade war.

FIGURE 6

EFFECTS OF A TRADE WAR; UNITED STATES RAISES TARIFF TO 29%, CHINA RAISES TARIFF TO 28.5%.

Probably more interesting than the level of optimal tariffs in a potential trade war is the adjustment of the U.S. economy in case such a trade war occurs. The dynamic adjustment of different measures of consumption and the terms of trade is illustrated in Figure 6. The terms of trade of the United States still increase but much less than in our benchmark case, due to the increase in the Chinese tariff. Aggregate consumption no longer increases but rather decreases both in the long run and even more in the short run. These results are in line with recent empirical evidence in Amiti et al. (2019) and Fajgelbaum et al. (2019) who show that the recent U.S. trade dispute led to a quick and significant drop in imports and aggregate real income but to no significant change in the U.S. terms of trade.

Remember that unilaterally raising tariffs implies two counteracting effects. On the one hand, the tariff reduces the efficiency in production because international trade is reduced and with it specialization and concentration of production in more productive firms. On the other hand, a tariff redistributes income from the affected country to the imposing country. However, if both countries raise their tariff, the first effect is still in place while the second effect is largely reduced (as illustrated by the much weaker increase in the U.S. TOT), or even negative in the case of China. This explains why in this scenario aggregate U.S. consumption declines (along with China’s consumption).

So from an aggregate perspective, the trade war scenario resembles a prisoner’s dilemma. Given the strategy of the other country, each country acts in its own best interest, but from a joint perspective this leads to an inferior equilibrium. Both countries would be better off if they could coordinate on an equilibrium with lower tariffs.

Thus Figure 6 reconfirms that protectionism is harmful. However, the figure adds a nuance to that picture. As before the different groups of workers are affected very differently by the

increase in tariffs, and while most workers are negatively affected, the unskilled workers in the import-competing sector actually gain even in this scenario. In the new steady state, their consumption is basically the same as in the old steady state but during the transition period (about eight years) they can enjoy temporarily enhanced consumption. Thus even in this trade war scenario some workers are gaining and might lend political support to protectionist ideas.

## 6. OPTIMAL SECTOR-SPECIFIC TARIFFS

So far it was assumed that the same tariff is charged in both sectors. We now relax this assumption to allow for the setting of different tariffs in both sectors. In this setup, we again look at unilaterally optimal tariffs, that is, we go back to our assumption that only the United States is allowed to change its tariff, while China keeps its tariff at the empirically observed 6%. It is important to consider sector-specific tariff increases because our previous analysis showed that workers employed in different sectors have very different preferences about tariffs, especially if they have a short-run perspective.

In our analysis of sector-specific tariffs, we again compare the tariffs chosen under the assumption that policymakers only care about the infinite future, the new steady state, with the outcome when policymakers care about short-run effects, too. Based on the steady state analysis, the unilaterally optimal tariffs are 30.5% for the unskilled-intensive sector and 34.3% for the skill-intensive sector. Thus the optimal tariff for the skill-intensive sector is substantially larger than the optimal tariff for the unskilled-intensive sector. The reason is that the imports of the skill-intensive good are quantitatively less important than the imports of the unskilled-intensive sector. Consequently, the distortions created by a tariff on the skill-intensive good are also quantitatively less important and a higher tariff can be afforded.

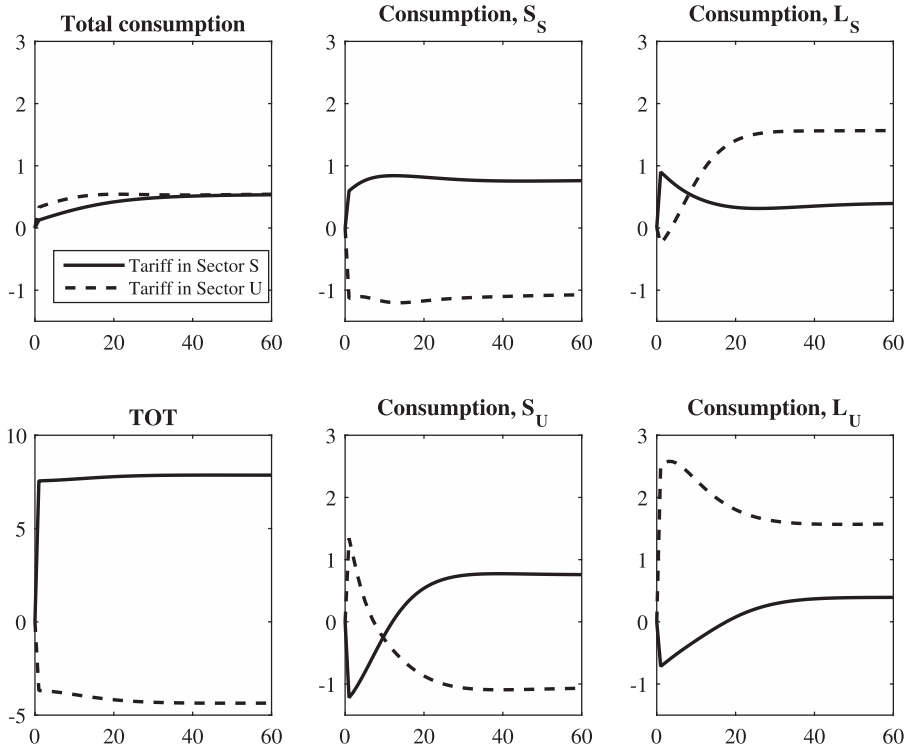
Figure 7 shows the dynamic adjustment to the optimal equilibrium of the static analysis under the assumption that in the initial steady state one sector-tariff is already at this optimal level while the other tariff is still at the calibrated level of 3%. Thus the solid line shows the adjustment from an equilibrium with  $t_S = 3\%$  and  $t_U = 30.5\%$  to an equilibrium with  $t_S = 34.3\%$  and  $t_U = 30.5\%$  while the dashed line shows the adjustment from an equilibrium with  $t_S = 34.3\%$  and  $t_U = 3\%$  to an equilibrium with  $t_S = 34.3\%$  and  $t_U = 30.5\%$ . We are showing this specific experiment because it is useful in demonstrating the dynamic effects of changing sector-specific tariffs although, of course, the policymaker changes both tariffs at the same time. Since in the new steady state both tariffs will be at their optimal level, it is more useful to assume that one tariff is already at this level while the other tariff adjusts to this level.

Figure 8 shows the optimal tariff of the dynamic analysis for different time horizons of the policymaker. The left panel represents a policymaker who maximizes welfare of all workers, the right panel a policymaker who maximizes welfare of unskilled workers. Looking at the tariff chosen by a policymaker with a very long time horizon, we see again the pattern that the optimal tariffs of the dynamic analysis are lower than the optimal tariffs of the static analysis. As in the previous analysis, consumption increases only sluggishly following an increase in tariffs (see “total consumption” in Figure 7). For this reason, a policymaker that cares about the adjustment process chooses a lower tariff than a policymaker that only cares about the new steady state.

Figure 7 also reveals that consumption increases much more slowly in response to an increase in  $t_S$  compared to an increase in  $t_U$ . This explains the steeper profile for  $t_S$  in Figure 8, so that the tariff of the skill-intensive sector depends more strongly on the time horizon of the policymaker. For policymakers with a very short time horizon, it is even possible that a higher tariff is chosen for the unskilled-intensive sector instead of the skill-intensive sector.

Although the effects of both tariffs on aggregate consumption are relatively similar, Figure 7 also shows that their effects on worker-specific outcomes are very different. Both sector-specific tariffs imply a shift in production toward the sector where the tariff is raised because imports in that sector become directly more expensive so that consumption has to rely more strongly on domestic production. In the long run, this favors the production factors that are

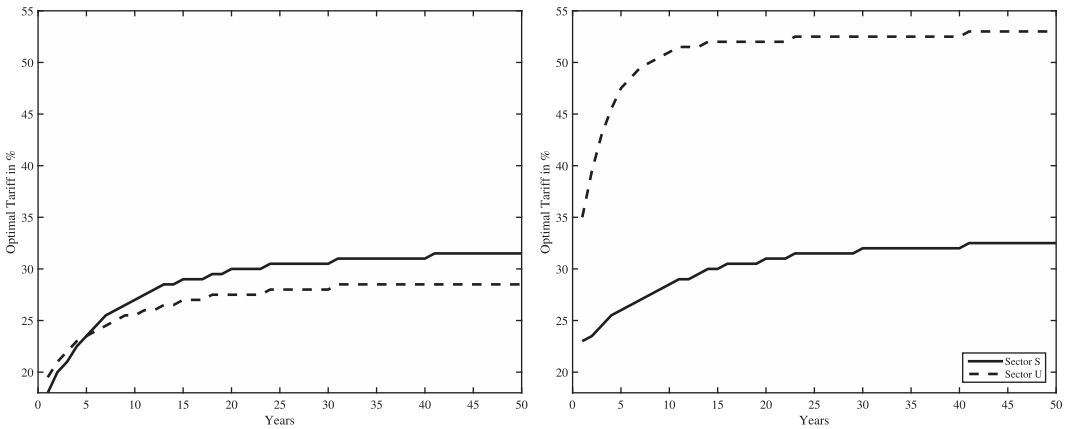




NOTES: Quarters on the horizontal axis, percent deviations from the old steady state on the vertical axis.

FIGURE 7

EFFECTS OF AN INCREASE IN SECTOR-SPECIFIC U.S. TARIFFS FROM 3% TO THE OPTIMUM OF THE STATIC ANALYSIS

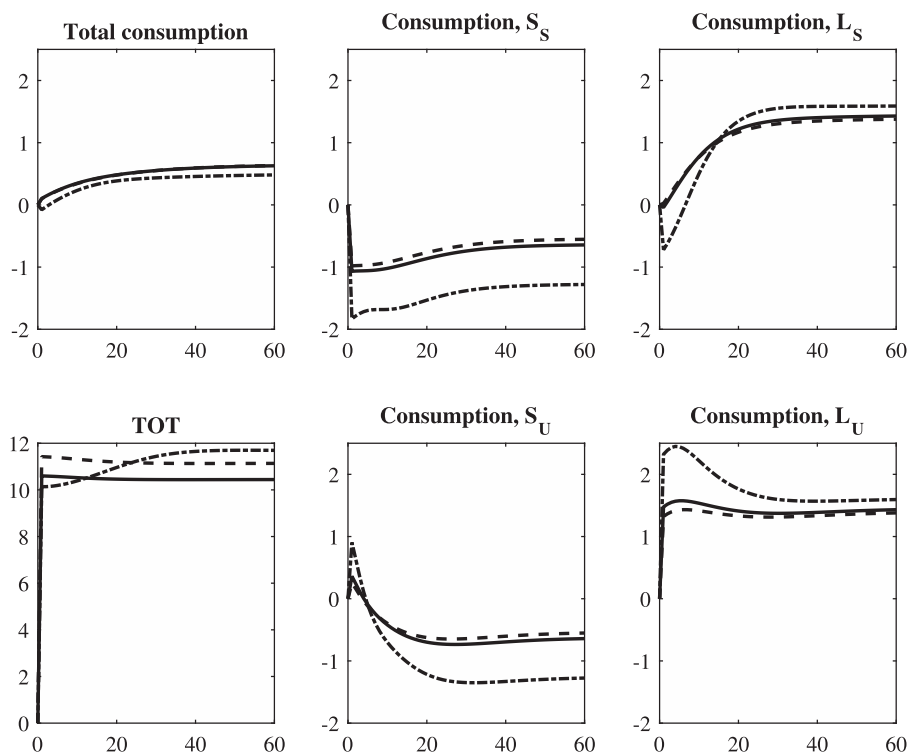


NOTES: Left panel: tariff maximizes consumption of all workers; right panel: tariff maximizes consumption of unskilled workers.

FIGURE 8

OPTIMAL SECTOR-SPECIFIC TARIFFS IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON

used more intensively in the sector where the tariff is increased. In the short run, this favors the production factors currently employed in that sector. This explains why unskilled workers prefer substantially higher tariffs in the import-competing sector, especially when they have a long time perspective because their gains are larger once most of the adjustment to the new equilibrium is accomplished.



NOTES: Quarters on the horizontal axis, percent deviations from the old steady state on the vertical axis. Solid line: benchmark of unilateral tariff; dashed line: sector-specific tariff; dotted-dashed line: sector-specific tariff for unskilled workers.

FIGURE 9

EFFECTS OF AN INCREASE IN SECTOR-SPECIFIC U.S. TARIFFS FROM 3% TO THE LONG-RUN OPTIMUM OF THE DYNAMIC ANALYSIS

Finally, Figure 9 shows the dynamic adjustment of selected variables from the old steady state with tariffs of 3% to the new steady state of optimal sector-specific tariffs under the assumption that the policymakers have a very long time horizon (50 years or more) and that the policymakers either maximize the welfare of all workers (dashed line) or the welfare of unskilled workers (dotted-dashed line).<sup>27</sup> The adjustment processes of these scenarios are compared to the adjustment process of our benchmark case in which the tariff of both sectors is increased by the same amount.

Figure 9 shows that the adjustment of aggregate consumption is virtually the same in our benchmark case and the case where the policymakers set different tariffs in both sectors but maximize consumption of all workers. Nevertheless, there are some minor differences concerning worker-specific outcomes. Skilled workers lose a bit less if tariffs are sector-specific while unskilled workers gain a bit less.

Naturally, the effects are stronger when the policymaker maximizes the welfare only of unskilled workers, but the picture is also more diverse. Again we see the pattern that unskilled workers in the skill-intensive sector lose in the short run while they gain in the long run. Thus a policy that maximizes the welfare of all unskilled workers might even hurt some unskilled workers in the short run. Aggregate consumption is generally lower in this scenario and even drops in the very short run. We can conclude that sector-specific tariffs are especially bad for skilled workers if policymakers care more about unskilled workers.

<sup>27</sup> The main difference to Figure 7 is that here both tariffs are increased at the same time, while tariffs were increased separately in Figure 7.

## 7. CONCLUSION

This article analyzes the distributional consequences and the optimal setting of import tariffs in a dynamic model with two countries, two sectors, two factors of production, endogenous firm entry, and firm heterogeneity. This setup allows for rich and diverse distributional effects of import tariffs while at the same building on a tractable and intuitive model. It also allows for the consideration of adjustment dynamics and potential short-sightedness of worker-voters and policymakers.

We find that the distributional effects of tariffs depend both on the skill class of a worker and on the sector where she is employed but the weight of both factors depends importantly on the time perspective of the worker/policymaker. The shorter the time perspective, the more important is the sector. With a very long-run time perspective, the sector becomes more or less irrelevant.

Due to these diverse and time-dependent distributional effects, the preferences for import tariffs can differ substantially across workers and time. For example, although skilled workers tend to lose from tariffs in the long run, if they are employed in the unskilled-intensive sector and have a sufficiently short time perspective, they might still vote in favor of higher tariffs. Conversely, even though unskilled workers gain from tariffs in the long run, if they are employed in the skill-intensive sector and have a sufficiently short time perspective, they might vote for low tariffs.

The workers gaining most from raising tariffs are unskilled workers in the unskilled-intensive sector and thus they are the ones most in favor of raising tariffs, irrespective of their time perspective. Interestingly, we find that these workers even gain in a trade war in which not only the domestic country raises the tariff but in which the trading partner country retaliates by also raising the tariff. In this scenario, aggregate consumption of both countries falls. The same is true for the consumption of skilled workers and for the consumption of unskilled workers in the skill-intensive sector, but not for the consumption of unskilled workers in the unskilled-intensive sector. Thus these workers might be willing to support raising tariffs even in the face of threats of retaliation.

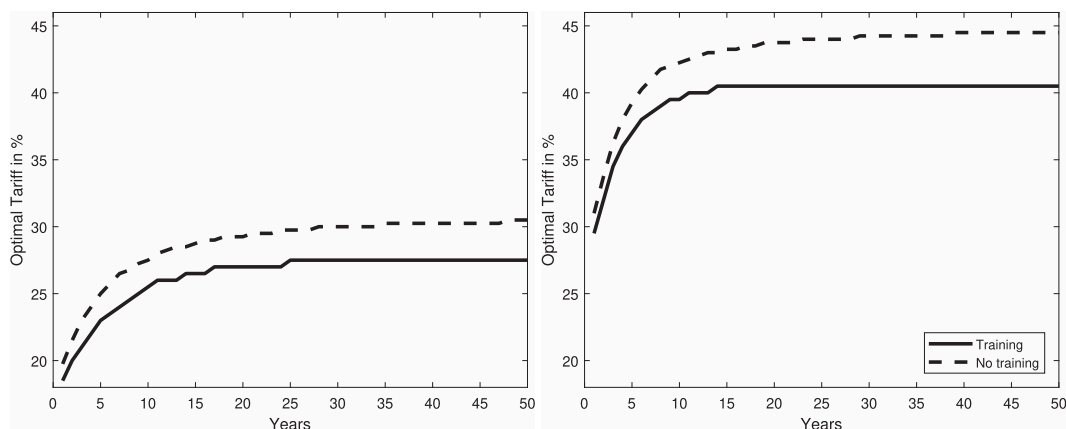
## APPENDIX A: THE ROLE OF WORKER MOBILITY

A.1. *Endogenous Skill Formation.* So far it was assumed that the number of skilled workers is exogenously given. This is the standard assumption in the trade literature and allows for a simpler model. However, we have seen that an increase in the tariff reduces the demand for skilled workers and thus it is to be expected that workers would be investing less in their skills.

To take account of this, we extend the model to introduce endogenous skill formation, by allowing newly entering workers to train to become skilled workers. To model this, we assume that newly entering workers need to pay a training cost  $\varepsilon^T$  that is drawn from the random distribution  $\Gamma(\varepsilon^T)$  with support on  $[\varepsilon_{\min}^T, \infty)$ . An entering worker decides to train if the value of being skilled is high enough to justify the training cost, that is, if

$$(A.1) \quad V_t^s - \varepsilon_t^T > V_t^l,$$

where  $V^s$  is the expected present discounted value of consumption for a skilled worker and  $V^u$  is the same value for an unskilled worker. Equation (A.1) defines a threshold  $\bar{\varepsilon}_t^T$  for which



NOTES: Left panel: tariff maximizes consumption of all workers; right panel: tariff maximizes consumption of unskilled workers.

FIGURE A1

OPTIMAL TARIFF IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON WITH ENDOGENOUS TRAINING

a worker is indifferent between training and not training and the probability of training then is

$$(A.2) \quad \eta_t^T = \Gamma \left[ \max(\bar{\varepsilon}_t^T, \varepsilon_{\min}^T) \right].$$

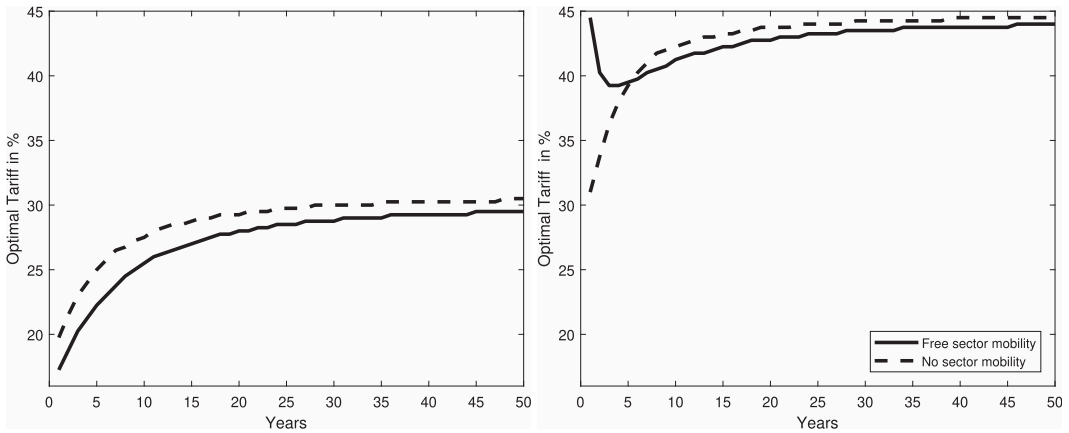
To simulate the model, we assume that the training cost follows an exponential distribution with a parameter  $scaleT$  for H and  $scaleT^*$  for F.<sup>28</sup> The parameters are set so that the pre-liberalization steady state training probability in H and F match the shares of skilled workers in the labor force of each country, such that  $\eta_T = 0.222$  for H and  $\eta_T = 0.0955$  for F. This ensures that the pre-liberalization steady state is the same in the model with and without training.

The implications of endogenous skill formation for optimal tariffs are illustrated in Figure A1 that compares the case of endogenous skill formation to our benchmark case with an exogenously given number of skilled and unskilled workers. The left panel shows the case where the tariff maximizes the present discounted value of the consumption of all workers, the right panel the tariff that maximizes the consumption of unskilled workers.

In both cases, the optimal tariff is lower under endogenous skill formation. As explained above, raising tariffs lowers the demand for skills with the implication that fewer workers find it worthwhile to invest in their skills to become a skilled worker. Thus raising tariffs is more costly under endogenous skill formation and the optimal tariff is lower. Note that in this scenario raising tariffs is also less beneficial for unskilled workers because this leads to an increase in the supply of unskilled workers putting downward pressure on their wages. They still prefer higher tariffs than skilled workers but to a lesser extent than in our benchmark.

*A.2. Sector Mobility.* In line with recent empirical evidence, we have assumed that the mobility of workers across sectors is very limited. In this section, we take the opposite case and assume that workers can freely move across sectors at any time. This implies that the wage differential across sectors completely vanishes. If the wage in one sector was slightly higher, workers would move to that sector until the wage differential has vanished. The

<sup>28</sup> We choose the exponential distribution because it has only one parameter, the scale parameter, and its minimum is always zero.



NOTES: Left panel: tariff maximizes consumption of all workers; right panel: tariff maximizes consumption of unskilled workers.

FIGURE A2

OPTIMAL TARIFF IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON WITH FREE SECTOR MOBILITY

number of workers in each sector is then endogenously determined by the condition that the wage is the same in both sectors.

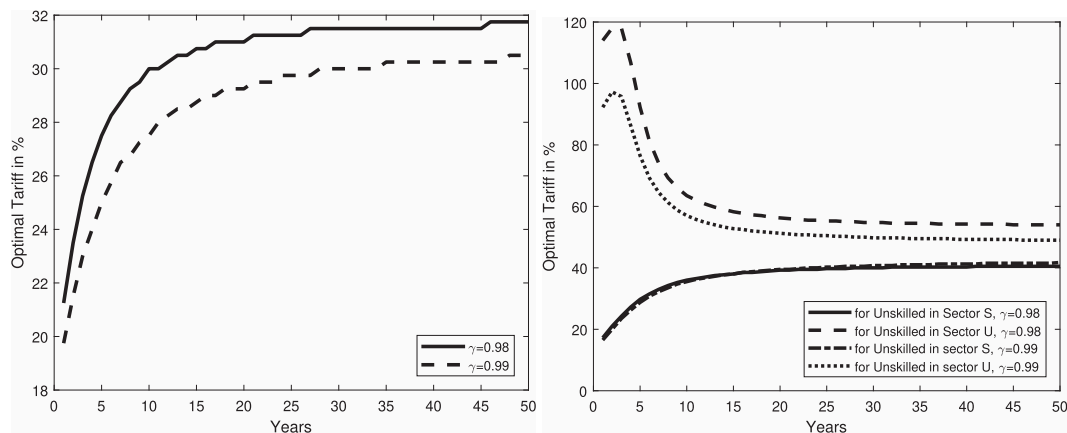
Given a specific tariff, the steady states of both versions of the model are basically the same. So according to a static analysis, the optimal tariff would be the same in both cases. However, as Figure A2 shows, the dynamic analysis yields quite different results, especially but not only in the short run.

The tariff that maximizes aggregate consumption is always lower when workers are mobile across sectors than when they are immobile. The reason is that under full mobility of workers firm investment increases more strongly and more quickly after an increase in tariffs. In the version of the model with limited mobility, firm investment during the transition is subdued due to the “wrong” allocation of workers. This is no longer the case under full mobility, implying more firm investment and thus lower aggregate consumption during the transition. Since aggregate consumption is lower, the tariff that maximizes the present discounted value of consumption of all workers is smaller.

For the unskilled workers, there is an additional effect. As explained above, an increase in the tariff raises the relative demand for unskilled workers, but workers need to reallocate across sectors for this effect to become important. Under full mobility of workers, this reallocation happens much faster and thus unskilled workers gain much more quickly. Due to the slow adjustment of firms, the consumption of unskilled workers is actually overshooting their long-run equilibrium. This explains why the tariff that maximizes the consumption of unskilled workers is especially high with a short-run perspective and might even be higher than in the benchmark with immobile workers.

## APPENDIX B: ROBUSTNESS

In this section, we explore the sensitivity of optimal tariffs with respect to a variety of aspects in our model such as household preference parameters, parameters responsible for access to export markets, and parameters that determine sector asymmetry. We show that the qualitative implications of our model are robust with respect to all of these parameter changes. In all scenarios discussed in this section, we illustrate unilaterally optimal economy-wide tariffs, assuming that the tariff in the United States is set optimally while the tariff in China is held constant.



NOTES: Left panel: tariff maximizes consumption of all workers; right panel: tariff maximizes consumption of unskilled workers.

FIGURE B1

OPTIMAL TARIFF IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON WITH LOWER DISCOUNT FACTOR

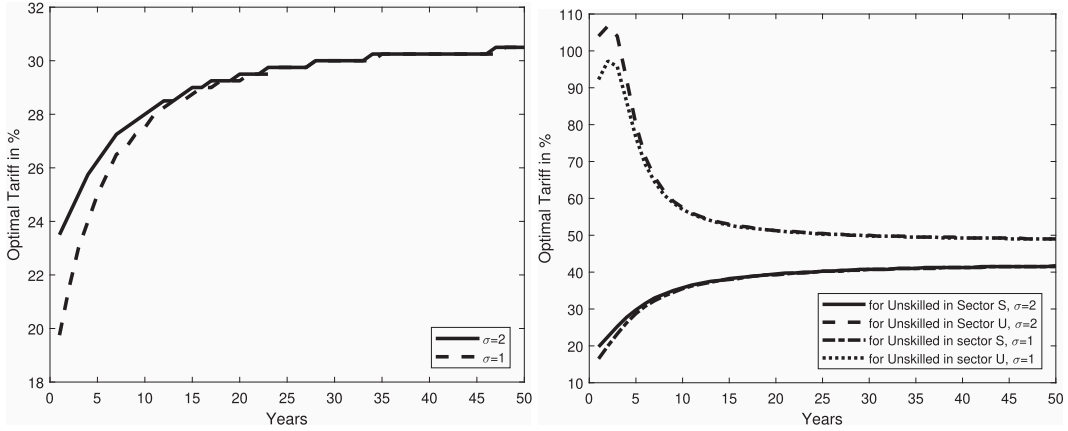
**B.1. Sensitivity to Household Parameters.** Since dynamic aspects play a crucial role in our analysis, it is important to understand how optimal tariffs are affected by parameters that dictate attitudes toward current versus future consumption. First, we explore how optimal tariffs are affected by the subjective discount factor of the household and then by the intertemporal elasticity of substitution of the household.

**B.1.1. Discount factor.** Figure B1 illustrates optimal tariffs under our benchmark discount factor  $\gamma = 0.99$  and under a lower discount factor  $\gamma = 0.98$ . The left panel shows the tariffs that maximize the present discounted value of the consumption of all workers while the right panel shows the tariffs that maximize the present discounted value of the consumption of unskilled workers in sector S and sector U, respectively.<sup>29</sup>

The right panel shows the optimal tariff for specific worker groups. Most notably the discount factor has a substantial impact on the optimal tariff from the perspective of unskilled workers in the unskilled-intensive sector, but basically no effect for the optimal tariff from the perspective of unskilled workers in the skill-intensive sector. Remember that both groups experience very different time profiles in their consumption: the consumption of workers in the unskilled-intensive sector is higher in the short run than in the long run, while the opposite is true for workers in the skill-intensive sector (the same is true for skilled workers, compare Figure 3). Lowering the discount factor makes consumers more impatient and increases the weight of consumption in the near future. Since higher tariffs stimulate the income and consumption of workers in the unskilled-intensive sector in the short run, a lower discount factor makes higher tariffs even more attractive to these workers. In contrast, workers in the skill-intensive sector do not gain much in the short run and therefore a lower discount factor has a much smaller effect on the optimal tariff from their perspective.

The left panel shows the optimal tariff from the perspective of all workers. This figure is harder to interpret because the change in discount factors also changes the steady state. In the economy with lower discount factors, the initial steady state (i.e., prior to the increase in the tariff) features more specialization and thus more trade. A higher volume of trade implies that more can be gained from higher tariffs, and therefore the optimal tariff is higher in the economy with lower discount factors. Importantly, however, while the optimal level of tariffs

<sup>29</sup> To not overload the illustrations, we restrict ourselves to those measures that are in our view most informative. Further illustrations are available upon request.



NOTES: Left panel: tariff maximizes the utility consumption of all workers; right panel: tariff maximizes the utility of consumption of unskilled workers.

FIGURE B2

OPTIMAL TARIFF IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON WITH LOWER INTERTEMPORAL ELASTICITY OF SUBSTITUTION

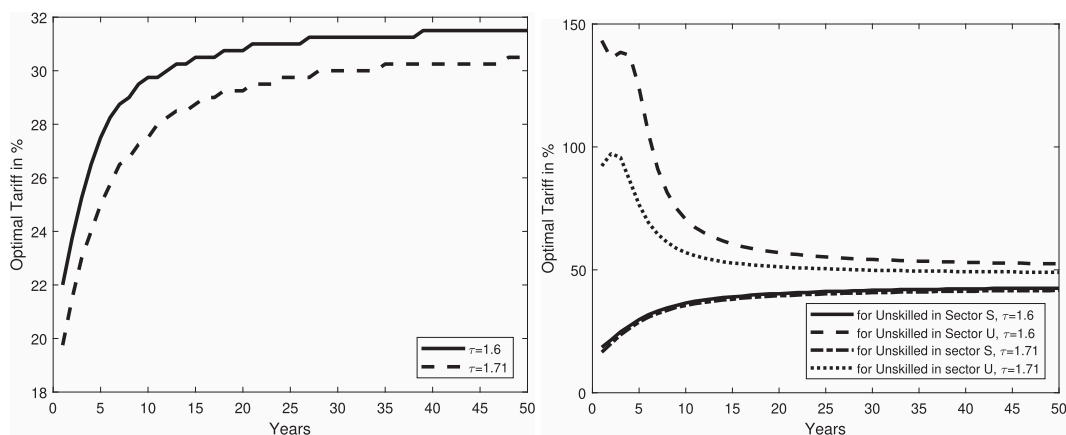
is affected by the level of the discount factor, all the qualitative predictions of our model remain intact.

**B.1.2. Intertemporal elasticity of substitution.** Figure B2 compares the optimal tariffs under our benchmark case of log-utility where the intertemporal elasticity of substitution is  $\frac{1}{\sigma} = 1$  and under an alternative case where the intertemporal elasticity of substitution is lower  $\frac{1}{\sigma} = 0.5$ .<sup>30</sup> The left panel shows the tariff maximizing the present discounted value of the utility of all workers while the right panel shows tariffs maximizing the present discounted value of the utility of unskilled workers employed in sectors S and U.<sup>31</sup> The first important observation is that for planning horizons of 10 years or longer the optimal tariffs do not depend on the size of the intertemporal elasticity of substitution. This is because the intertemporal elasticity of substitution relates to the concavity of the utility function and dictates how consumption adjusts over time. A higher  $\sigma$  implies that households are less willing to substitute current with future consumption and they prefer a more flat consumption profile over time (the higher the  $\sigma$  is, the more they prefer to smooth their consumption). Consumption converges to its new steady state about 10 years after the tariff is raised. Consumption is flat after that and thus  $\sigma$  no longer matters. That is why there is no difference in the preferred optimal tariff when  $\sigma$  is higher.

In the short run though decision makers do prefer higher tariffs. This is because the discount factor  $(\gamma^{s-t}(1-\delta)^{s-t}(\frac{C_{t+s}}{C_t})^{-\sigma})$  of the mutual fund responsible for firm investment is lower when  $\sigma$  is higher, which implies that the gain from firm investment is smaller. As a consequence, firm investment increases more slowly while consumption increases more strongly after the tariff is raised. As a result, optimal tariffs are higher when  $\sigma$  is higher in the short run.

<sup>30</sup> For this experiment, we use a standard utility function with constant intertemporal elasticity of substitution:  $u(C) = C^{1-\sigma}/(1-\sigma)$ .

<sup>31</sup> Note that since we are here discussing the sensitivity of our results to a change in the utility function, the optimal tariffs illustrated in Figure B2 are the tariffs maximizing the present discounted value of utility instead of the present discounted value of consumption.



NOTES: Left panel: tariff maximizes consumption of all workers; right panel: tariff maximizes consumption of unskilled workers.

FIGURE B3

OPTIMAL TARIFF IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON WITH LOWER TRADE COSTS

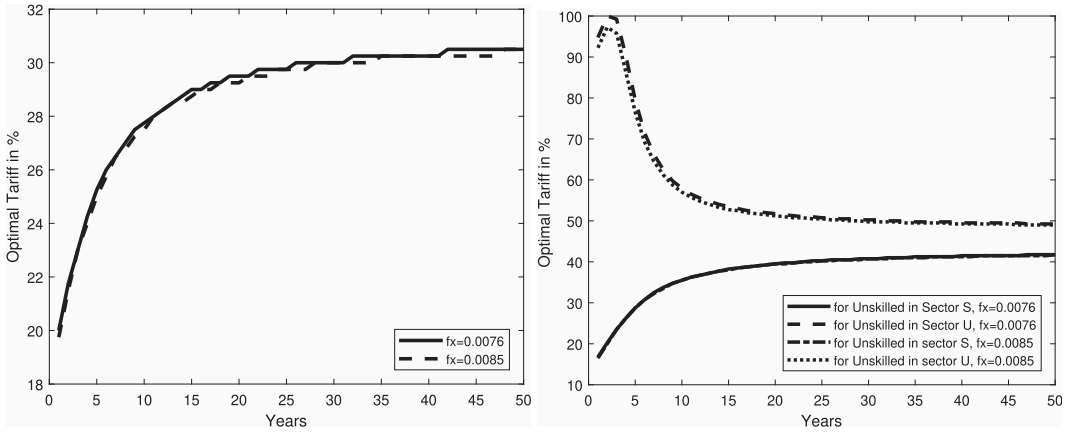
**B.2. Access to Export Markets.** Next, we examine how ease to access export markets affects preferred optimal tariffs. First, we focus on the effect of trade costs and then we examine the role of fixed export costs.

**B.2.1. Trade costs.** Figure B3 illustrates how optimal tariffs change when the iceberg trade costs are lowered from  $\tau = 1.71$  to  $\tau = 1.6$ , by 7.4%, with the left panel showing the tariffs that maximize consumption of all workers and the right panel showing the tariffs that maximize the consumption of unskilled workers employed in sector S and sector U, respectively. Lower trade costs lead decision makers to prefer higher tariffs. This is because lower trade costs make the potential gains from raising the tariffs much bigger. The “terms of trade externality” that raises consumption after a tariff increase is magnified as imports are a much greater share in demand and the amount of tariff income to be redistributed from foreign producers to domestic consumers is also greater. Unskilled workers in the unskilled-intensive sector prefer especially high tariffs in the short run when trade costs are lower because the import share in that sector is especially high and unskilled workers have the most to gain from higher tariffs.<sup>32</sup>

**B.2.2. Fixed export costs.** Figure B4 shows how optimal tariffs change when fixed export costs are lowered by 10%, from  $f_x = 0.0085$  to  $f_x = 0.0076$ . Similarly to the case of lower trade costs, lower fixed costs of exporting make access to foreign markets easier and increase the share of imports in domestic demand. This magnifies the “terms of trade externality” after raising tariffs and leads decision makers to prefer higher tariffs. Note, however, that the effect of lower fixed export costs on the optimal tariff is very small, because the effect on the import share is also small. Trade costs have a much larger effect on the preferred optimal tariff because they have a bigger impact on the import share.

<sup>32</sup> Note that after the initial increase the optimal tariff for unskilled workers in the unskilled-intensive sector goes down and then up again. The possibility of this up-and-down pattern exists because raising the tariff leads to hump-shaped responses in consumption (with different slopes as well) for the unskilled in sector U. This can imply that for low and high horizons a higher tariff is better and for intermediate horizons a lower tariff is better. We see the same pattern arise when the skill intensity parameter is changed.

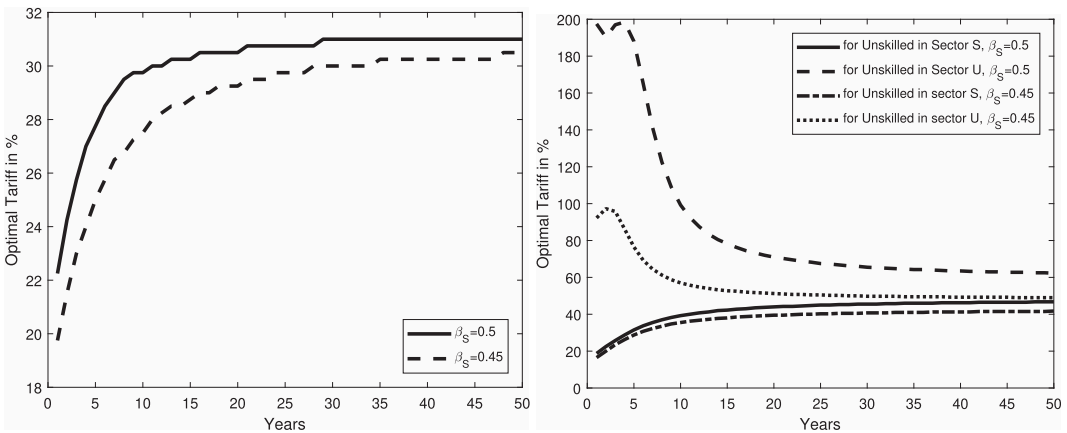




NOTES: Left panel: tariff maximizes consumption of all workers; right panel: tariff maximizes consumption of unskilled workers.

FIGURE B4

OPTIMAL TARIFF IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON WITH LOWER FIXED EXPORT COSTS



NOTES: Left panel: tariff maximizes consumption of all workers; right panel: tariff maximizes consumption of unskilled workers.

FIGURE B5

OPTIMAL TARIFF IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON WITH HIGHER SKILL INTENSITY

**B.3. Sensitivity to Asymmetry Parameters.** Finally, we explore the sensitivity of our results with respect to the degree of specialization. Recall that specialization is especially important for preferred optimal tariffs across different groups of workers.

**B.3.1. Skill intensity.** Figure B5 illustrates the impact of a higher skill-intensity parameter in sector S on optimal tariffs. Note that increasing skill-intensity in the skill-intensive sector from our benchmark  $\beta_S = 0.45$  to  $\beta_S = 0.5$  increases the asymmetry between both sectors (skill intensity in the unskilled-intensive sector is  $\beta_U = 0.32$ ). More asymmetry between sectors makes specialization more important and thus raises inequality. Unskilled workers are relatively worse off than skilled workers and therefore gain more from raising tariffs. Note that sector asymmetry is especially important in the short run as short-run changes in income are mainly governed by the sector of employment. Under enhanced specialization, an increase in tariffs leads to a bigger increase in the relative demand for labor in the unskilled-intensive sector and puts more upward pressure on the relative wages of workers in the unskilled-

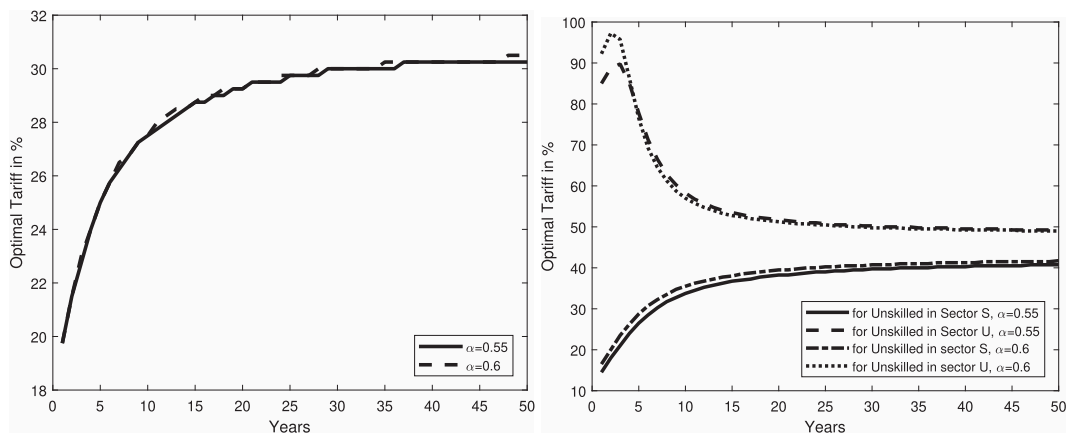


FIGURE B6

OPTIMAL TARIFF IN DEPENDENCE OF THE POLICYMAKER'S PLANNING HORIZON WITH LOWER SECTOR SHARE. LEFT PANEL: TARIFF MAXIMIZES CONSUMPTION OF ALL WORKERS; RIGHT PANEL: TARIFF MAXIMIZES CONSUMPTION OF UNSKILLED WORKERS.

intensive sector. Thus unskilled workers in that sector prefer high tariffs, even as high as 200% in the short run. That is why enhanced specialization also magnifies the difference in tariff preferences across different groups of workers, especially in the short run.

**B.3.2. Sector share in consumption basket.** Figure B6 illustrates the effect of a decline in the share of the skill-intensive sector in the household consumption basket on optimal tariffs. A decline in  $\alpha$  from 0.6 to 0.55 makes the skill-intensive sector less important and the unskilled-intensive sector more important in total demand. In contrast to the previous experiment, this effectively reduces the asymmetry and increases the relative demand for labor in sector U in the short run and for unskilled labor in the long run. As a result, raising tariffs is less beneficial for workers employed in sector U who, as the right panel of the figure shows, prefer lower tariffs in the short run when  $\alpha$  is higher. It also leads unskilled workers in general to prefer lower tariffs. The tariff maximizing the consumption of all workers is also slightly lower but the difference is so small that it is barely visible.

#### APPENDIX C: PROOF OF EXISTENCE AND UNIQUENESS OF THE STEADY STATE

Table C1 presents the list of equations that define the steady state of our model. Asterisk denotes variables pertaining to F. Note that due to the absence of fixed costs of production  $\tilde{z}_d = (k/(k - (\theta - 1)))^{\frac{1}{\theta-1}} z_{\min}$  is given. Equations (A.1)–(A.25) hold for the Home country for each sector  $i$  where  $i = S$  is the skill intensive sector and  $i = U$  is the unskilled intensive sector. This results in a total of 50 sector-specific equations for H. Aggregate equations (A.26)–(A.36) hold for H, which results in a total of 61 equations for H. Equivalent equations hold for F. The equations for both countries in addition to the bond clearing conditions (A.37)–(A.38) and the international trade conditions (A.39)–(A.40) form a system of 126 equations that uniquely identifies the world steady state equilibrium, described by a vector of the following variables:  $N_{x,i}, N_{e,i}, N_{d,i}, \tilde{z}_{x,i}, \tilde{d}_{d,i}, \tilde{d}_{x,i}, \tilde{v}_i, \tilde{d}_i, \tilde{\rho}_{d,i}, \tilde{\rho}_{x,i}, \psi_i, S_i, L_i, w_i^s, w_i^l, S_{e,i}, L_{e,i}, V_i^s, V_i^l, C_i^s, C_i^l, B_i^s, B_{*,i}^s, B_i^l, B_{*,i}^l, T_i^s, T_i^l$ , for each sector in H (54 in total for both sectors) and the equivalent 54 variables in F. There remain the aggregate variables, eight for H:  $C, B, B_*, T^l, \Pi, r, \bar{\varepsilon}^S, \bar{\varepsilon}^L$  and eight equivalents for F:  $C^*, B^*, B_*^*, T^{l*}, \Pi^*, r^*, \bar{\varepsilon}^{*S}, \bar{\varepsilon}^{*L}$ , and the real exchange rate  $Q$ , and the trade balance  $tb$ , for a total of 126 variables that describe the world economy.

TABLE C1  
STEADY STATE EQUATIONS

| Equation Number | Equation  | Equation Description                              |
|-----------------|---|---|
| A.1             | $N_{d,i}(\bar{\rho}_{d,i})^{1-\theta} + N_{x,i}^*(\bar{\rho}_{x,i}^*)^{1-\theta} = (\psi_i)^{1-\theta}$   | Sector price index equation                       |
| A.2             | $\bar{\rho}_{d,i} = \frac{\theta}{\theta-1} (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} \frac{1}{\bar{z}_{d,i}}$  | Average price of domestic producers               |
| A.3             | $\bar{\rho}_{x,i} = \frac{t_i^* \tau^*}{Q} \frac{\theta}{\theta-1} (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} \frac{1}{\bar{z}_{x,i}}$   | Average price of export producers                 |
| A.4             | $\bar{d}_i = \bar{d}_{d,i} + \frac{N_{x,i}}{N_{d,i}} \bar{d}_{x,i}$   | Average total profit                              |
| A.5             | $\bar{d}_{d,i} = \frac{1}{\theta} \left( \frac{\bar{\rho}_{d,i}}{\psi_i} \right)^{1-\theta} \alpha_i C$   | Average profit of domestic producers              |
| A.6             | $\bar{d}_{x,i} = \frac{Q}{\theta t_i^*} \left( \frac{\bar{\rho}_{x,i}}{\psi_i} \right)^{1-\theta} \alpha_i C^* - f_x (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i}$   | Average profit of export producers                |
| A.7             | $\bar{v}_i = f_e (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i}$   | Free entry condition                              |
| A.8             | $\bar{d}_{x,i} = f_x (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} \frac{\theta-1}{k-(\theta-1)}$   | Cutoff export condition                           |
| A.9             | $\frac{N_{x,i}}{N_{d,i}} = \left( \frac{\bar{z}_{d,i}}{\bar{z}_{x,i}} \right)^k$  | Percent of exporters                              |
| A.10            | $\delta N_{d,i} = (1 - \delta) N_{e,i}$   | Number of domestic producers                      |
| A.11            | $\bar{v}_i = \gamma (1 - \delta) (\bar{v}_i + \bar{d}_i)$   | Recursive form of firm value                      |
| A.12            | $\frac{w_i^s}{w_i^l} = \frac{\beta_i}{(1-\beta_i)} \frac{L_i}{S_i}$   | Relative labor demand                             |
| A.13            | $w_i^s S_i + w_i^l L_i + \bar{d}_i N_{d,i} = \bar{v}_i N_{e,i} + N_{d,i} \left( \frac{\bar{\rho}_{d,i}}{\psi_i} \right)^{1-\theta} \alpha_i C + N_{x,i} \frac{Q}{t_i^*} \left( \frac{\bar{\rho}_{x,i}}{\psi_i} \right)^{1-\theta} \alpha_i C^*$ | Sector accounting condition                       |
| A.14            | $S_{e,i} = s S_i$   | Skilled workers flow condition                    |
| A.15            | $L_{e,i} = s L_i$   | Unskilled workers flow condition                  |
| A.16            | $V_i^s = \log(C_i^s) + \gamma (1 - s) V_i^s$  | Value function of skilled workers                 |
| A.17            | $V_i^l = \log(C_i^l) + \gamma (1 - s) V_i^l$  | Value function of unskilled workers               |
| A.18            | $B_i^s + \frac{\eta}{2} (B_i^s)^2 + Q B_{*,i}^s + Q \frac{\eta}{2} (B_{*,i}^s)^2 + C_i^s S_i = (1 + r) B_i^s + Q(1 + r^*) B_{*,i}^s + w_i^s S_i + \Pi S_i + T_i^s + T^l S_i$  | Skilled workers budget constraint                 |
| A.19            | $B_i^l + \frac{\eta}{2} (B_i^l)^2 + Q B_{*,i}^l + Q \frac{\eta}{2} (B_{*,i}^l)^2 + C_i^l L_i = (1 + r) B_i^l + Q(1 + r^*) B_{*,i}^l + w_i^l L_i + \Pi L_i + T_i^l + T^l L_i$  | Unskilled workers budget constraint               |
| A.20            | $(1 + \eta B_i^s) = \gamma (1 + r)$   | Skilled workers Euler equation: H bonds           |
| A.21            | $(1 + \eta B_{*,i}^s) = \gamma (1 + r^*)$   | Skilled workers Euler equation: F bonds           |
| A.22            | $(1 + \eta B_i^l) = \gamma (1 + r)$   | Unskilled workers Euler equation: H bonds         |
| A.23            | $(1 + \eta B_{*,i}^l) = \gamma (1 + r^*)$   | Unskilled workers Euler equation: F bonds         |
| A.24            | $T_i^s = \frac{\eta}{2} (B_i^s)^2 + Q \frac{\eta}{2} (B_{*,i}^s)^2$   | H bond cost re-imbursement to skilled households  |
| A.25            | $T_i^l = \frac{\eta}{2} (B_i^l)^2 + Q \frac{\eta}{2} (B_{*,i}^l)^2$   | F bond cost reimbursement to unskilled households |
| A.26            | $T^l (S + L) = \frac{t_S - 1}{t_S} N_{x,S}^* \left( \frac{\bar{\rho}_{x,S}^*}{\psi_S} \right)^{1-\theta} \alpha_S C + \frac{t_U - 1}{t_U} N_{x,U}^* \left( \frac{\bar{\rho}_{x,U}^*}{\psi_U} \right)^{1-\theta} \alpha_U C$                     | Tariff revenue                                    |
| A.27            | $\bar{\varepsilon}^S = V_U^s - V_S^s$   | Skilled worker entry threshold                    |
| A.28            | $\bar{\varepsilon}^L = V_U^l - V_S^l$   | Unskilled worker entry threshold                  |
| A.29            | $\frac{S_{e,S}}{sS} = 1 - J(\bar{\varepsilon}^S)$   | Skilled worker entry condition                    |

(Continued)

TABLE C1  
CONTINUED

| Equation Number | Equation  | Equation Description                      |
|-----------------|---|---|
| A.30            | $\frac{L_{e,S}}{sL} = 1 - J(\bar{\varepsilon}^L)$   | Unskilled worker entry condition          |
| A.31            | $S = S_S + S_U$   | Labor market clearing for skilled labor   |
| A.32            | $L = L_S + L_U$   | Labor market clearing for unskilled labor |
| A.33            | $(\frac{\psi_S}{\alpha_S})^{\alpha_S} (\frac{\psi_U}{\alpha_U})^{\alpha_U} = 1$   | Aggregate price index                     |
| A.34            | $\Pi(S + L) = \bar{d}_S N_{d,S} + \bar{d}_U N_{d,U} - \bar{v}_S N_{e,S} - \bar{v}_U N_{e,U}$  | Firm transfer                             |
| A.35            | $B \equiv (B_S^s + B_U^s + B_S^l + B_U^l)$  | Definition of aggregate H bond holdings   |
| A.36            | $B_* \equiv (B_{*,S}^s + B_{*,U}^s + B_{*,S}^l + B_{*,U}^l)$  | Definition of aggregate F bond holdings   |
| A.37            | $B + B^* = 0$   | Bond clearing for H bonds                 |
| A.38            | $B_* + B_*^* = 0$   | Bond clearing for F bonds                 |
| A.39            | $tb = \sum_{i=S,U} [Q \frac{1}{\bar{r}_i} N_{x,i} (\frac{\bar{\rho}_{x,i}}{\bar{\psi}_i})^{1-\theta} \alpha_i C^* - \frac{1}{\bar{r}_i} N_{x,i} (\frac{\bar{\rho}_{x,i}^*}{\bar{\psi}_i})^{1-\theta} \alpha_i C]$ | Trade balance                             |
| A.40            | $B + QB_* = (1 + r)B + (1 + r^*)B_*Q + tb$  | Net foreign assets law of motion          |

The subsequent discussion of the existence and uniqueness of the steady state equilibrium is similar to the proof of Proposition 3 in the appendix of Bernard et al. (2007) and the proof in the appendix of Lechthaler and Mileva (2019). We focus our discussion on the H economy. Equivalent considerations hold for the F country.

At the steady state, as long as  $\eta > 0$ , bond adjustment costs are positive and this guarantees that international bond holdings are zero and that trade is balanced. In particular, the Euler conditions (Equations (A.20)– (A.23)) holding for both sectors in both countries imply that all households in H and F, no matter the sector, hold an equal amount of H and F bonds, such that  $B_S^s = B_U^s = B_S^{s*} = B_U^{s*} = B_S^l = B_U^l = B_S^{s*} = B_U^{s*}$  for H bonds and  $B_{*,S}^s = B_{*,U}^s = B_{*,S}^{s*} = B_{*,U}^{s*} = B_{*,S}^l = B_{*,U}^l = B_{*,S}^{s*} = B_{*,U}^{s*}$  for F bonds. Based on the definitions of aggregate bond holding for H (A.35 and A.36), we obtain that workers in H and F hold the same aggregate amount of H bonds  $B = B^*$  and similarly for F bonds,  $B_* = B_*^*$ . Then based on the bond clearing conditions (A.37 and A.38), we obtain that  $B = B^* = 0$  and  $B_* = B_*^* = 0$ , and conversely for individual household bonds. Equation (A.40) implies that trade is always balanced at the steady state  $tb = 0$ . With households bond holdings being zero, the Euler equations on H bonds imply that  $r = 1/\gamma - 1$  and the Euler equations of F bonds that  $r^* = 1/\gamma - 1$ . Note that for a well-defined real interest rate, we require that  $\gamma > 0$  while for a nonnegative real interest rate,  $\gamma < 1$ . Finally, zero bond holdings also imply that the bond cost reimbursements are zero at the steady state  $T_i^s = T_i^l = 0$  (Equations (A.24) and (A.25)).

Following Bernard et al. (2007), we suppose for the moment that the equilibrium wage vector is known. Defining factor intensities in the skill-intensive sector as  $\lambda_S^s = S_S/S$  and  $\lambda_S^l = L_S/L$ , the factor-clearing equations (A.31) and (A.32) can be reformulated as

$$\begin{aligned} \frac{L}{S} &= \frac{L_S + L_U}{S} = \frac{L_S}{S_S} \frac{S_S}{S} + \frac{L_U}{S_U} \frac{S_U}{S} \\ &= \frac{L_S}{S_S} \lambda_S^s + \frac{L_U}{S_U} (1 - \lambda_S^s) \end{aligned}$$

and

$$\begin{aligned} \frac{S}{L} &= \frac{S_S + S_U}{L} = \frac{S_S}{L_S} \frac{L_S}{L} + \frac{S_U}{L_U} \frac{L_U}{L} \\ &= \frac{S_S}{L_S} \lambda_S^l + \frac{S_U}{L_U} (1 - \lambda_S^l). \end{aligned}$$

Using Equation (A.12) for both sectors, these become

$$\begin{aligned} \frac{L}{S} &= \frac{(1 - \beta_S)}{\beta_S} \frac{w_S^s}{w_S^l} \lambda_S^s + \frac{(1 - \beta_U)}{\beta_U} \frac{w_U^s}{w_U^l} (1 - \lambda_S^s) \\ \frac{S}{L} &= \frac{\beta_S}{(1 - \beta_S)} \frac{w_S^l}{w_S^s} \lambda_S^l + \frac{\beta_U}{(1 - \beta_U)} \frac{w_U^l}{w_U^s} (1 - \lambda_S^l). \end{aligned}$$

Given wages and exogenous endowments, these two equations uniquely define the factor intensities in the skill-intensive sector  $\lambda_S^s$  and  $\lambda_S^l$ , and thereby  $S_S$  and  $L_S$ . Then the factor-clearing conditions uniquely define  $S_U$  and  $L_U$ . In particular,

$$\lambda_S^s = \frac{\frac{L}{S} - \frac{(1 - \beta_U)}{\beta_U} \frac{w_U^l}{w_U^s}}{\left( \frac{(1 - \beta_S)}{\beta_S} \frac{w_S^s}{w_S^l} - \frac{(1 - \beta_U)}{\beta_U} \frac{w_U^s}{w_U^l} \right)}$$

and

$$\lambda_S^l = \frac{\frac{S}{L} - \frac{\beta_U}{(1 - \beta_U)} \frac{w_U^l}{w_U^s}}{\frac{\beta_S}{(1 - \beta_S)} \frac{w_S^l}{w_S^s} - \frac{\beta_U}{(1 - \beta_U)} \frac{w_U^l}{w_U^s}}.$$

Let  $Skill_U = w_U^s/w_U^l$  and  $Skill_S = w_S^s/w_S^l$ . Then,

$$\lambda_S^s = \frac{\frac{L}{S} - \frac{(1 - \beta_U)}{\beta_U} Skill_U}{\left( \frac{(1 - \beta_S)}{\beta_S} Skill_S - \frac{(1 - \beta_U)}{\beta_U} Skill_U \right)}$$

and

$$\lambda_S^l = \frac{\frac{S}{L} - \frac{\beta_U}{(1 - \beta_U)} \frac{1}{Skill_U}}{\frac{\beta_S}{(1 - \beta_S)} \frac{1}{Skill_S} - \frac{\beta_U}{(1 - \beta_U)} \frac{1}{Skill_U}}.$$

Simplifying and re-arranging terms yield the following:

$$\begin{aligned} \lambda_S^s &= \frac{\beta_S L \beta_U - \beta_S (1 - \beta_U) Skill_U S}{S \beta_U (1 - \beta_S) Skill_S - S \beta_S (1 - \beta_U) Skill_U} \\ \lambda_S^l &= \frac{S (1 - \beta_U) Skill_U (1 - \beta_S) Skill_S - \beta_U L (1 - \beta_S) Skill_S}{L \beta_S (1 - \beta_U) Skill_U - L \beta_U (1 - \beta_S) Skill_S}. \end{aligned}$$

An important restriction for the existence of the steady state is that  $\beta_U (1 - \beta_S) Skill_S \neq \beta_S (1 - \beta_U) Skill_U$  since otherwise the share of workers in the skill intensive sector is not well defined. Note that this restriction is satisfied as we assume that  $\beta_S > \beta_U$ . Similarly, other restrictions necessary for existence are that  $L > 0$  and  $S > 0$ .

The conditions for worker flows in each sector (Equations (A.14) and (A.15)) deliver the number of skilled and unskilled workers entering each sector at the steady state  $S_{e,i}$  and  $L_{e,i}$  as a function of sector employment ( $S_i$  and  $L_i$ ). Note that another important parameter restriction for the existence of positive worker entry at the steady state is  $s > 0$ .

The free entry condition (Equation (A.7)) pins down the average value of the firm  $\tilde{v}_i$  as a function of the wages and model parameters. For firms to have positive value, we require that  $f_e > 0$ . Otherwise we have unlimited firm entry. Combining the recursive form of firm value (Equation (A.11)) with the free entry condition (Equation (A.7)) yields

$$f_e(w_i^s)^{\beta_i}(w_i^l)^{1-\beta_i}\frac{1-\gamma(1-\delta)}{\gamma(1-\delta)} = \tilde{d}_i,$$

which pins down average profits for each sector. Here we see other important parameter restrictions for the existence of positive firm profits at the steady state:  $\gamma > 0$  and  $\delta < 1$ .

We can use Equation (A.8) to derive the average profits for firms that export  $\tilde{d}_{x,i}$ . Note that  $k > \theta - 1$  is another necessary restriction for the existence of the steady state export profit. In addition, note that only when  $f_x > 0$ , only a fraction of the existing firms export. If,  $f_x = 0$ , then all existing firms will be exporters.

Next, it is useful to define average domestic revenue  $\tilde{r}_{d,i} = (\tilde{\rho}_{d,i}/\psi_i)^{1-\theta}\alpha_i C$ , average export revenue for H  $\tilde{r}_{x,i} = (\tilde{\rho}_{x,i}/\psi_i^*)^{1-\theta}\alpha_i C^*$ , and F  $\tilde{r}_{x,i}^* = (\tilde{\rho}_{x,i}^*/\psi_i^*)^{1-\theta}\alpha_i C$ . Using this definition for average domestic revenue in Equation (A.4) and the fraction of exporters in A9 yields  $\tilde{d}_i = \tilde{r}_{d,i}/\theta + (\tilde{z}_d/\tilde{z}_{x,i})^k \tilde{d}_{x,i}$ . Note that if  $k = 0$ , all domestic producers export and we require that  $k > 0$  for only a fraction of the firms to export. The definitions of domestic and export revenues together with the pricing equations (A.2) and (A.3) imply that

$$\frac{\tilde{r}_{d,i}}{\tilde{r}_{x,i}} = \frac{(\tilde{\rho}_{d,i})^{1-\theta}}{(\tilde{\rho}_{x,i}^*)^{1-\theta}} = \frac{((w_i^s)^{\beta_i}(w_i^l)^{1-\beta_i})^{1-\theta}}{(Q\tau t_i(w_i^{s*})^{\beta_i}(w_i^{l*})^{1-\beta_i})^{1-\theta}} \left(\frac{\tilde{z}_d}{\tilde{z}_{x,i}}\right)^{\theta-1}$$

and

$$\frac{\tilde{r}_{d,i}^*}{\tilde{r}_{x,i}} = \frac{(\tilde{\rho}_{d,i}^*)^{1-\theta}}{(\tilde{\rho}_{x,i}^*)^{1-\theta}} = \frac{((w_i^{s*})^{\beta_i}(w_i^{l*})^{1-\beta_i})^{1-\theta}}{\left(\frac{\tau^* t_i^*}{Q}(w_i^s)^{\beta_i}(w_i^l)^{1-\beta_i}\right)^{1-\theta}} \left(\frac{\tilde{z}_d}{\tilde{z}_{x,i}}\right)^{\theta-1}.$$

Next, Equations (A.6) and (A.8) imply that

$$\tilde{r}_{x,i} = f_x(w_i^s)^{\beta_i}(w_i^l)^{1-\beta_i}\frac{k}{k-(\theta-1)}\frac{\theta t_i^*}{Q}$$

and

$$\tilde{r}_{x,i}^* = f_x^*(w_i^{s*})^{\beta_i}(w_i^{l*})^{1-\beta_i}\frac{k}{k-(\theta-1)}\theta Q t_i.$$

Thus, domestic revenues are only a function of the export cutoffs, wages, the real exchange rate, and parameters,

$$\tilde{r}_{d,i} = \left[ \frac{((w_i^s)^{\beta_i}(w_i^l)^{1-\beta_i})^{1-\theta}}{(Q\tau t_i(w_i^{s*})^{\beta_i}(w_i^{l*})^{1-\beta_i})^{1-\theta}} \left(\frac{\tilde{z}_d}{\tilde{z}_{x,i}}\right)^{\theta-1} \right] \left[ f_x^*(w_i^{s*})^{\beta_i}(w_i^{l*})^{1-\beta_i}\frac{k}{k-(\theta-1)} \right] \theta Q t_i$$

and

$$\tilde{r}_{d,i}^* = \left[ \frac{\left( (w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i} \right)^{1-\theta}}{\left( \frac{\tau^* t_i^*}{Q} (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} \right)^{1-\theta}} \left( \frac{\tilde{z}_d}{\tilde{z}_{x,i}} \right)^{\theta-1} \right] \left[ f_x (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} \frac{k}{k - (\theta - 1)} \right] \frac{\theta t_i^*}{Q}.$$

Substituting these equations for domestic revenue in Equation (A.4) delivers

$$\begin{aligned} \tilde{d}_i &= \frac{1}{\theta} \left[ \frac{\left( (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} \right)^{1-\theta}}{\left( Q \tau t_i (w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i} \right)^{1-\theta}} \left( \frac{\tilde{z}_d}{\tilde{z}_{x,i}^*} \right)^{\theta-1} \right] \left[ f_x^* (w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i} \frac{k}{k - (\theta - 1)} \right] \theta Q t_i \\ &\quad + \left( \frac{\tilde{z}_d}{\tilde{z}_{x,i}} \right)^k \tilde{d}_{x,i} \end{aligned}$$

and

$$\tilde{d}_i^* = \frac{1}{\theta} \left[ \frac{\left( (w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i} \right)^{1-\theta}}{\left( \frac{\tau^* t_i^*}{Q} (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} \right)^{1-\theta}} \left( \frac{\tilde{z}_d}{\tilde{z}_{x,i}} \right)^{\theta-1} \right] \left[ f_x (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} \frac{k}{k - (\theta - 1)} \right] \frac{\theta t_i^*}{Q} + \left( \frac{\tilde{z}_d}{\tilde{z}_{x,i}^*} \right)^k \tilde{d}_{x,i}^*.$$

Note that from the latter condition and A8, we obtain

$$\begin{aligned} \left( \frac{\tilde{z}_d}{\tilde{z}_{x,i}^*} \right) &= \left\{ \frac{\tilde{d}_i^*}{f_x^* (w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i} \frac{\theta-1}{k-(\theta-1)}} \right\} - \frac{f_x (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} k}{f_x^* (w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i} (\theta - 1)} \frac{t_i^*}{Q} \\ &\quad \times \left( \left[ \frac{\left( (w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i} \right)^{1-\theta}}{\left( \frac{\tau^* t_i^*}{Q} (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} \right)^{1-\theta}} \left( \frac{\tilde{z}_d}{\tilde{z}_{x,i}} \right)^{\theta-1} \right] \right)^{\frac{1}{k}}, \end{aligned}$$

and substituting for  $(\tilde{z}_d/\tilde{z}_{x,i}^*)$  into the first condition, we obtain an equation only in terms of the export cutoff:

$$\tilde{d}_{x,i} \left( \frac{\tilde{z}_d}{\tilde{z}_{x,i}} \right)^k + \frac{\tilde{r}_{x,i}^*}{\theta} \frac{A^{1-\theta}}{(Q \tau t_i)^{1-\theta}} \left[ \frac{\tilde{d}_i^*}{\tilde{d}_{x,i}^*} - \frac{f_x}{f_x^*} \frac{k}{(\theta - 1)} \left( \frac{t_i^* A}{Q} \right)^\theta \left( \frac{\tilde{z}_d}{\tau^*} \right)^{1-\theta} (\tilde{z}_{x,i})^{1-\theta} \right]^{\frac{\theta-1}{k}} = \tilde{d}_i,$$

where  $\tilde{d}_{x,i} = (\theta - 1)/(k + 1 - \theta) f_x (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i}$ ,  $\tilde{d}_{x,i}^* = (\theta - 1)/(k + 1 - \theta) f_x^* (w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i}$ ,  $\tilde{r}_{x,i}^* = f_x^* (w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i} k/(k - (\theta - 1)) \theta Q t_i$ ,  $\tilde{d}_i = f_e (w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i} (1 - \gamma(1 - \delta))/(\gamma(1 - \delta))$ ,  $\tilde{d}_i^* = f_e^* (w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i} (1 - \gamma(1 - \delta))/(\gamma(1 - \delta))$ , and  $A = ((w_i^s)^{\beta_i} (w_i^l)^{1-\beta_i})/((w_i^{s*})^{\beta_i} (w_i^{l*})^{1-\beta_i})$ . Note that given positive wages and a positive real exchange rate, and given the parameter restrictions discussed so far,  $\tilde{d}_{x,i} > 0$ ,  $\tilde{d}_{x,i}^* > 0$ ,  $\tilde{r}_{x,i}^* > 0$ ,  $\tilde{d}_i > 0$ ,  $\tilde{d}_i^* > 0$ , and  $A > 0$ . Thus, the left side is a hyperbola for  $\tilde{z}_{x,i} > 0$  that guarantees existence and uniqueness for  $\tilde{z}_{x,i}$ . Ghironi and Melitz (2005, TA) employ a similar strategy to prove uniqueness and existence of the steady state.

Now that we have obtained the export cutoffs equation, (A.9) allows us to pin down the fraction of exporting firms. We have also obtained average domestic revenue  $\tilde{r}_{d,i}$  and profits  $\tilde{d}_{d,i}$ .

Substituting for the  $N_{e,i}$  from Equation (A.10), and for average domestic and export revenue allows to write Equation (A.13) as

$$w_i^s S_i + w_i^l L_i = N_{d,i} \left( \tilde{v}_i \frac{\delta}{(1-\delta)} - \tilde{d}_i \right) \left( +\tilde{r}_{d,i} + \frac{N_{x,i}}{N_{d,i}} \frac{Q}{t_i^*} \tilde{r}_{x,i} \right),$$

which allows us to pin down the number of producing firms  $N_{d,i}$ . Then Equations (A.9) and (A.10) deliver the number of exporters as  $N_{x,i} = (\tilde{z}_d/\tilde{z}_{x,i})^k N_{d,i}$  and new entrants  $N_{e,i} = \delta N_{d,i}/(1-\delta)$ . Note that to obtain positive firm entry at the steady state, we require that  $0 < \delta < 1$ .

The domestic and export prices are obtained from Equations (A.2) and (A.3) as a function of wages and  $Q$  and Equation (A.1) pins down the sector price index  $\psi_i$ . Note that Equation (A.2) implies another important restriction for the existence of a positive steady state domestic price, namely  $\theta > 1$  and  $\tilde{z}_d > 0$  (which holds as long as  $z_{\min} > 0$  and  $k > \theta - 1$ ). In addition, if we re-write Equation (A.1) as  $N_{d,i}(\tilde{\rho}_{d,i}/\psi_i)^{1-\theta} + N_{x,i}^*(\tilde{\rho}_{x,i}^*/\psi_i)^{1-\theta} = 1$  and multiply both sides by  $\alpha_i C$ , we can substitute for domestic and import revenue and write it as  $N_{d,i}\tilde{r}_{d,i} + N_{x,i}^*\tilde{r}_{x,i}^* = \alpha_i C$  to obtain total consumption  $C$  in each country. Note that  $1 > \alpha_S > 0$  in order to have positive demand in both sectors.

Tariff revenue  $T^l$  is pinned down by Equation (A.26), depending only on parameters and variables already determined and positive as long as tariffs are positive. The transfer of the mutual fund  $\Pi$  to workers is pinned down by Equation (A.34). Based on the household budget constraints (A.18) and (A.19) and the fact that bond holdings are zero at the steady state, we obtain the consumption per worker such that  $C_i^s = w_i^s + \Pi + T^l$  for skilled workers and  $C_i^l = w_i^l + \Pi + T^l$  for unskilled workers. Then, Equations (A.16) and (A.17) imply that  $V_i^s = \log(w_i^s + \Pi + T^l)/(1 - \gamma(1 - s))$  and  $V_i^l = \log(w_i^l + \Pi + T^l)/(1 - \gamma(1 - s))$ . Note that tariff revenue and the firm transfer are equal across workers that implies that the differences in welfare across workers are only a function of differences in wages at the steady state.

To pin down the wage vector, we need to go back to our assumptions regarding worker entry. The main factor influencing a worker's choice of sector is the wage differential across sectors with workers preferring the sector with the higher wage. However, sector choice is also affected by preferences: upon entering the workforce each worker draws her sector preference ( $\varepsilon^S$  for skilled and  $\varepsilon^L$  for unskilled) from a symmetric random distribution with cumulative distribution function  $J(\varepsilon^S)$  for skilled workers and cumulative distribution function  $J(\varepsilon^L)$  for unskilled workers. A worker is indifferent between entering sectors at a threshold value of  $\bar{\varepsilon}^S$  if  $\bar{\varepsilon}^S = V_U^s - V_S^s$  for skilled workers and  $\bar{\varepsilon}^L$  if  $\bar{\varepsilon}^L = V_U^l - V_S^l$  for unskilled workers. Substituting for the value functions of workers, we get that

$$\bar{\varepsilon}^S = \frac{\log(w_U^s + \Pi + T^l)}{1 - \gamma(1 - s)} - \frac{\log(w_S^s + \Pi + T^l)}{1 - \gamma(1 - s)}$$

and

$$\bar{\varepsilon}^L = \frac{\log(w_U^l + \Pi + T^l)}{1 - \gamma(1 - s)} - \frac{\log(w_S^l + \Pi + T^l)}{1 - \gamma(1 - s)}.$$

Finally, substituting for the  $\bar{\varepsilon}^S$  in Equation (A.29) and for  $\bar{\varepsilon}^L$  in Equation (A.30), we obtain

$$\frac{S_{e,S}}{sS} = 1 - J \left( \frac{\log(w_U^s + \Pi + T^l)}{1 - \gamma(1 - s)} - \frac{\log(w_S^s + \Pi + T^l)}{1 - \gamma(1 - s)} \right)$$



and

$$\frac{L_{e,S}}{sL} = 1 - J \left( \frac{\log(w_U^l + \Pi + T^t)}{1 - \gamma(1 - s)} - \frac{\log(w_S^l + \Pi + T^t)}{1 - \gamma(1 - s)} \right).$$

Recall that  $S_{e,S} = sS_S$  and  $L_{e,S} = sL_S$  to obtain

$$\begin{aligned} \frac{S_S}{S} &= 1 - J \left( \frac{\log(w_U^s + \Pi + T^t)}{1 - \gamma(1 - s)} - \frac{\log(w_S^s + \Pi + T^t)}{1 - \gamma(1 - s)} \right) \\ \frac{L_S}{L} &= 1 - J \left( \frac{\log(w_U^l + \Pi + T^t)}{1 - \gamma(1 - s)} - \frac{\log(w_S^l + \Pi + T^t)}{1 - \gamma(1 - s)} \right). \end{aligned}$$

These equations uniquely pin down the allocation of workers, since wage differentials motivate workers to prefer entering comparative advantage sectors over comparative disadvantaged ones while relative sector preferences reduce the incentives to enter only one sector. In equilibrium, both aspects balance and worker flows are uniquely pinned down.

Recall that  $S_S/S = \lambda_S^s$  and

$$\lambda_S^s = \frac{\frac{L}{S} - \frac{(1-\beta_U)}{\beta_U} \frac{w_U^s}{w_U^l}}{\left( \frac{(1-\beta_S)}{\beta_S} \frac{w_S^s}{w_S^l} - \frac{(1-\beta_U)}{\beta_U} \frac{w_U^s}{w_U^l} \right)},$$

and, conversely, that  $L_S/L = \lambda_S^l$ , and

$$\lambda_S^l = \frac{\frac{S}{L} - \frac{\beta_U}{(1-\beta_U)} \frac{w_U^l}{w_U^s}}{\frac{\beta_S}{(1-\beta_S)} \frac{w_S^l}{w_S^s} - \frac{\beta_U}{(1-\beta_U)} \frac{w_U^l}{w_U^s}}.$$

Thus we obtain the following equations for wages based on worker re-allocation:

$$\begin{aligned} \frac{\frac{L}{S} - \frac{(1-\beta_U)}{\beta_U} \frac{w_U^s}{w_U^l}}{\left( \frac{(1-\beta_S)}{\beta_S} \frac{w_S^s}{w_S^l} - \frac{(1-\beta_U)}{\beta_U} \frac{w_U^s}{w_U^l} \right)} &= 1 - J \left( \frac{\log(w_U^s + \Pi + T^t)}{1 - \gamma(1 - s)} - \frac{\log(w_S^s + \Pi + T^t)}{1 - \gamma(1 - s)} \right) \\ \frac{\frac{S}{L} - \frac{\beta_U}{(1-\beta_U)} \frac{w_U^l}{w_U^s}}{\frac{\beta_S}{(1-\beta_S)} \frac{w_S^l}{w_S^s} - \frac{\beta_U}{(1-\beta_U)} \frac{w_U^l}{w_U^s}} &= 1 - J \left( \frac{\log(w_U^l + \Pi + T^t)}{1 - \gamma(1 - s)} - \frac{\log(w_S^l + \Pi + T^t)}{1 - \gamma(1 - s)} \right). \end{aligned}$$

Note that based on the previous discussion, both the firm transfer  $\Pi$  and tariff revenue  $T^t$  are a function of the wage vector and the real exchange rate. Note also that similar equations hold for F. Thus we can use the two equations above for each country as well as Equation (A.13) for each sector in each country to pin down the wage vector for H and F and the fact that trade is balanced ( $tb = 0$ ) to pin down the real exchange rate as a function of relative exports:

$$Q = \frac{N_{x,S}^* r_{x,S}^* / t_S + N_{x,U}^* r_{x,U}^* / t_U}{N_{x,S} r_{x,S} / t_S^* + N_{x2} r_{x2} / t_U^*}.$$

Extending the model to incorporate training involves adding equations to ensure that the steady state supply of skilled and unskilled workers is identified. To assess the relative value

of skilled versus unskilled entry, we define the average value of a skilled, and unskilled workers as

$$V^s = \frac{S_{e,S}}{S_e} V_S^s + \frac{S_{e,U}}{S_e} V_U^s$$

and

$$V^l = \frac{L_{e,S}}{L_e} V_S^l + \frac{L_{e,U}}{L_e} V_U^l,$$

where  $S_e = S_{e,S} + S_{e,U}$  and  $L_e = L_{e,S} + L_{e,U}$  are the total skilled and unskilled workers entering the labor force. Note that Equations (A.14) and (A.15) imply that for a stable steady state  $S_e = sS$ ,  $L_e = sL$  and for total worker entry  $S_e + L_e = s(S + L)$ . Then, the level of the threshold training cost where a worker is indifferent between entering as skilled versus unskilled is  $\bar{\varepsilon}^T = V^s - V^l$ . To ensure a positive and unique probability of training at the steady state, we have to assume a probability distribution for the training cost  $\Gamma(\varepsilon_t^T)$  that is only defined for nonnegative values and gives zero probability to negative values, like the exponential distribution. Then, the probability of training is pinned down as  $\eta^T = \Gamma(\bar{\varepsilon}^T) = 1 - \exp(-scaleT\bar{\varepsilon}^T)$  and the share of skilled workers is obtained by  $S/(S + L) = S_e/(S_e + L_e) = \eta^T$ .

Modifying the model to allow for perfect worker mobility across sectors involves eliminating the equations in the model related to worker entry and exit. Under perfect mobility, we can no longer pin down the fraction of entering workers in the economy, and Equations (A.14), (A.15), (A.27)–(A.30) drop out. Perfect worker mobility implies that the wage differential across sectors completely vanishes. If the wage in one sector was slightly higher, workers would move to that sector until the wage differential has vanished. The number of workers in each sector is then endogenously determined by the condition that the value of workers is the same in both sectors, in particular we add the following two equations to the model to replace the worker entry equations:  $V_S^s - V_U^s = 0$  and  $V_S^l - V_U^l = 0$ . The system of equations for the dynamic model changes in the same way, the worker flow and the worker entry equations are eliminated and replaced with conditions for equal worker values across sectors.

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