Optimal Trade Policy with International Technology Diffusion

Yan Bai * Keyu Jin † Dan Lu ‡ Hanxi Wang §

Abstract

We study optimal dynamic trade policies in an Eaton-Kortum model with technology diffusion through trade. The process of innovation and diffusion is one in which new ideas are combined with insights from others. Trade thus affects technology by determining the distribution from which producers draw their insights. Our theory shows that optimal policies capture a dynamic motive for a country to alter global technology. These policies take into account selection effects, country endowments, and other alterations to trade patterns that affect the degree and quality of diffusion. We provide explicit formulas showing that a Home country would like to subsidize imports from places that improve the quality of learning at Home; or lower its export tax to another country if a) higher productivity in that country is good for the Home, and b) more exports to that country improve the quality of learning and, in turn, the country's technology. We also calibrate the model using cross-country data and quantify dynamic trade policies and their attendant welfare implications.

Keywords: Technology diffusion, Trade, Optimal dynamic policies

*Bai: Department of Economics, University of Rochester; yan.bai@rochester.edu.

†Jin: Department of Economics, London School of Economics; k.jin@lse.ac.uk.

‡Lu: Department of Economics, The Chinese University of Hong Kong; danlv27@gmail.com. Dan acknowledge the support from the Research Grants Council of Hong Kong under Grant GRF-14505721.

§Wang: Department of Economics, The Chinese University of Hong Kong; wanghanxi@link.cuhk.edu.hk.

1 Introduction

Globalization is not only about the exchange of goods and services but also about the exchange of embodied ideas. As we observe technological convergence in the data,[1] a possible account of this pattern is that there is international technology diffusion and knowledge spillovers.[2] How and when that diffusion occurs has also inspired a significant amount of work dedicated to understanding the relationship between openness and diffusion, as well as attendant welfare consequences.[3] The powerful explanation that diffusion of ideas can occur through trade has many theoretical underpinnings,[4] as well as suggestive empirical evidence that learning from importing holds in the data.[5] Finally, it has also become an important strategy for developing countries' growth.

A number of papers examine the link between trade and technological diffusion but so far few consider a country's optimal policy in the presence of such externalities. This paper fills the gap. We study dynamic optimal trade policies in a multi-country model with technology diffusion through trade. We theoretically characterize optimal dynamic trade policies, and then calibrate the model using cross-country data to quantify the optimal policies both during transition and at the steady state.

A country may benefit from importing from certain countries that have better technologies, but whose goods may not be the cheapest. Consumers may enjoy importing goods with low prices, but not take into account the fact that these cheaper products may have little diffusion benefits. Producers may want to sell to a market but do not take into account the impact of its diffusion on that country. These decisions feed back onto the domestic economy and

[1]Large literature suggested a strong relationship between openness and growth, for example, Ben-David (1993), Sachs, Warner, Åslund, and Fischer (1995), Coe and Helpman (1995), and Frankel and Romer (1999). We find technology convergence across countries, see Appendix E.

[2]Grossman and Helpman (1991), Eaton and Kortum (1996), Eaton and Kortum (1999), Parente and Prescott (2005). Also, see the handbook chapter of Klenow and Rodriguez-Clare (2005) for a review.

[3]Eaton and Kortum (2006); Atkeson and Burstein (2010); Cai, Li, and Santacreu (2022).

[4]Lucas Jr (2009), Alvarez, Buera, Lucas et al. (2013), Arkolakis, Ramondo, Rodríguez-Clare, and Yeaple (2018), Somale (2021), Cai, Li, and Santacreu (2022), Buera and Oberfield (2020), Cai and Xiang (2022).

[5]Coe and Helpman (1995), Grossman and Helpman (1991), Sjöholm (1996), MacGarvie (2006). See Keller (2010) handbook chapter for a review.

impact trade, technology, and welfare, but consumers and producers do not internalize these effects. We show in this paper that a government has an incentive to manipulate trade to impact the level, source, and destination of technological diffusion, and hence affect the level of technologies across countries and over time.

This is a timely question in the wake of recent trade disputes between countries such as the U.S. and China, with a critical point of tension surrounding China's perceived technological catching-up through direct or indirect spillovers. Should the U.S. government encourage or discourage trade with China in the presence of technology diffusion? What should China's unilateral policy look like, on the other hand?

To grasp the mechanisms at hand, consider the simple case of a two-country setting, in which the Home sets a unilateral policy, and the foreign country is assumed to be passive. In the case without diffusion, Home's optimal policy would consist of imposing an import tariff so as to manipulate its terms of trade in its favor. Export tax can be set to zero according to Lerner symmetry, which indicates the equivalence of export taxes and import tariffs in a two-country setting. In the case of diffusion, however, Home has a motive to manipulate trade in order to affect the degree of technological diffusion both domestically and abroad. Consider the reasons for which Home might care about Foreign's level of technology. On the one hand, a higher level of Foreign technology makes its goods cheaper. On the other hand, it reduces Home's exports and hence tax revenue and income. In addition, Foreign's level of technology affects the extent of diffusion to Home and hence Home's future levels of technology. If the overall effect is that a higher Foreign technology is good for Home, and if exporting more to Foreign improves its technology, then Home in this instance would want to lower its export tax (and lower than in the case without diffusion). If it is better for Foreign to learn from its own producers (rather than importers), Home may want to increase its export tax. Similarly, Home can now use tariffs to determine how much and from where to import in order to benefit from diffusion from others.

To demonstrate these insights, we use an Eaton-Kortum model with technology diffusion. We theoretically characterize the optimal dynamic trade policies and quantitatively compute these policies by calibrating the model to cross-country data. Our model has a similar setup to Buera and Oberfield (2020), which extends Eaton and Kortum (2002) with technology diffusion through imports. A country's evolution of technology depends on the initial stock of the technology and new ideas, which arrive stochastically and exogenously to each potential producer. The quality of new ideas is determined by Home's original components combined with random insights that are drawn from the distribution of productivity among all producers that sell goods to the country, i.e., from both domestic producers and foreign sellers. Trade affects the creation and diffusion of ideas by determining the distribution from which producers draw their insights.

In the private equilibrium, consumers in each country buy from the cheapest producers in the destination market. A country's overall level of technology is determined by a country's own efficiency (taken to be exogenous) and its physical proximity to other economies with high productivity. The level of diffusion is a weighted average of (imported) productivity, where the weights are import shares. Hence, it is not the Foreign country's overall technology T that matters, but the average productivity of the goods sold to Home markets. The higher the diffusion parameter, the higher the T, but trade's impact on diffusion is non-monotone.

Trade costs also play an important role not only because they affect import shares. Of course, higher trade costs mean that a country imports less and thus learns less from the Foreign country. But higher trade costs also mean that only the more productive foreign producers get to sell to Home, and thus improve the quality of learning. Lastly, a country's endowment also matters. When a country imports from a low-wage country, the quality of learning is low as they import from sellers that have a cost advantage rather than a productivity advantage. This reduces Home's imports from other countries with potentially higher productivity goods that have diffusion benefits. Thus, selection due to cheaper wages rather than productivity may be less desirable.

We consider the Home government's unilateral dynamic policies while Foreign governments are passive. The Home government's policies consist of country-specific export taxes and import tariffs over time. Theoretical results show exactly that if Home's imported goods from a certain country impart greater diffusion benefits than the average quality afforded at Home, then Home should subsidize imports from that country. It can also choose export taxes in order to increase or decrease exports to Foreign. Our formula also shows that if, on the margin, a Foreign country learns more from Home than from other producers, and that higher Foreign technology is desirable to Home, then Home would want to lower its export tax to the country. In the multi-country case, Home determines country-specific export taxes and tariffs jointly.

Based on the multi-country setup, we use data to quantitatively study optimal unilateral trade policies for the US and China, and the implied welfare impact. We compute the optimal trade policies for both the steady state and the transition to the steady state.[6] We calibrate the model to 20 countries, including the nineteen largest countries, based on their GDP in 2016, and the rest of the world. Bilateral trade costs are calibrated using data from 2016 and model equations. Then, the exogenous innovation efficiencies α_n for each of the 20 countries and the diffusion parameter ρ are calibrated jointly using national account, trade data from 2000 to 2016, and our model. The calibrated innovation efficiencies, on average, are higher for countries with higher real GDP per input. This set of parameters is consistent with 2016 being a steady state for the private equilibrium in our model, as well as with a minimal distance between the private equilibrium and data for the changes of technology in 2000-2016.

Under U.S. unilateral policies, the U.S. gains in both the short run and long run, while most other countries lose. Remarkably, this stands in stark contrast to unilateral Chinese policies, which raise many countries' welfare alongside China's enormous gains. Take the U.S. example first. It employs heterogeneous import tariffs and export taxes. The U.S., already enjoying the highest levels of technology, subsidizes imports from a few advanced economies but on average imposes import tariffs based on terms of trade considerations. It lowers export taxes to other countries so as to increase *their* learning. The U.S. technology level rises in both the short and long run, but these policies lead to a reduction of technology in most other

[6] We consider the economy to be in a steady state in the last year of our data sample, the year 2016. When the Home government implements optimal dynamic policies, technologies change and slowly accumulate to a new steady state; the optimal policies involve a path of policies over time.

countries. The reason is that by imposing import tariffs, the US subsequently buys relatively more from itself and drives up its own wages relative to all other countries. As a result, other countries buy less and learn less from the US and see a decline in technology. Trade costs have an important influence over optimal policies because of the selection effect they engender. For nearby countries such as Canada and Mexico, the U.S. imposes higher tariffs than on other countries with similar levels of technology because imports from the two countries are greater due to proximity and lower wages in Mexico rather than due to higher technology.

This mechanism—that policies alter wages, which in turn change trade patterns and technology diffusion–is the same one that underlies Chinese unilateral policies. But the global impact is quite different. In the first instance, Chinese policies are much more beneficial for China than U.S. ones are for the U.S. The reason is that China is much less efficient and can learn more. China, by and large, subsidizes imports from more advanced countries relative to the ROW. The dispersion in tariffs is larger than under U.S. policies, allowing China to reap more gains both in the short and long run. Unlike in the case of U.S. policies, fewer countries lose out in the long run. China buys more from more advanced countries and less from inefficient ones, driving up wages in the former while pushing down wages in the latter. As a result, countries with falling wages sell more to the world. Take the two countries, Korea and Japan. China imports too much from these countries, given the low trade costs, and thus imposes import tariffs. The fall in China's demand for their goods depresses their wages, and as a result, many countries switch to importing from Korea and Japan. Given that these two economies have higher efficiency, buying more from them improves the importing countries' learning. There are other countries that lose out–for instance, countries such as India and Indonesia with low initial levels of technology are subject to import tariffs by China and see falling wages. By switching their purchases toward domestic goods, they learn less when importing less, and the overall technology levels in these countries fall.

Over time, China's technology improves dramatically, and its relative wage increases. Countries subsequently buy less from China. But even though the relative wage in China rises in the long run compared to private equilibrium, advanced countries still want to import more from

China compared to the private equilibrium—indicating drastic technological improvement in China. Even though the more advanced countries import more from China, they also benefit from the technological improvements in China.

In sum, the key difference between the U.S. and China stems from their efficiency and technology levels. The U.S. is the leader of world technology and thus has a small incentive to impose heterogeneous tariffs across countries to take advantage of foreign technologies. As a result, the import tariffs are less dispersed. The U.S. relative wage increases, and the reduced ability to import from the U.S. dominates in determining other countries' falling technologies. In contrast, China is one of the least efficient countries in the world, and it designs more differential trade policies across countries. The change in relative wages and trade with other countries allow many of these countries to gain. But these two cases become more similar as we increase the technology diffusion parameter. In that case, the U.S. uses more differential trade policies across countries, and some countries import more from the US and see technology and welfare gains.

The optimal policies and their associated welfare gains depend on the diffusion parameter, which we calibrate through the lens of our model. As a robustness, we consider alternative values of diffusion parameters. We find out that when diffusion is larger, optimal tariffs and export taxes become more dispersed across countries. It is worth noting that we do not view our contribution as identifying the diffusion parameter, even though we propose a method that is different from the literature and uses data from all countries and all years in our sample. A better estimation method may involve identification strategies or micro-level data related to diffusion. Relatedly, the diffusion may vary across sectors and products. It is reasonable to think that some products do not bear much technology, and hence less externality. The heterogeneous diffusion across sectors/products would affect optimal policies and the associated welfare gains. Again, measuring diffusion is complicated, and we leave it to future study. Nevertheless, our contribution lies in providing a clean illustration and a toolkit for analyzing optimal policies under diffusion.

2 Theoretical Framework

We study optimal trade policies in an Eaton and Kortum (2002) framework with international technology diffusion as in Buera and Oberfield (2020). The world has N countries, and each country n has a measure L_n of labor.

Consumers in all countries have the same discount factor β and per-period utility over final goods C given by $u(C) = \frac{C^{1-\sigma}}{1-\sigma}$. Final goods in each country n aggregates the consumption of a continuum of varieties with a Cobb-Douglas function, $C_n = \exp \int_0^1 \ln c_n(\omega) d\omega$. All goods are tradable under an iceberg trade cost d_{ni} between country n and i.

The technology development in a country depends on the initial stock of the technology and new ideas. New ideas arrive stochastically and exogenously to potential producers of each good. However the quality of new ideas depends on the country's own original component and random insights gained from technologies in other countries. Insights are drawn from sellers to the country and are randomly and uniformly drawn from the distribution of productivity among all producers that sell goods to a country, including domestic producers and foreign sellers.[7]

Let $\pi_{ni,t}$ be the trade share from country i to country n in period t. In this case of "learning from sellers" as in Buera and Oberfield (2020), the frontier of knowledge follows a Frechet distribution, with parameter T_{nt} and θ, and the evolution of the scale of the Frechet, that is, the stock of knowledge, evolves according to[8]

$$T_{n,t+1} = (1-\delta)T_{nt} + \alpha_n \sum_{i=1}^{N} \left[\pi_{ni,t} \left(\frac{T_{it}}{\pi_{ni,t}} \right)^{\rho} \right], \tag{1}$$

[7] In our sample period, we also find a positive relationship between patent citations and imports: when China imports more from country c in the past, it also cites more patents from country c. Exports and patent citations, however, exhibit a negative relationship. Thus, a mechanism of learning from imports is consistent with our empirical findings of positively correlated imports and patent citations. See appendix E.

[8] Our model is isomorphic to the detrended semi-endogenous model in Buera and Oberfield (2020), which assumes the growth rate of α_n is exogenously driven by population growth γ and the scale of the Frechet distribution T_t grows asymptotically at $\frac{\gamma}{1-\rho}$. After detrend, the technology evolution in their model is the same as equation (1) with $\delta = \frac{\gamma}{1-\rho}$. The exogenous growth rate does not affect optimal policies, and thus we consider the detrended model.

where α_n is the arrival rate of ideas with country n's original component. The fraction $T_{it}/\pi_{ni,t}$ is an average of productivity among those in country i that sell to country n. Holding fixed country i's stock of knowledge among all the potential producers, a smaller trade share $\pi_{ni,t}$ reflects more selection into selling goods to n, and hence higher productivity among those sellers. Hence, a higher trade cost would induce more selection, all else equal. $(T_{it}/\pi_{ni,t})^{\rho}$ reflects the average quality of insights country n draws from i through imports, where ρ captures the contribution of the quality of insights from others to the productivity of new ideas. We can further define I_{nt} as the weighted average of quality of insights in country n, using trade shares as weights, $I_{nt} = \sum_{i=1}^{N} \left[\pi_{ni,t} \left(\frac{T_{it}}{\pi_{ni,t}} \right)^{\rho} \right]$.

Given the frontier distribution, the expressions for price indices and trade shares are identical to those in Eaton and Kortum (2002). Here, We examine the Home government's (country 1) unilateral policies while foreign governments are assumed to be passive. Specifically, the Home government can impose country-specific export taxes τ^x_{nt} and import tariffs τ^m_{nt} for $n > 1$ at any period t. Without loss of generality, we normalize Home consumer price to be 1, $P_{1t} = 1$ for any period t.

Definition 1 (World Private Equilibrium)**.** *The world private equilibrium consists of consumption $\{C_{nt}\}$, technology $\{T_{nt}\}$, expenditures $\{x_{nt}\}$, prices $\{P_{nt}\}$, and wages $\{w_{nt}\}$ such that taking as given Home government's trade policies $\{\tau^x_{nt}\}$ and $\{\tau^m_{nt}\}$, consumers maximize expected discounted utility, with constraints $P_{nt}C_{nt} = x_{nt}$; technology evolves according to (1), and markets clears for each country $n > 1$ in each period t:*[9]

$$x_{nt} = \sum_{i \neq 1}^{N} \pi_{in,t} x_{it} + \frac{1}{1+\tau^m_{nt}} \pi_{1n,t} x_{1t}, \tag{2}$$

[9]As in the standard EK model, trade shares depend on technology, wages, trade costs d, and trade policies imposed by country 1, given by

$$\pi_{11,t} = \frac{T_1 w_1^{-\theta}}{T_{1t} w_{1t}^{-\theta} + \sum_{n \neq 1} T_{nt} (w_{nt}(1+\tau^m_{nt}) d_{1n,t})^{-\theta}}, \quad \pi_{i1,t} = \frac{T_{1t}(w_{1t}(1+\tau^x_{it}) d_{i1,t})^{-\theta}}{T_{1t}(w_{1t}(1+\tau^x_{it}) d_{i1,t})^{-\theta} + \sum_{n \neq 1} T_{nt}(w_{nt} d_{in,t})^{-\theta}}$$

$$\pi_{in,t} = \frac{T_{nt}(w_{nt} d_{in,t})^{-\theta}}{T_{1t}(w_{1t}(1+\tau^x_{it}) d_{i1,t})^{-\theta} + \sum_{m \neq 1} T_{mt}(w_{mt} d_{im,t})^{-\theta}}, \quad \pi_{1i,t} = \frac{T_{it}(w_{it}(1+\tau^m_{it}) d_{1i,t})^{-\theta}}{T_{1t} w_{1t}^{-\theta} + \sum_{n \neq 1} T_{nt}(w_{nt}(1+\tau^m_{nt}) d_{1n,t})^{-\theta}}.$$

where expenditures are given by $x_{it} = w_{it}L_i$ for country $i > 1$ and

$$x_{1t} = w_{1t}L_1 + \sum_{i \neq 1}^{N} \frac{\tau_{it}^x}{1+\tau_{it}^x}\pi_{i1t}x_{it} + \sum_{i \neq 1}^{N} \frac{\tau_{it}^m}{1+\tau_{it}^m}\pi_{1it}x_{1t}. \tag{3}$$

Optimal Trade Policies The government in the Home country (country 1) is benevolent and chooses the optimal unilateral trade policies $\{\tau_{nt}^x, \tau_{nt}^m\}$ directed at country $n > 1$ to maximize the aggregate of Home consumers' lifetime utilities, subject to the world private equilibrium given by Definition 1. The Home government's problem is equivalent to choosing the sequence $\{\tau_{nt}^x, \tau_{nt}^m\}_{t=0}^{\infty}$ and private allocations and prices to solve the following problem

$$\max \sum_{t=0}^{\infty} \beta^t u(C_{1t}) \tag{4}$$

subject to the evolution of technology (1), the market clearing conditions (2), Home's expenditure (3), and the normalization of price index, for any period t

$$P_{1t} = \left[T_{1t}w_{1t}^{-\theta} + \sum_{n \neq 1} T_{nt}(w_{nt}(1+\tau_{nt}^m)d_{1n,t})^{-\theta} \right]^{-\frac{1}{\theta}} = 1. \tag{5}$$

Note that the Ramsey and Markov problem are equivalent here, given that there are no forward-looking constraints.[10] Appendix B specifies the recursive problem of the Home government and characterizes the optimal policies with first-order conditions. We proceed to present the key findings in the following propositions, omitting time t subscript for notational convenience.

[10]Bai, Jin, and Lu (2023) has endogenous technology accumulation through individual innovation. Hence, future trade policies affect Foreign innovation decisions. In that case, Ramsey's optimal policies are time-inconsistent, and Ramsey and Markov produce different outcomes.

2.1 Theoretical Characterization

Proposition 1 (**Exogenous Technology with No Diffusion**). *When technology is exogenous ($\rho = 0$), optimal trade policies consist of a country-specific import tariff and country-specific export taxes that rise with the trade share in country n, π_{n1}, $\forall n > 1$. Specifically,*

$$\tau_n^m = -\frac{\gamma_n}{u_c}, \qquad 1 + \tau_n^x = \frac{1 + \theta(1 - \pi_{n1})}{\theta \sum_{i \neq 1}(1 + \tau_i^m)\pi_{ni}}. \tag{6}$$

where γ_n is the multiplier on the market clearing condition (2) for each country n.

Proof: Appendix A.

When T is exogenous, the overall level of optimal tariffs and export taxes are not uniquely pinned down (tax neutrality holds as in Lerner (1936) and Costinot and Werning (2019)). Thus, we can set zero tariff or export tax for one country. γ_n is the multiplier on the market clearing condition (2) for each country n, optimal tariffs show Home uses country-specific tariffs to manipulate relative wages across them. Export taxes are used to exploit the country's monopoly power, and they increase with π_{n1}, the share of goods that country n imports from Home. In other words, the export tax for a specific country increases as the market power of the Home country's goods in tthat country increases. This schedule of trade policies is consistent with the one proposed by Costinot, Donaldson, Vogel, and Werning (2015), where the government can manipulate relative prices in its favor by limiting the supply of its export goods.

In the case of two countries, Home can optimally impose export tax $\tau_2^x = 0$ and import tariff $\tau_2^m = \frac{1}{\theta \pi_{22}}$ according to Proposition 1. As is clear, import tariffs increase with the share of goods that Home (country 1) sells to Foreign (country 2) as $\pi_{21} = 1 - \pi_{22}$.

Proposition 2 (**Tax neutrality with technology diffusion**). *Tax neutrality holds in this model with technology diffusion. Thus, the level of export taxes and tariffs cannot be pinned down and do not affect real allocations.*

Proof: Appendix B.1. This proposition shows that even under technology diffusion, tax neutrality still holds and we can set zero export tax for one country.

Proposition 3 (With Technology Diffusion). *With technology diffusion, the optimal export tax and import tariff satisfy*

$$1+\tau_n^x = \frac{1+\theta(1-\pi_{n1})}{\theta\sum_{i\neq 1}(1-\gamma_i/\gamma_x)\pi_{ni} + \frac{(1-\rho)\theta}{\gamma_x x_n}\alpha_n\gamma_{Tn}\left[\left(\frac{T_1}{\pi_{n1}}\right)^{\rho} - I_n\right]}, \tag{7}$$

and

$$\frac{1}{1+\tau_n^m} = \frac{u_c + \gamma_x\left[\theta\pi_{11} + \sum_{i\neq\{1,n\}}^{N}(\frac{1-\gamma_i/\gamma_x}{1+\tau_i^m})\theta\pi_{1i}\right] + \frac{(1-\rho)\theta}{x_1}\alpha_1\gamma_{T1}\left[\left(\frac{T_n}{\pi_{1n}}\right)^{\rho} - I_1\right]}{(\gamma_x-\gamma_n)\left[1+\theta(1-\pi_{1n})\right]}, \tag{8}$$

$$\frac{1}{1+\tau_n^m} = \frac{\gamma_x}{\gamma_x-\gamma_n} + \gamma_{T1}\frac{(1-\rho)\theta\alpha_1}{(\gamma_x-\gamma_n)(1+\theta)x_1}\left[\left(\frac{T_n}{\pi_{1n}}\right)^{\rho} - \left(\frac{T_1}{\pi_{11}}\right)^{\rho}\right] \tag{9}$$

where γ_x, γ_{Tn}, γ_n are the multipliers of the world private equilibrium conditions associated with the government's optimization problem (4), with γ_x being the multiplier on Home expenditure equation (3), γ_{Tn} the multiplier on technology accumulation (1) for each country n, and γ_n the multiplier on the market clearing condition (2) for each country $n > 1$.

Proof: Appendix B.2.

With technology diffusion, the incentive to exploit the country's monopoly power still presents as the expenditure country n on country 1 goods, π_{n1}, showing up in the export tax formula (7). Most importantly, the Home government is incentivized to manipulate trade to allocate technologies worldwide. However, the Home government has to respect the private equilibrium. That's the reason the multipliers $\{\gamma_{Tn}\}$ on technology accumulation and $\{\gamma_n\}_{n>1}$ on the market clearing conditions show up in the tax and tariff formulae. Moreover, the government chooses these policies in a dynamic way. γ_{Tn} depends on the government's future policies. Hence, current trade policies affect technology accumulations and future trade policies, which in turn shape the current policies through γ_{Tn}. When there are no diffusions,

$\rho = 0$, the government cannot use policies to manipulate the exogenous technology accumulation. In this case, $\gamma_{Tn} = 0$, and we can show that optimal policies of (7)-(8) are the same as (6) in the exogenous case.

Furthermore, according to the export tax formula (7), when $\gamma_{Tn}\left[(T_1/\pi_{n1})^{\rho} - I_n\right] > 0$, Home would want to lower its export tax than the case where there is no diffusion. The term $(T_1/\pi_{n1})^{\rho} - I_n$ captures the relative import quality of country n from Home country, namely the quality of insights embodied in the goods that country n imports from Home country, relative to country n's average quality of insights. If the overall effect is that higher country n's technology is good for the Home, then the marginal benefit of an additional increase in T_n is positive for Home country, i.e., $\gamma_{Tn} > 0$. In this case, Home wants to lower its export taxes to country n, relative to the standard terms of trade incentives, so that country n imports more from Home country and improves its technology.

Similarly, the import tariffs are also affected by the relative import qualities of the Home country. According to the tariff formula (8), Home government considers its import quality from country n relative to its own average quality of insight, i.e. $(T_n/\pi_{1n})^{\rho} - I_1$. If this relative import quality is positive and $\gamma_{T1} \geq 0$, importing from country n is also beneficial from idea learning. In this case, the Home government would lower the tariff on the country n's goods.

2.2 A Simple Case with Two Countries

This section uncovers the government's incentives to manipulate global technology allocations by theoretically examining a two-country model. The key is the import quality of insights relative to domestic quality. When imports bring a higher quality of insights, for example, when Foreign has better technologies, Home government would like to lower import tariffs to learn from Foreign. Home country may want to lower its export tax to another country if a) higher productivity in that country is good for Home, and b) more exports to that country improves the quality of learning and, in turn, Foreign's technology. When Foreign's import quality from Home is high, Home government lowers its export tax so that Foreign can learn from imports from Home, which benefits Home consumers with lower Foreign prices.

Furthermore, we illustrate the mechanism with two numerical examples, varying Foreign efficiency α_2 and varying diffusion parameter ρ.

Corollary 1. *With two countries, the optimal export taxes and import tariffs under technology diffusion satisfy*

$$\frac{1}{1+\tau_2^x} = 1 + (1-\rho)\frac{\theta\pi_{22}}{1+\theta\pi_{22}}\frac{\alpha_2}{\gamma_x x_2}\gamma_{T_2}\left[\left(\frac{T_1}{\pi_{21}}\right)^\rho - \left(\frac{T_2}{\pi_{22}}\right)^\rho\right], \tag{10}$$

$$\frac{1}{1+\tau_2^m} = \frac{\theta\pi_{22}}{1+\theta\pi_{22}}\left\{1 + (1-\rho)\frac{\theta}{1+\theta}\frac{\alpha_1}{\gamma_x x_1}\gamma_{T_1}\left[(\frac{T_2}{\pi_{12}})^\rho - (\frac{T_1}{\pi_{11}})^\rho\right]\right\}. \tag{11}$$

Proof see Appendix C. The proof is a straightforward application of Proposition 3 with $N=2$ and normalizing $\gamma_2 = -\frac{\gamma_x}{\theta\pi_{22}}$.

According to the tax neutrality in Proposition 2, we can set one export tax to zero. In a two-country case, we can normalize $\gamma_2 = 0$ hence $\tau_2^m = 0$ and solve for τ_2^x; or $\tau_2^x = 0$ and solve γ_2 and tariff τ_2^m; or $\gamma_2 = -\frac{\gamma_x}{\theta\pi_{22}}$ hence none of export tax and tariff is zero. With either normalization, the taxes will incorporate both incentives. Here, we choose to normalize $\gamma_2 = -\frac{\gamma_x}{\theta\pi_{22}}$ as it is most convenient to illustrate the incentives behind optimal policies to control both outbound and inbound technological diffusions via trade. Compared to the exogenous technology, no diffusion case where $\tau_2^m = 1/(\theta\pi_{22})$ and $\tau_2^x = 0$, the optimal export tax and tariff under technology diffusion takes into account the incentive to alter trade so as to be able to manipulate technology, which can be seen in the export tax (10), which is no longer zero, and the tariff (11), which include an additional term besides $\tau_2^m = 1/(\theta\pi_{22})$.

The incentive to manipulate technology using export tax is encapsulated in the term $\gamma_{T_2}[(\frac{T_1}{\pi_{21}})^\rho - (\frac{T_2}{\pi_{22}})^\rho]$. The multipliers γ_{Tn} for $n = 1,2$ are associated with the constraints of technology accumulation (1). We label the term in the brackets, $(\frac{T_1}{\pi_{21}})^\rho - (\frac{T_2}{\pi_{22}})^\rho$ or $(\frac{T_2}{\pi_{12}})^\rho - (\frac{T_1}{\pi_{11}})^\rho$, as an *'import quality'*, which is greater than 0 if a country learns more from importing than from domestic sellers. For example, $(\frac{T_1}{\pi_{21}})^\rho - (\frac{T_2}{\pi_{22}})^\rho$ is country 2's relative import quality.

Let's first consider why Foreign's technology matters for Home. First, as Home imports from Foreign, a higher level of foreign technology makes its goods cheaper; on the other hand, a more productive Foreign induces Home to export less and reduce its tax revenue and income. Third, Foreign technology affects Home's future technology. This occurs both directly as Foreign technology diffuses to Home, but also indirectly via trade shares. If a higher T_2 benefits Home ($\gamma_{T_2} > 0$ reflects the benefit of higher foreign technology), and if it is the case that exporting more to Foreign would make them learn more ($T_1/\pi_{21} > T_2/\pi_{22}$), Home would want to lower its export tax so that Foreign can purchase more from Home and in turn improve its technology.

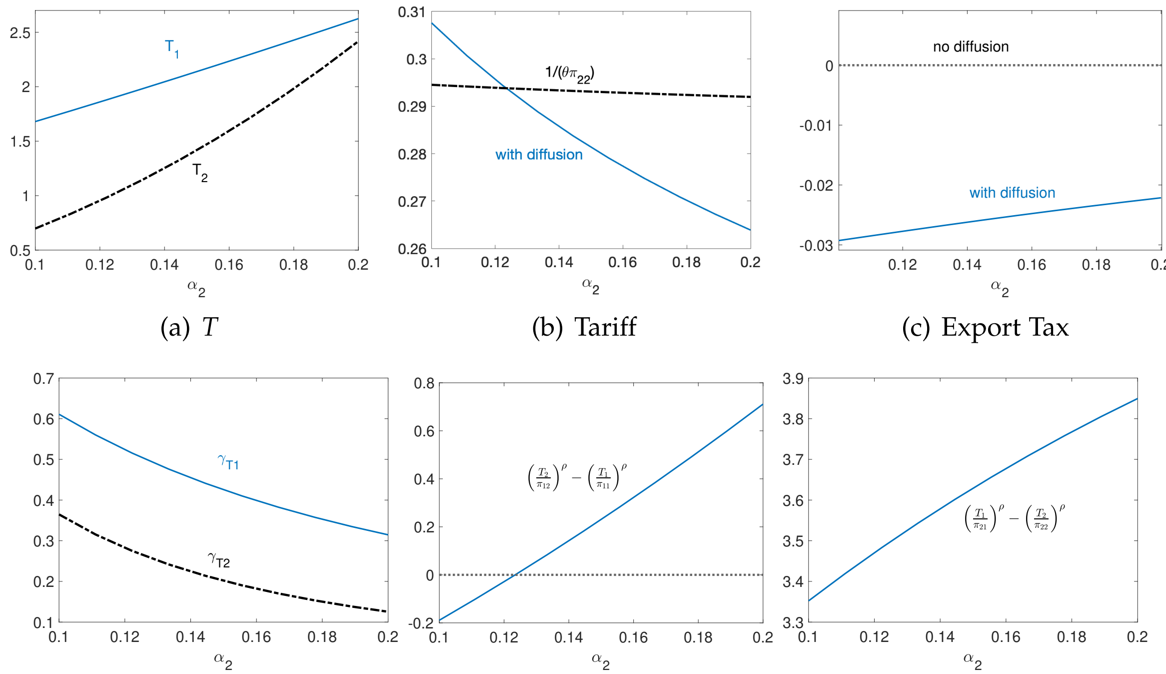
Similarly, when the average quality of insights derived from imports is higher than that accrued from domestic producers ($T_2/\pi_{12} > T_1/\pi_{11}$), the Home government would want to promote imports through subsidies ($\tau_2^m < \frac{1}{\theta\pi_{22}}$), as in equation (11). The import tariffs take into account not only the standard terms of trade consideration but also the incentive to alter imports hence the diffusion from Foreign technology to Home. According to the tariff formula (11), Home government considers its import quality from country 2 relative to its own average quality of insight.

Figure 1 presents a numerical example where one country's efficiency level rises. For the sake of illustration, let the U.S. be country 1, and China country 2. China is less efficient than the U.S. but is larger in size so its goods are cheaper. We allow China's efficiency α_2 to rise from 0.1 to 0.2 and examine the consequent optimal policy.[11] We plot the steady-state optimal trade policies. As China becomes more efficient, the U.S. also improves its T_1 as a result of diffusion from China (Figure 1(a)). The increase in α_2 also improves the U.S.' import quality as $(T_2/\pi_{12})^\rho - (T_1/\pi_{11})^\rho$ increases (Panel (e)). As a result, the U.S. lowers import tariffs (Panel (b)). In this example, when α_2 is larger than 0.12, the U.S.' relative import quality is positive, inducing a relatively lower import tariff compared without diffusion and the standard terms of trade incentive, which is $1/(\theta\pi_{22})$ in Panel (b).

Export taxes take into account the international diffusion effect. Because the U.S. is more productive than China, with $\alpha_1 \geq \alpha_2$, China's relative import quality is positive, i.e., $(T_1/\pi_{21})^\rho >$

[11] In this example, we assume that $\theta = 4$, $\sigma = 2$, $\beta = 0.94$, $\delta = 0.2$, $\rho = 0.6$, $\alpha_1 = 0.2$, $d_{12} = d_{21} = 1.2$, and $L_1 = 1$, $L_2 = 3$.

Figure 1: Optimal Policies with Increasing Foreign Efficiency



(a) T (b) Tariff (c) Export Tax

(d) γ_T (e) Home import quality (f) Foreign import quality

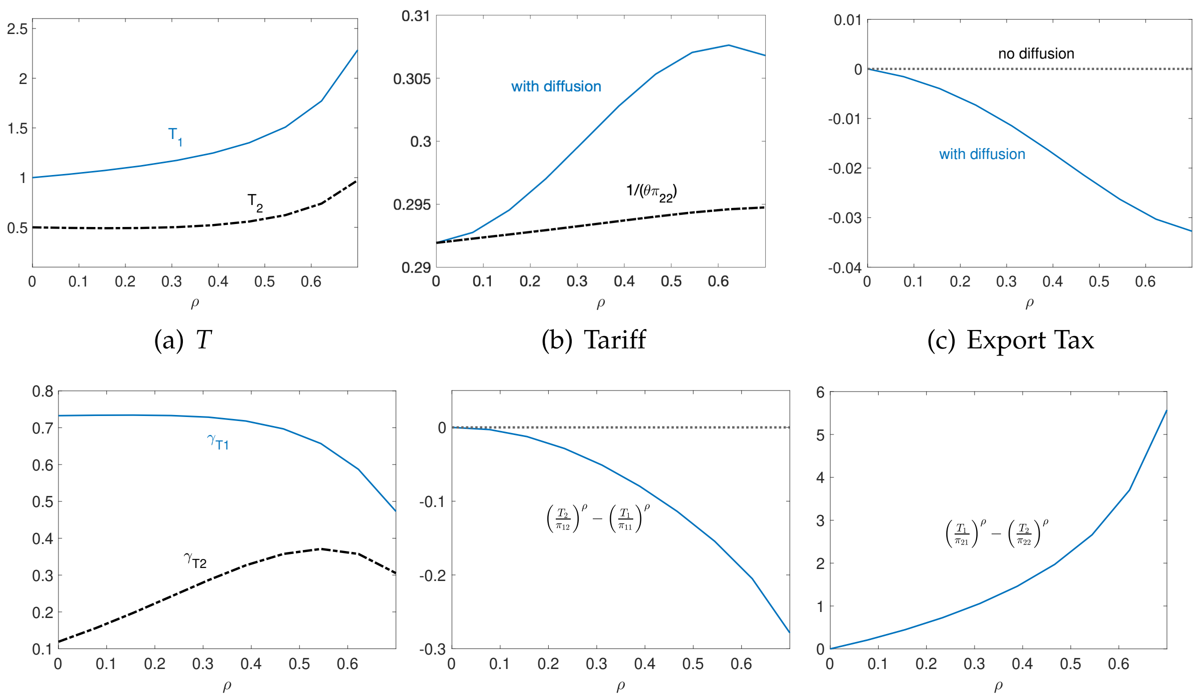
Note: This figure plots the Home optimal policies and the associated equilibrium at the steady state when we vary Foreign country's arrival rates α_2. Home import quality is defined as $(T_2/\pi_{12})^{\rho} - (T_1/\pi_{11})^{\rho}$, and Foreign import quality is $(T_1/\pi_{21})^{\rho} - (T_2/\pi_{22})^{\rho}$. γ_{T_1} and γ_{T2} are the multipliers on technology accumulations (1).

$(T_2/\pi_{22})^{\rho}$, as shown in Panel (f). $\gamma_{T_2} > 0$, consequently, the U.S. export tax is below that without diffusion, as shown in Panel (c). However, the export tax does not decline when α_2 is higher. Even though China's import quality is increasing (Panel (f)), γ_{T_2} has been decreasing. This competitive force dominates the increasing learning effect and reverses the fall in export taxes, as shown in Panel (c).

Next, we consider a case in which the diffusion parameter ρ varies from 0 to 0.7, while retaining the assumption that $\alpha_1 = 0.2$, $\alpha_2 = 0.1$.[12] Figure 2 presents the optimal policies at the steady state, and the resultant level of technology, multipliers, and foreign import qualities at the steady state as ρ rises in value. As in the previous example, the U.S. imports from China because of low import prices, and thus imposes a tariff higher compared to without diffusion

[12]In this numerical example, $\theta = 4$, $\sigma = 2$, $\beta = 0.94$, $\delta = 0.2$, $d_{12} = d_{21} = 1.2$, $L_1 = 1$, $L_2 = 3$.

Figure 2: Optimal Policies with Increasing Diffusion



(a) T (b) Tariff (c) Export Tax

(d) γ_T (e) Home import quality (f) Foreign import quality

Note: This figure plots the Home optimal policies and the associated equilibrium at the steady state when we vary the diffusion parameter ρ. Home import quality is defined as $(T_2/\pi_{12})^{\rho} - (T_1/\pi_{11})^{\rho}$, and Foreign import quality is $(T_1/\pi_{21})^{\rho} - (T_2/\pi_{22})^{\rho}$. γ_{T_1} and γ_{T2} are the multipliers on technology accumulations (1).

as its relative import quality from China is negative (Panel (e)). At the same time, China's import quality is positive (Panel (f)), which leads to a lower export tax of the US relative to the case without diffusion.

Although China's technology is improving, its import quality is still increasing to a certain degree because the U.S. is becoming more productive. When $\rho = 0$, diffusion doesn't depend on trade, and so optimal policies are identical to those without diffusion, namely a tariff of $1/(\theta\pi_{22})$ and zero export tax (Panel (b) and (c)). Diffusion rises along with the value of ρ, allowing both T_1 and T_2 to increase. In this case, U.S. technology T_1 increases faster with ρ, forcing its import quality to fall, and China's relative import quality to rise. The impact of diffusion through trade, however, is not monotone in ρ. When ρ is closer to 1,

$\alpha_n \sum_{i=1}^{N} \left[\pi_{ni,t} \left(\frac{T_{it}}{\pi_{ni,t}} \right)^{\rho} \right] \approx \alpha_n \sum_{i=1}^{N} T_{it}$, and diffusion depends less on trade. The incentive to use tariffs thus starts to fall, as shown in Panel (b).

3 Quantitative Analysis

In this section, we study optimal trade policies quantitatively. To this end, we back out the key parameters such as efficiency parameters, trade costs, and the diffusion parameter using cross-country data. With these parameters, we study the dynamic optimal trade policies during the transition path and in the long run, as well as their attendant welfare implications.

3.1 Sample Selection

Real national account data, including real GDP, physical capital, and employment, comes from PWT 10.1. The data on trade in goods is obtained from BACI and CEPII's database, which is based on COMTRADE. This database provides a harmonized world trade matrix for 253 countries. We use the HS revision 92 and our analysis focuses on the period ranging from 2000 to 2016, preceding the U.S. and China trade war.

We start with the sample of 169 countries, which is the overlap of the two datasets, where the total import value of these countries accounts for 98% of the total import in all countries in 2016. To mitigate the effect of entrepot trade, we combine (1) Belgium, Luxembourg, and the Netherlands, (2) Indonesia, Malaysia, Singapore, and Thailand, and (3) China and Hong Kong, into single entities.

The19 largest countries, based on their GDP in 2016, account for about 80% of the total imports in the sample of 169 countries in 2016. All other countries are considered to be the rest of the world. The final sample of countries in our quantitative analysis thus consists of a balanced panel of 20 countries when we include ROW.[13]

[13]The 19 largest countries include USA, China/HK, Japan, Germany, United Kingdom, France, India, Indonesia/Malaysia/Singapore/Thailand, Italy, Brazil, Canada, Republic of Korea, Belgium/Luxembourg/Netherlands, Australia, Russian Federation, Spain, Mexico, Switzerland, Sweden. We exclude Turkey and Argentina due to the unstable changes in their price indexes from 2010 to 2016.

3.2 Parameterization

The parameters comprise those that are common across countries—such as the Fréchet parameter θ, technology depreciation δ, and the diffusion parameter ρ— and the ones that are country-specific, including the composite input endowment $\{L_n\}$, the matrix of bilateral trade costs $\mathbf{d} = [d_{in}]$, and innovation efficiencies $\{\alpha_n\}$. We choose $\theta = 4$, consistent with the trade elasticity estimated from Simonovska and Waugh (2014). The rest of the parameters are calibrated using the cross-country national accounts and trade data.

The composite input endowment L_n, with $K_n^{\zeta} emp_n^{1-\zeta}$, for each country n, is calibrated using physical capital (K) and employment (emp) in 2016 from PWT 10.1. The capital share ζ is chosen to be 0.36 to match the corporate labor share in the US calculated by Karabarbounis and Neiman (2014).

We back out the matrix of trade costs $\mathbf{d}$ using the year 2016 data and the model equations. The iceberg cost of shipping goods to the country i from country n satisfies

$$d_{in} = \frac{P_i}{P_n} \left(\frac{\pi_{nn}}{\pi_{in}} \right)^{\frac{1}{\theta}}. \tag{12}$$

Hence, the trade cost from n to i is higher if the trade share from n to i is lower compared to the share that the country n sells to itself, controlling the prices of the two markets. Using this ratio, country n's wage and technology cancel out, and give a relation between trade costs, trade share and prices.

To calibrate the technology depreciation δ, we apply the equivalence between our model and the detrended semi-endogenous growth model in Buera and Oberfield (2020), where the growth rate of innovation efficiencies is exogenously driven by the population growth γ, hence the scale of the Frechet distribution T_t grows asymptotically at $\frac{\gamma}{1-\rho}$. In their model, technology evolves according to

$$\tilde{T}_{it+1} = \tilde{T}_{it} + \tilde{\alpha}_{it} \left[\pi_{iit}^{1-\rho} \tilde{T}_{it}^{\rho} + \sum_{n \neq i} \pi_{int}^{1-\rho} \tilde{T}_{nt}^{\rho} \right]. \tag{13}$$

Using the definition of detrended technology and innovation efficiency as $T_{it} \equiv \tilde{T}_{it} e^{-\frac{\gamma}{1-\rho}(t-2016)}$ and $\alpha_i \equiv \left(1 - \frac{\gamma}{1-\rho}\right) \tilde{\alpha}_{it} e^{-\gamma(t-2016)}$, we can show that equation (13) becomes equation (1) in our model with $\delta = \gamma/(1-\rho)$.[14] We choose the population growth rate γ to be 0.78% to match the median annual population growth rate of the 20 economies in our sample from 2000 to 2016.

We then jointly calibrate the country-specific innovation efficiency and the diffusion parameter ρ using an iterative method, which involves two steps. In the first step, for any given ρ, we back out the country-specific arrival rates $\boldsymbol{\alpha} = (\alpha_1, \ldots, \alpha_n)$ using the year 2016 data, assuming the economy is at a steady state. In the second step, with the backed-out $\boldsymbol{\alpha}$, we use the nonlinear least-squares method to estimate the diffusion parameter ρ using the panel data from 2000-2016. We repeat the two steps until we find the fixed point of ρ and $\boldsymbol{\alpha}$.[15]

Specifically, in the first step, for a given ρ and $\gamma = 0.78\%$, we choose α_i for each country i to satisfy the technology evolution in 2016 at the balanced growth path,

$$\frac{\gamma}{1-\rho} \tilde{T}_{i,2016} = \alpha_i \left[\pi_{ii,2016}^{1-\rho} \tilde{T}_{i,2016}^{\rho} + \sum_{n \neq i} \pi_{in,2016}^{1-\rho} \tilde{T}_{n,2016}^{\rho} \right], \tag{14}$$

where $\pi_{in,2016}$ comes from the observed trade share matrix in 2016, and the technology $\tilde{T}_{i,2016}$ is constructed using trade flow and real GDP per input using the model equation $\tilde{T}_{it} = \pi_{iit} \left(\frac{w_{it}}{P_{it}}\right)^{\theta}$. Real GDP per input w/P corresponds to $GDP/(K^{\zeta} emp^{1-\zeta})$, which is constructed using GDP, capital, and employment data from PWT 10.1.

In the second step, with the calculated $\boldsymbol{\alpha}$ from 2016, we estimate the diffusion parameter ρ using the nonlinear least square method with data from 2000-2016 and the following equation,

$$\tilde{T}_{it+1} = \tilde{T}_{it} + \frac{\alpha_i}{1 - \gamma/(1-\rho)} e^{\gamma(t-2016)} \left[\pi_{iit}^{1-\rho} \tilde{T}_{it}^{\rho} + \sum_{n \neq i} \pi_{int}^{1-\rho} \tilde{T}_{nt}^{\rho} \right], \tag{15}$$

where we plug the relation $\tilde{\alpha}_{it} = \frac{\alpha_i}{1 - \frac{\gamma}{1-\rho}} e^{-\gamma(t-2016)}$ into equation (13). We continue these two steps until the estimated ρ is the same as that in the first step. The estimated $\rho = 0.4985$ is

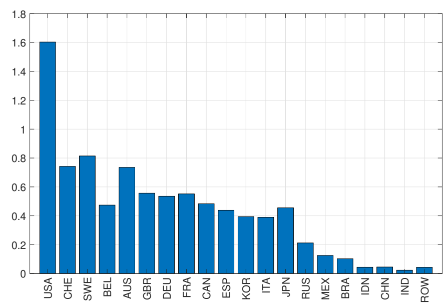
[14] Here, we used the approximation $e^{-\frac{\gamma}{1-\rho}} \approx 1 - \frac{\gamma}{1-\rho}$.

[15] Note that we assume the world has been in a steady state since 2016. However, we do not have to take a stand on whether the world was on a transition path or a steady state between the years 2000 and 2016.

statistically significant at the 1% level. We use $\rho = 0.5$ in our baseline when computing the Home government's optimal dynamic policies.

Figure 3 plots the backed-out arrival rates α for each of the 20 countries. We order the countries by the level of real GDP per input, while ROW is always placed last. On average, the arrival rates are higher for countries with higher GDP per input; the U.S. has the highest α, and China and India are the least efficient in innovating.

Figure 3: Arrival Rates Across Countries



Note: This figure plots the calibrated arrival rates in 2016 with 20 countries and technology diffusion $\rho = 0.5$.

Discussion on estimating ρ. Our estimated $\rho = 0.5$ is close to the value estimated in the literature, though we adopt a different estimation method and data sample. For example, Buera and Oberfield (2020) finds that ρ is about 0.6. First, in their calculation $\gamma = 1\%$, which is the average population growth rate in the US between 1962 and 2000. Instead, we consider the average population growth rate for a sample of 20 countries between 2000 and 2016, and our value is 0.78%. Second, they compute the $\alpha_{US,1962}$ as at the steady state using equation (14) and $\alpha_{US,2000}$ using equation (15). Given the growth rate of α as the population growth rate 1%, only when $\rho = 0.6$, the accumulated growth of α match $\alpha_{US,1962}$ and $\alpha_{US,2000}$. Instead, we use the nonlinear least square method, which considers all years from 2000 to 2016 and all countries in our sample to estimate ρ.

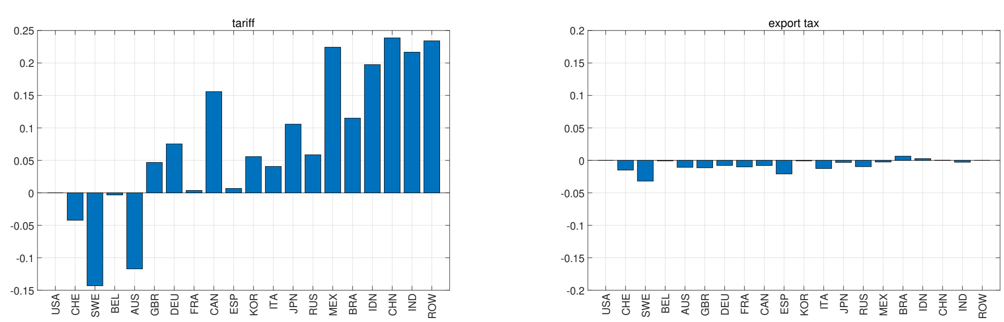
It is worth noting that we do not view our contribution as identifying the diffusion parameter ρ, even though we propose an alternative method to estimate it using panel data within our model. The identification may need to use alternative strategies or micro-level data. This deserves future research. Besides using $\rho = 0.5$ as the benchmark value, we conduct robustness analysis over alternative ρ values. Moreover, our work does provide a toolkit for analyzing optimal policies with different levels of diffusion.

In the next subsection, we study optimal policies assuming that countries are in a steady state at the end of the sample period, the year 2016. In the analysis, the parameter values remain at the steady state level, including the calibrated ρ and γ, arrival rates of ideas α_i, iceberg costs $d_{in,2016}$, and composite inputs $L_{i,2016}$ for each country. The optimal policies are for the U.S. or China during the transition path and in the long-run steady state. We use our estimated $\rho = 0.5$ in the baseline, and we explore the robustness of optimal dynamic policies under alternative diffusion values, including $\rho = 0.6$ and 0.4.

3.3 Unilateral Optimal Dynamic Policies of the U.S.

In this section, we examine U.S. optimal policies, assuming that the fundamentals (trade costs, arrival rates, and endowments) are fixed at 2016 levels. Optimal policies are given by equation (7) and (8) in Proposition 3. Proposition 2 indicates that one of the taxes can be normalized to zero, and thus we assign export taxes on ROW-goods to be zero throughout different exercises. Appendix D describes our computation algorithm and the system of equations that characterizes the optimal policies and the associated world equilibrium.

Figure 4: US Optimal Policies with Diffusion ($\rho = 0.5$), 20 Countries, Steady State



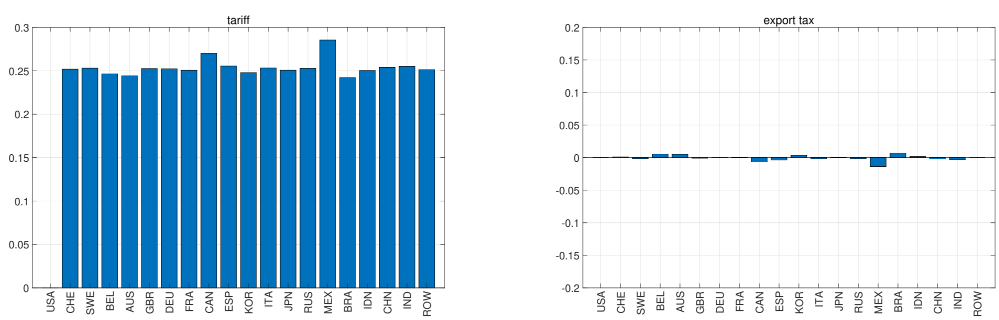
(a) Tariff (b) Export tax

Note: This figure plots US optimal trade policies at the steady state in the model with 20 countries and technology diffusion $\rho = 0.5$.

Consider optimal trade policies in the long run, as shown in Figure 4. At the steady state, the U.S. invokes heterogeneous import tariffs and export taxes. Import subsidies are largely positively correlated with a country's TFP level, while export taxes are largely negatively correlated with a country's TFP level. Imports from developed countries such as Switzerland, Sweden, and Australia receive more subsidies, while most emerging economies such as Indonesia, India, and China face larger U.S. tariffs (fewer subsidies).

Trade costs have an important influence over optimal policies: higher trade costs to the U.S. imply high productivity after selection, as only more productive producers are able to sell to the U.S. And thus, for the same reason, the U.S. imposes a higher tariff on Canada and Mexico than on other countries with similar efficiency levels, as there are lower trade costs associated with the two economies. Similarly, endowments also matter; the U.S. imports more from Mexico not only because of lower trade costs but also because of lower wages in Mexico—rather than high technology. Thus, tariffs imposed on Mexico are higher than others with similar levels of efficiency. Table 1 reports detailed numbers.

Figure 5: US Optimal Policies without Diffusion ($\rho = 0$), 20 Countries, Steady State



(a) Tariff (b) Export tax

Note: This figure plots US optimal trade policies at the steady state with 20 countries but no diffusion.

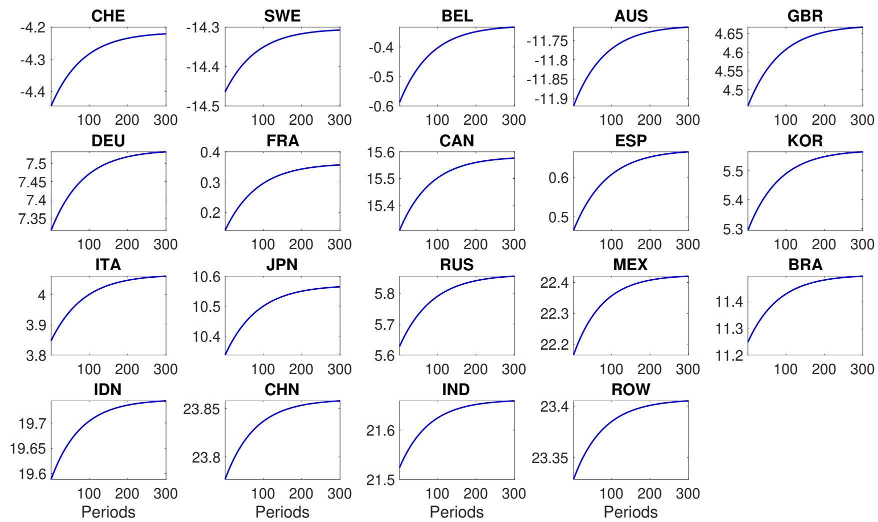
As a reference, we also present optimal policies with no technology diffusions by setting $\rho = 0$. Note that in this exercise, we do not recalibrate α_n since the goal is to compare with U.S. optimal policies under no technology diffusion. Figure 5 plots the U.S. optimal policies with $\rho = 0$. Export taxes and import tariffs come from equation (6) of Proposition 1 combined with the associated equilibrium. The tariffs comprise solely the terms of trade effect and around $1/\theta = 0.25$. Meanwhile, export taxes are small and close to zero.

From Figure 4 and 5, we can see that the U.S. lowers import tariffs and subsidizes exports for most countries under diffusion compared to the case without. Import subsidies take into consideration the presence of technology diffusion and the higher import quality from more productive countries. The amount of export taxes U.S. levies on a specific country depends on how much they can learn from the U.S.. Since most countries would gain from technological diffusion from the country with the highest level of technology—the U.S. lowers its export taxes. The benefit to U.S. consumers is that higher foreign productivity amounts to a fall in U.S. import prices.

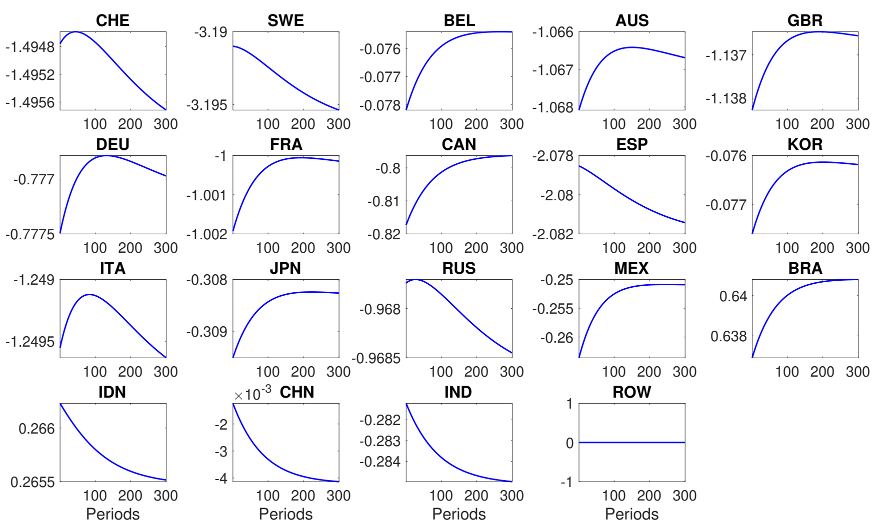
The dispersion of tariffs across foreign countries allows the U.S. to import more and learn more from more efficient countries, even if the overall level of tariffs is more dictated by the static terms of trade considerations than by incentives to alter diffusion. This, of course, impinges on overall levels of trade and technology, the reason why other countries see long-run losses. Note that optimal tariffs display greater cross-country variation than export taxes. This is because tariffs directly affect inbound diffusion, whereas export taxes affect Home only indirectly because Home's outbound diffusion in the first instance improves foreign technology before it benefits Home through lower prices.

Optimal Policies of the U.S. during Transition and Welfare We now examine optimal policies during the transitional period where technology levels go from their 2016 levels to the long-run steady state. Figure 6 shows the transition path of U.S. optimal policies, where the levels of technology in the first years are those of the private-equilibrium steady-state. As expected, the ranking of export and tariff subsidies is largely positively correlated with a country's initial technology level, shown in Figure 7.

Figure 6: US Optimal Trade Policies during Transition



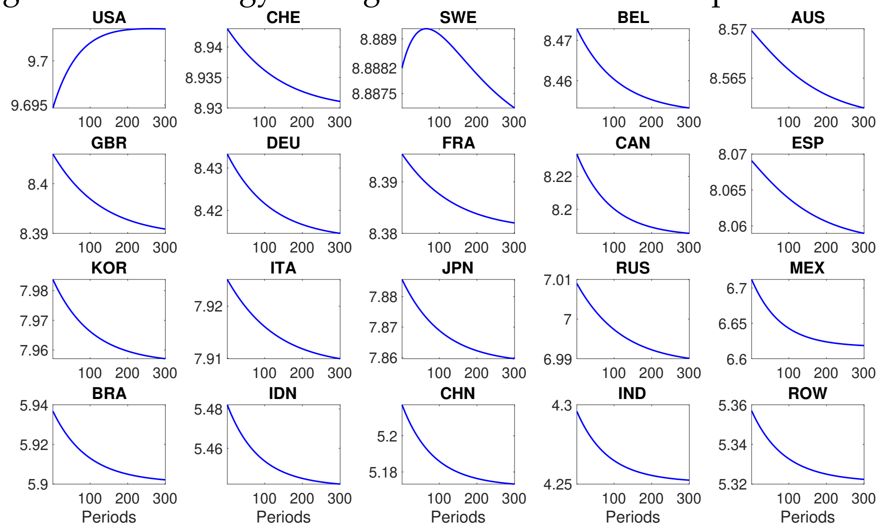
(a) Tariff



(b) Export tax

Note: This figure plots the transition paths of US optimal import tariffs (t) and export taxes (τ_x) with technology diffusions, $\rho = 0.5$. The export tax on ROW is normalized to be zero.

Figure 7: Technology during Transition under US Optimal Policies



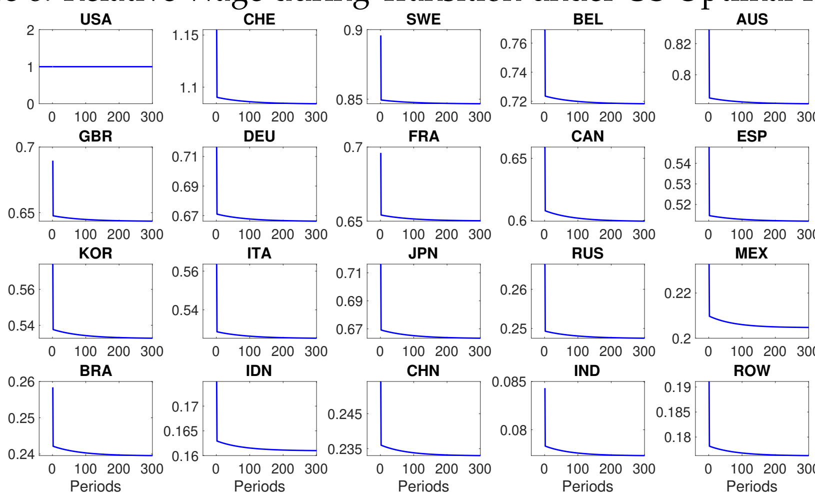
Note: This figure plots the transition path of logged technology under the US's optimal dynamic trade policies with technology diffusion, $\rho = 0.5$.

On the transition path, other countries' T fall relative to the U.S. (Figure 7). This causes import tariffs to rise further since it is less desirable to subsidize foreign imports given the larger gap with U.S. technology. To understand why countries' technologies tend to fall, consider the two dynamic driving forces: on the one hand, when the U.S. imposes import tariffs on most countries, it increases the demand for its domestic goods, occasioning an increase in U.S wages and a relative fall in all other countries' wages (Figure 8). As a result of higher relative U.S. wages, imports from the U.S. fall (as shown in Figure 9), and other countries learn less from the U.S. This results in lower levels of technology in those countries.

On the other hand, the fact that the U.S. technology improves over time (first panel of Figure 7), also raises technologies in other countries through trade spillovers. But that improvement is relatively small—only about 0.87%, for the simple reason that the U.S. is already a leader in terms of technology and sees little room for improvement. Consequently, the first force, driven by reduced imports from the U.S. due to higher U.S. wages, dominates the second effect, and causes all countries except the U.S. to experience a technology regress. Still, countries with high efficiency see a smaller decline in technology than countries with lower efficiency since the former is subsidized relatively more. At the same time, more efficient countries with larger

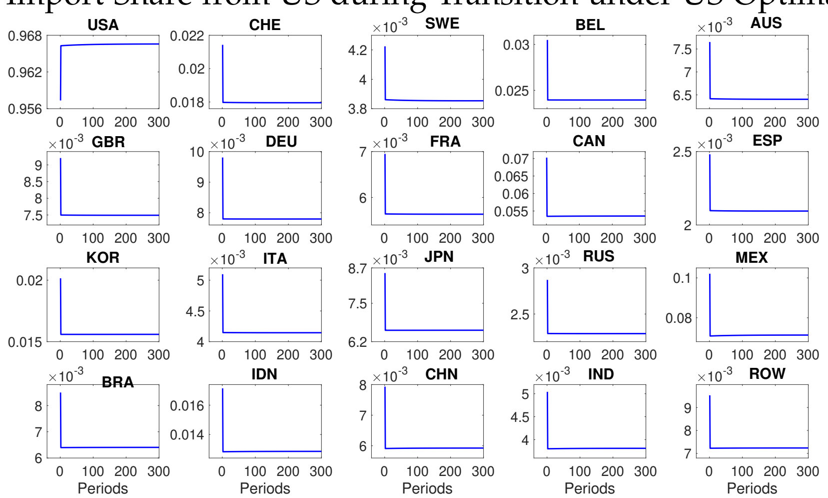
α 's also have higher steady-state technologies (detailed numbers can be seen in Table 1). But most importantly, technology levels fall in all countries as a result of the U.S. policy.

Figure 8: Relative Wage during Transition under US Optimal Policies



Note: This figure plots relative wage to the US under US optimal trade policies with technology diffusion.

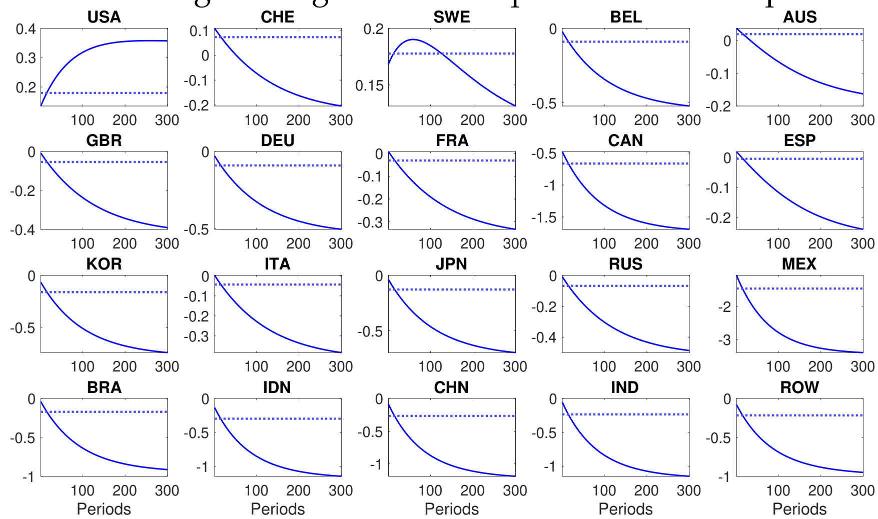
Figure 9: Import Share from US during Transition under US Optimal Policies



Note: This figure plots the evolution of import shares from US $\{\pi_{i,US}\}$ for $i = 1, 2, .., 20$ overtime under the US's optimal trade policies with technology diffusion.

Figure 10 depicts the transition path for the percentage change in consumption and consumption equivalence (blue dotted lines) under U.S. optimal policies–relative to private consumption levels at the original steady-state without policy. Over time, U.S. consumption rises along with rises in technology. The blue dotted line shows that the U.S. benefits 0.18% from

Figure 10: Percentage Change of Consumption under US Optimal Policies



Note: This figure plots the transition path for the percentage change in consumption and consumption equivalence in our benchmark— relative to consumption under the private equilibrium with diffusion. In each subfigure, the solid blue line is the percentage change in consumption, and the dotted blue line is the percentage change in consumption equivalences.

its optimal policies, taking into account both short-run and long-run effects. Most other countries lose due to tariffs and long-run technology decline. Table 1 reports detailed numbers of changes in consumption equivalence.

Table 1 summarizes optimal U.S. export taxes and import tariffs, the change in levels of technology, and real consumption, all at the steady state, as well as the change in consumption equivalence considering the whole transition path and the steady state. The U.S. welfare increase of 0.18% comes from the high levels of consumption in the short run and the increase in technology, which further raises consumption levels in the later periods. This leads to a relatively smaller increase in consumption equivalence compared to the consumption increase observed in the new steady state. As for other countries, during the transition, technology declines, and the changes in consumption equivalence are higher than the changes in consumption at the steady state.

Table 1: US Optimal Policies, $\rho = 0.5$, 20 countries

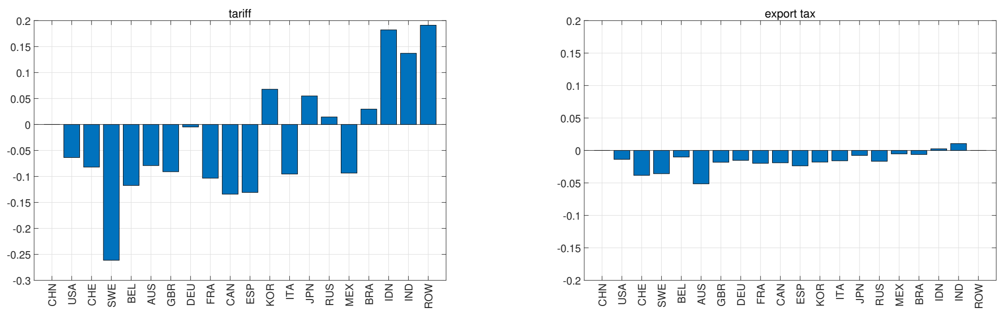
Country	Export tax at SS (%)	Tariff at SS (%)	Change of technology at SS (%)	Change of real consumption at SS (%)	Change of consumption equivalence(%) SR+LR
USA			0.87	0.35	0.18
CHE	-1.50	-4.22	-1.34	-0.24	0.07
SWE	-3.20	-14.31	-0.21	0.10	0.18
BEL	-0.08	-0.33	-2.13	-0.56	-0.09
AUS	-1.07	-11.71	-0.91	-0.19	0.02
GBR	-1.14	4.67	-1.67	-0.43	-0.05
DEU	-0.78	7.54	-2.04	-0.54	-0.09
FRA	-1.00	0.36	-1.49	-0.37	-0.03
CAN	-0.80	15.58	-5.08	-1.75	-0.66
ESP	-2.08	0.67	-1.16	-0.27	-0.00
KOR	-0.08	5.57	-2.87	-0.79	-0.16
ITA	-1.25	4.07	-1.68	-0.42	-0.04
JPN	-0.31	10.57	-2.81	-0.74	-0.13
RUS	-0.97	5.86	-2.07	-0.53	-0.07
MEX	-0.25	22.42	-9.71	-3.46	-1.46
BRA	0.64	11.50	-3.68	-0.96	-0.17
IDN	0.27	19.75	-4.25	-1.19	-0.30
CHN	-0.00	23.86	-4.61	-1.24	-0.27
IND	-0.29	21.66	-4.57	-1.19	-0.23
ROW	0.00	23.41	-3.67	-0.99	-0.22

Note: This table summarizes US optimal export taxes and tariffs on the other 19 countries and the associated equilibrium technology and consumption at the steady state, relative to the initial private equilibrium, as well as the change in consumption equivalence considering the whole transition path and the steady state.

3.4 Unilateral Optimal Dynamic Policies of China

We next examine optimal policies from China's perspective, shown in Figure 11. The export tax on ROW is again normalized to zero. Since China has a low arrival rate α among the 20 countries shown in Figure 3, it is heavily incentivized to subsidize its imports— especially from countries with high efficiency. The export taxes for most countries are lower than those in the exogenous technology/no diffusion case (Figure 12), reflecting its incentive to let other countries learn from the high quality of insights derived from its exports. This is all the more true for most emerging countries, such as India and Indonesia. It may seem puzzling given China's low levels of technology among the 20 countries. But since China's exports amount to a very small fraction of spending in many countries, this implies high trade costs from China, and thus a more positive selection. Note that high trade costs for developing countries are also consistent with evidence in the literature. The fact that trade costs matter is again evident in the optimal tariffs set on Korea and Japan. Optimal tariffs are higher for these two countries compared to other countries with similar levels of efficiency, because of their implied lower trade cost to China.

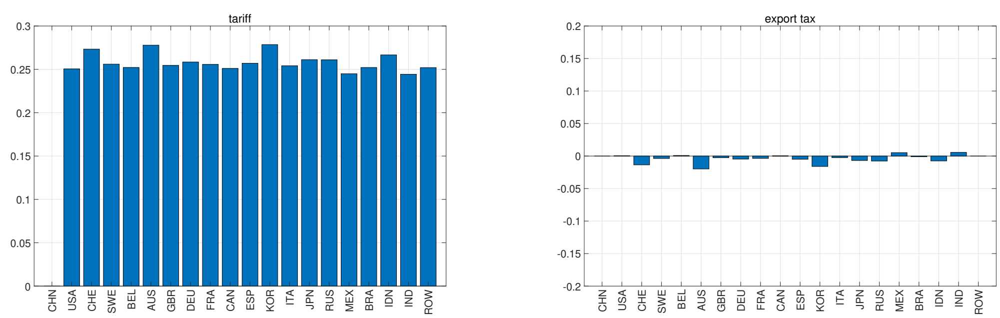
Figure 11: China Optimal Policies with Diffusion ($\rho = 0.5$), 20 Countries, Steady State



(a) Tariff (b) Export tax

Note: This figure plots China's optimal trade policies at the steady state in the model with 20 countries with technology diffusion.

Figure 12: China Optimal Policies without Diffusion ($\rho = 0$), 20 Countries, Steady State



(a) Tariff (b) Export tax

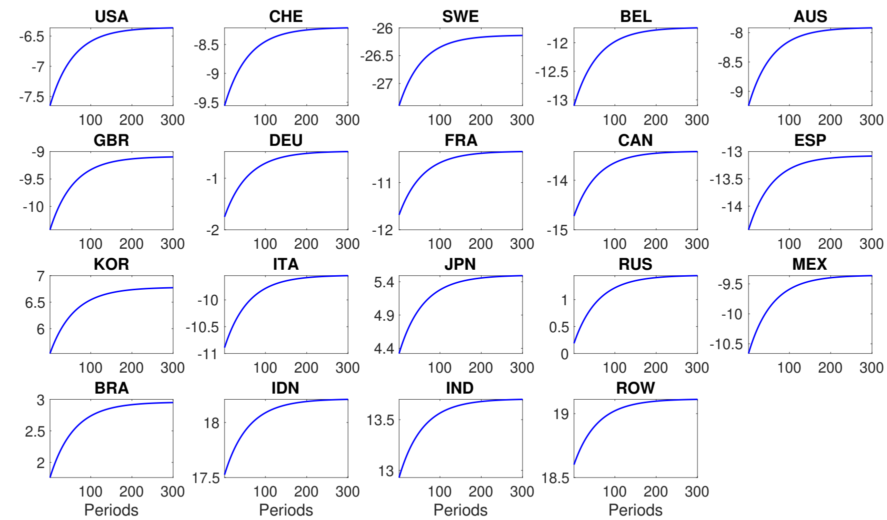
Note: This figure plots China's optimal trade policies at the steady state in the model with 20 countries but no technology diffusion.

Optimal Policies of China during Transition and Welfare Figure 13 shows the transition under Chinese optimal policies. Similar to the U.S. case, China initially imposes export taxes and import subsidies close to their steady-state levels. The overall level of subsidies (for static terms of trade consideration) leads to a decline in China's technological gap with others, shown in Figure 14, and this then causes import subsidies to fall over time—-indicating China's catching up.

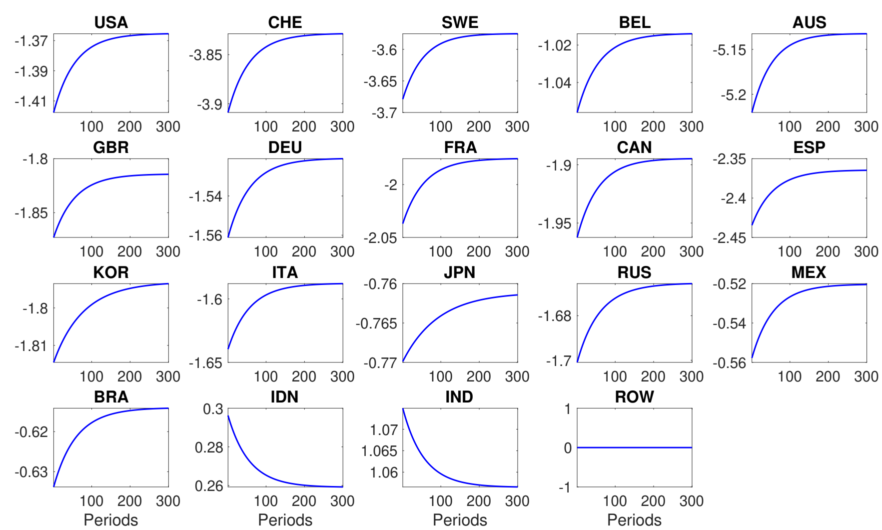
As Figure 14 shows, the global impact stands in stark contrast to that of the U.S. optimal policies. Whereas in the latter, all other countries' technology falls, China's policies drive a larger heterogeneity in technological changes. Some countries like the U.S., Switzerland, Sweden, Australia, and Canada experience a large increase in technology, while countries such as Korea, Japan, Brazil, India, and Indonesia suffer a decline. Countries such as India and Indonesia with low initial levels of technology see falling wages as a result of higher import tariffs, and as a result, substitute imports with domestic goods which leads to less learning from imports. These results suggest that the Chinese optimal policies generally benefit advanced economies more than they benefit developing ones.

Despite distinct outcomes under U.S. and China policies, the underlying forces are similar: policies alter wages and China's technology level, which then change patterns in trade and diffusion.

Figure 13: China Optimal Trade Policies during Transition



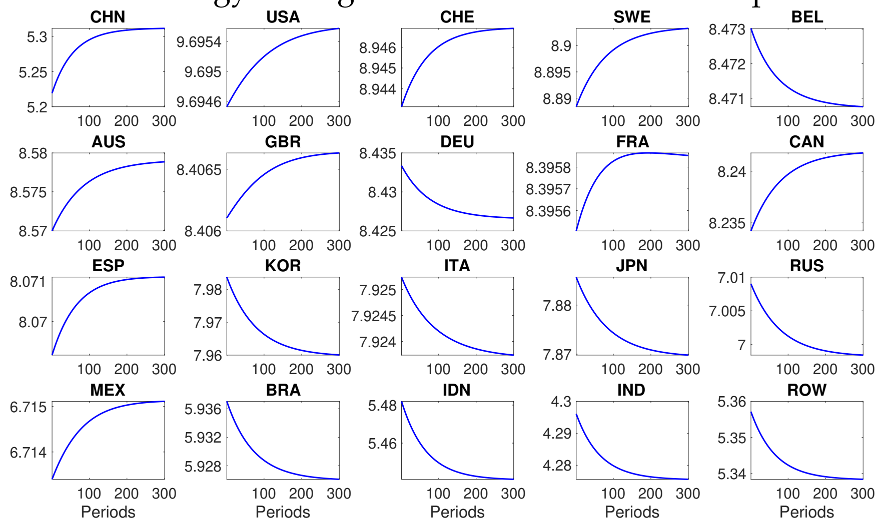
(a) Tariff



(b) Export tax

Note: This figure plots the transition paths of China's optimal import tariffs (t) and export taxes (τ_x) under technology diffusion. The export tax on ROW is normalized to be zero.

Figure 14: Technology during Transition under China's Optimal Policies



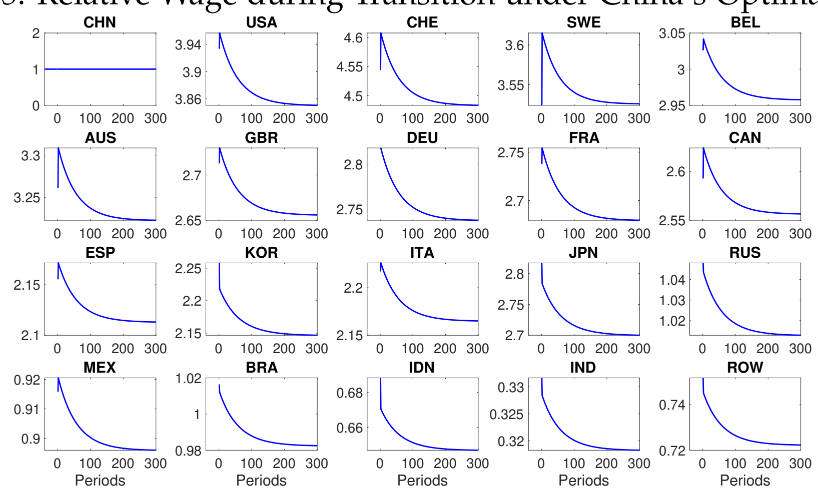
Note: This figure plots technology during transition under China's optimal trade policies with technology diffusion.

The two cases differ because under U.S. policies, it ends up buying relatively more from itself than from others, and the rise in its relative wages reduces the imports and learning in other countries. This effect is strong enough to mute any wage differentials across countries. By contrast, in the China case, the larger dispersion in tariffs induces China to buy more from more advanced countries and less from developing ones. This initially drives up the wages slightly in the former countries and pushes down the wages in the latter (Figure 15), causing the former to start to import more from China (Figure 16). As explained above, importing more from China doesn't necessarily mean learning less —as high trade costs from China result in more positive selection.

Another driving force affecting all other countries is the neighboring effect in the multi-country setup—where countries such as Korea and Japan are subject to higher tariffs because of their implied lower trade cost. The fall in wages in Korea and Japan, however, makes their goods more competitive in the world market and, in turn, benefits the advanced economies. Advanced economies., for instance, would switch to imports from Korea and Japan relative to other developing countries and, given their higher levels of α, benefit from improved learning.

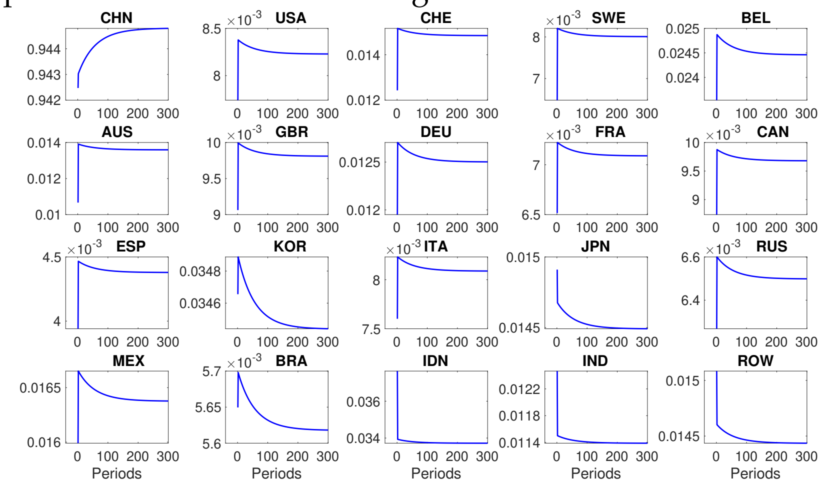
Due to these two forces, the advanced economies' technology increase on the impact. Over time, China's technology dramatic improvement in technology raises its relative wages, and countries start to buy less from it. Though they import less from China, China's own rise in technology contributes to the increase in technologies elsewhere. In the new steady state, similar to the U.S. under its own policies, China sees higher wages and improved technology. But unlike in the U.S. case, China's technology improves dramatically, by almost 10% in the long run due to the relatively low level of initial technology in China. This large increase in technology dominates the rising wage in China. As a result, in the long run, the U.S., Switzerland, Sweden, Australia, and Canada increase their import share from China compared to the private equilibrium, as shown in Figure 16 and they also benefit from the dramatic technological improvement in China.

Figure 15: Relative Wage during Transition under China's Optimal Policies



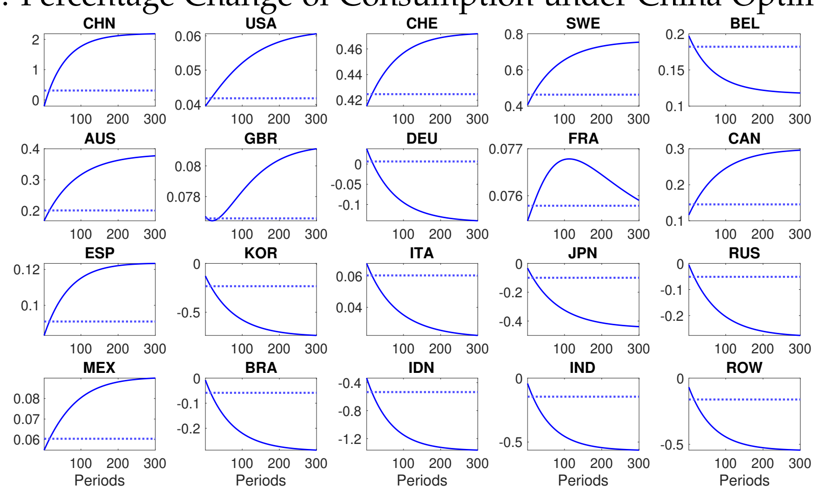
Note: This figure plots the transition path of relative wage to China in each period under China's optimal trade policies with technology diffusion.

Figure 16: Import Share from China during Transition under China's Optimal Policies



Note: This figure plots the evolution of import shares from China $\{\pi_{i,CN}\}$ for $i = 1, 2, .., 20$ over time under the China's optimal trade policies with technology diffusion.

Figure 17: Percentage Change of Consumption under China Optimal Policies



Note: This figure plots the percentage change of consumption and the percentage change of consumption equivalences under China's optimal trade policies with technology diffusion, from the consumption from the private equilibrium without China's trade taxes but under technology diffusion. In each subfigure, the solid blue line is the percentage change of consumption, and the dotted blue line is the percentage change of consumption equivalences.

Table 2: China Optimal Policies, $\rho = 0.5$, 20 countries

Country	Export tax at SS(%)	Tariff at SS(%)	Change of technology at SS(%)	Change of real consumption at SS(%)	Change of consumption equivalence(%)SR+LR
CHN			9.46	2.20	0.31
USA	-1.37	-6.36	0.11	0.06	0.04
CHE	-3.83	-8.20	0.39	0.47	0.42
SWE	-3.58	-26.13	1.55	0.76	0.46
BEL	-1.01	-11.73	-0.24	0.12	0.18
AUS	-5.13	-7.91	0.93	0.38	0.20
GBR	-1.81	-9.09	0.05	0.08	0.08
DEU	-1.52	-0.47	-0.70	-0.14	0.01
FRA	-1.98	-10.33	0.03	0.08	0.08
CAN	-1.89	-13.41	0.78	0.30	0.15
ESP	-2.36	-13.07	0.20	0.12	0.09
KOR	-1.79	6.78	-2.45	-0.75	-0.23
ITA	-1.59	-9.54	-0.16	0.02	0.06
JPN	-0.76	5.50	-1.66	-0.45	-0.10
RUS	-1.67	1.45	-1.10	-0.28	-0.05
MEX	-0.52	-9.35	0.18	0.09	0.06
BRA	-0.61	2.96	-1.13	-0.29	-0.06
IDN	0.26	18.21	-4.21	-1.38	-0.53
IND	1.06	13.71	-2.11	-0.57	-0.15
ROW	0.00	19.11	-1.93	-0.55	-0.16

Note: This table summarizes China's optimal export taxes and tariffs on the other 19 countries and the associated equilibrium technology and consumption at the steady state, relative to the initial private equilibrium, as well as the change in consumption equivalence considering the whole transition path and the steady state.

Figure 17 plots the percentage change of consumption paths and consumption equivalences under Chinese trade policies. China's welfare, in terms of consumption equivalence, increases by about 0.31%. Countries with higher efficiency may benefit from China's optimal policies, as they are highly subsidized, while countries with lower efficiency suffer welfare loss. Table 2 summarizes China's optimal policies and the attendant technology and welfare changes for each country.

3.5 Robustness Analysis for Different ρ

The quantitative results of optimal policies depend on the degree of diffusion 0.5. We calibrate the diffusion parameter through the lens of our model and compute the optimal policies and associated welfare gains. This section shows how policies and welfare change under alternative diffusion parameters. For each ρ, we calibrate $\{\alpha_n\}$ using equation (14) so that the world private equilibrium at the steady state is consistent with the year 2016 panel data. We then proceed to conduct analyses of the optimal policies of the U.S. and China. The value of ρ ranges from 0.4 to 0.6. Results are shown in Table 3-4.

Table 3: US Optimal Policies for different ρ

	$\rho = 0.4$				$\rho = 0.5$				$\rho = 0.6$			
Country	τ^x	τ^m	$\%\triangle T$	$\%\triangle CE$	τ^x	τ^m	$\%\triangle T$	$\%\triangle CE$	τ^x	τ^m	$\%\triangle T$	$\%\triangle CE$
USA			-1.05	0.17			0.87	0.18			4.86	0.25
CHE	-0.66	4.21	-1.81	-0.08	-1.50	-4.22	-1.34	0.07	-3.05	-11.59	0.61	0.31
SWE	-1.36	-3.54	-0.84	0.04	-3.20	-14.31	-0.21	0.18	-7.31	-23.23	2.28	0.43
BEL	0.24	6.83	-2.33	-0.17	-0.08	-0.33	-2.13	-0.09	-0.63	-6.71	-0.59	0.03
AUS	-0.18	-1.83	-1.36	-0.04	-1.07	-11.71	-0.91	0.02	-2.78	-20.05	1.29	0.15
GBR	-0.66	10.59	-1.72	-0.08	-1.14	4.67	-1.67	-0.05	-1.98	-0.78	-0.26	0.01
DEU	-0.43	12.62	-1.92	-0.11	-0.78	7.54	-2.04	-0.09	-1.39	2.87	-0.84	-0.05
FRA	-0.49	7.46	-1.49	-0.06	-1.00	0.36	-1.49	-0.03	-1.96	-6.00	-0.16	0.02
CAN	-0.85	18.83	-5.34	-0.73	-0.80	15.58	-5.08	-0.66	-0.74	12.52	-3.11	-0.57
ESP	-1.15	7.84	-1.15	-0.03	-2.08	0.67	-1.16	-0.00	-4.11	-5.75	0.21	0.06
KOR	0.15	11.13	-2.89	-0.19	-0.08	5.57	-2.87	-0.16	-0.50	0.53	-1.32	-0.10
ITA	-0.72	10.22	-1.60	-0.06	-1.25	4.07	-1.68	-0.04	-2.28	-1.53	-0.39	0.00
JPN	-0.15	14.71	-2.46	-0.12	-0.31	10.57	-2.81	-0.13	-0.62	6.76	-1.60	-0.12
RUS	-0.56	11.48	-1.76	-0.06	-0.97	5.86	-2.07	-0.07	-1.78	0.76	-0.92	-0.05
MEX	-0.73	24.08	-10.06	-1.43	-0.25	22.42	-9.71	-1.46	0.30	20.93	-7.19	-1.45
BRA	0.69	15.01	-3.54	-0.15	0.64	11.50	-3.68	-0.17	0.54	8.25	-1.98	-0.16
IDN	0.22	21.05	-4.27	-0.28	0.27	19.75	-4.25	-0.30	0.32	18.66	-2.61	-0.29
CHN	-0.09	24.26	-4.33	-0.23	-0.00	23.86	-4.61	-0.27	0.10	23.55	-3.07	-0.28
IND	-0.31	22.58	-4.33	-0.19	-0.29	21.66	-4.57	-0.23	-0.25	20.92	-2.94	-0.24
ROW	0.00	23.78	-3.57	-0.19	0.00	23.41	-3.67	-0.22	0.00	23.12	-2.18	-0.21

Note: This table summarizes US optimal export taxes and tariffs on the other 19 countries and the associated equilibrium technology and the change in consumption equivalence considering the whole transition path and the steady state, for different ρ. $\%\triangle$ denotes percentage change, CE denotes consumption equivalence.

Table 4: China Optimal Policies for different ρ

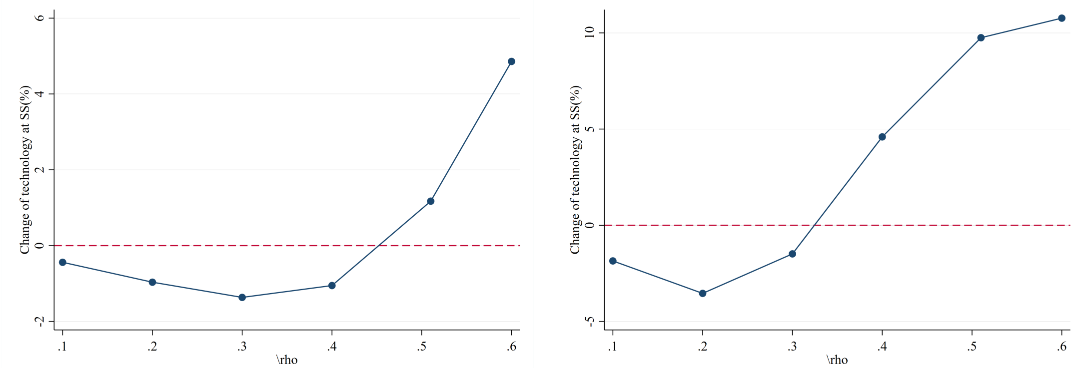
	$\rho = 0.4$				$\rho = 0.5$				$\rho = 0.6$			
Country	τ^x	τ^m	$\%\triangle T$	$\%\triangle CE$	τ^x	τ^m	$\%\triangle T$	$\%\triangle CE$	τ^x	τ^m	$\%\triangle T$	$\%\triangle CE$
CHN			4.59	0.18			9.46	0.31			10.77	0.43
USA	-1.07	-2.68	0.11	0.02	-1.37	-6.36	0.11	0.04	-1.52	-7.49	0.00	0.05
CHE	-3.32	-3.58	0.13	0.24	-3.83	-8.20	0.39	0.42	-4.03	-10.08	0.46	0.51
SWE	-2.60	-19.21	0.76	0.27	-3.58	-26.13	1.55	0.46	-4.27	-29.78	2.15	0.62
BEL	-0.77	-7.10	-0.09	0.10	-1.01	-11.73	-0.24	0.18	-1.13	-13.59	-0.36	0.21
AUS	-4.56	-3.22	0.39	0.11	-5.13	-7.91	0.93	0.20	-5.28	-9.95	1.20	0.26
GBR	-1.47	-4.87	0.07	0.04	-1.81	-9.09	0.05	0.08	-2.00	-10.69	-0.04	0.09
DEU	-1.32	2.31	-0.44	-0.01	-1.52	-0.47	-0.70	0.01	-1.60	-0.95	-0.89	-0.00
FRA	-1.60	-5.84	0.03	0.04	-1.98	-10.33	0.03	0.08	-2.18	-12.12	-0.05	0.09
CAN	-1.46	-8.50	0.54	0.09	-1.89	-13.41	0.78	0.15	-2.13	-15.50	0.77	0.18
ESP	-1.90	-8.11	0.11	0.05	-2.36	-13.07	0.20	0.09	-2.63	-15.18	0.15	0.11
KOR	-1.93	8.64	-1.70	-0.23	-1.79	6.78	-2.45	-0.23	-1.57	7.01	-2.94	-0.29
ITA	-1.28	-5.20	-0.07	0.03	-1.59	-9.54	-0.16	0.06	-1.75	-11.18	-0.30	0.07
JPN	-0.86	7.26	-0.95	-0.08	-0.76	5.50	-1.66	-0.10	-0.60	5.78	-2.22	-0.15
RUS	-1.53	3.97	-0.69	-0.04	-1.67	1.45	-1.10	-0.05	-1.67	1.21	-1.41	-0.08
MEX	-0.31	-5.29	0.26	0.03	-0.52	-9.35	0.18	0.06	-0.63	-10.79	-0.03	0.07
BRA	-0.57	4.94	-0.67	-0.04	-0.61	2.96	-1.13	-0.06	-0.59	3.07	-1.44	-0.09
IDN	0.01	17.96	-3.39	-0.47	0.26	18.21	-4.21	-0.53	0.42	19.38	-4.26	-0.59
IND	0.93	13.68	-1.41	-0.10	1.06	13.71	-2.11	-0.15	1.13	14.94	-2.31	-0.18
ROW	0.00	18.53	-1.42	-0.13	0.00	19.11	-1.93	-0.16	0.00	20.35	-2.05	-0.19

Note: This table summarizes China's optimal export taxes and tariffs on the other 19 countries and the associated equilibrium technology and the change in consumption equivalence considering the whole transition path and the steady state, for different ρ. $\%\triangle$ denotes percentage change, CE denotes consumption equivalence.

The main takeaway from these exercises is that as ρ increases from 0.4 to 0.6, optimal trade policies for both the US and China cases become more dispersed, i.e., higher subsidies to some countries' imports and higher tariffs on other countries. The welfare gains from optimal policies are consequently higher. It may look puzzling that when $\rho = 0.4$, the U.S.'s long-run technology decreases rather than rises under its own policies.

Consider Figure 18, which depicts the percentage change of US and China's technology at steady state for different ρ, under their optimal trade policies, respectively, from the private equilibrium. The change in technology is negative for low levels of ρ while turning more positive for higher levels of ρ. There are two opposing forces at play: the standard terms of trade effect and the spillover from trade diffusion. When ρ is small, the terms of trade effect dominates. The country that makes policy tends to increase import tariffs to exploit the terms of trade. As a result, countries trade less and learn less from trade. Technologies fall. When ρ gets larger, the spillover effect starts to dominate. The policy country would like to take advantage of the foreign country's technology through trade. Thus, it imposes differential tariffs across countries and improves learning and technology. The impact on one's own technology due to policies thus follows a U-shape.

Figure 18: Percentage change of technology at SS for different ρ



(a) Home country—-US (b) Home country—-China

Note: Panel(a) plots the US percentage change of technology (compared to the private equilibrium) at steady state under US optimal trade policies with technology diffusion for different ρ. Panel (b) plots China's percentage change of technology (compared to the private equilibrium) at steady state under China's optimal trade policies with technology diffusion for different ρ.

4 Conclusion

This paper examines optimal dynamic policies in a global economy when there is technological diffusion. We derive theoretical results to explain why and how a country will want to manipulate technological diffusion so as to alter levels of technology both at home and abroad. A country may lower or raise its export taxes to another country depending on whether it would like the foreign country to have higher or lower technology and how it would be achieved. It may also tax or subsidize imports from a country depending on whether the quality of learning from these imports is high and beneficial to the Home country. This new mechanism behind optimal policies adds to the conventional optimal policy aimed at manipulating terms of trade.

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Online Appendix to "Optimal Trade Policy with International Technology Diffusion"

by Yan Bai, Keyu Jin, Dan Lu, and Hanxi Wang

This appendix is organized as follows.

A Characterization of Policy with Exogenous Technology

We normalize the price of final goods as 1 and denote countries by i, n. The technology of all countries are exogenously given. The Home country government chooses $\{\tau_n^x, \tau_n^m\}$ to maximize the value of utility subject to the private equilibrium:

$$\max \; u(x_1)$$

Subject to for any period:

$$P_1 = \left[T_1 w_1^{-\theta} + \sum_{n \neq 1} T_n (w_n(1+\tau_n^m) d_{1n})^{-\theta} \right]^{-\frac{1}{\theta}} = 1 \quad (\gamma_P)$$

$$x_1 = w_1 L_1 + \sum_{i \neq 1}^{N} \frac{\tau_i^x}{1+\tau_i^x} \pi_{i1} (w_i L_i) + \sum_{i \neq 1}^{N} \frac{\tau_i^m}{1+\tau_i^m} \pi_{1i} x_1, \quad (\gamma_x)$$

$$w_n L_n = \sum_{i \neq 1}^{N} \pi_{in} x_m + \frac{1}{1+\tau_n^m} \pi_{1n} x_1, \quad (\gamma_n, \quad (N-1), n > 1)$$

where

$$
\begin{aligned}
x_i &= w_i L_i \\
P_i &= \left[T_1(w_1(1+\tau_i^x)d_{i1})^{-\theta} + \sum_{n\neq 1} T_n(w_n d_{in})^{-\theta} \right]^{-\frac{1}{\theta}} \\
\pi_{11} &= \frac{T_1 w_1^{-\theta}}{T_1 w_1^{-\theta} + \sum_{n\neq 1} T_n(w_n(1+\tau_n^m)d_{1n})^{-\theta}} \\
\pi_{i1} &= \frac{T_1(w_1(1+\tau_i^x)d_{i1})^{-\theta}}{T_1(w_1(1+\tau_i^x)d)^{-\theta} + \sum_{n\neq 1} T_n(w_n d_{in})^{-\theta}} \\
\pi_{in} &= \frac{T_n(w_n d_{in})^{-\theta}}{T_1(w_1(1+\tau_i^x)d_{i1})^{-\theta} + T_n(w_n d_{in})^{-\theta} + \sum_{m\neq\{i,n\}} T_m(w_m d_{im})^{-\theta}} \\
\pi_{1i} &= \frac{T_i(w_i(1+\tau_i^m)d_{1i})^{-\theta}}{T_1 w_1^{-\theta} + T_i(w_i(1+\tau_i^m)d_{1i})^{-\theta} + \sum_{n\neq\{1,i\}} T_n(w_n(1+\tau_n^m)d_{1n})^{-\theta}}
\end{aligned}
$$

Note that $\sum_n \pi_{i,n} = 1$ for any i.

A.1 First order conditions

FOC over x_1

$$
u_c + \sum_{n\neq 1}^{N} \gamma_n \frac{1}{1+\tau_n^m}\pi_{1n} - \gamma_x \left(1 - \sum_{n\neq 1}^{N} \frac{\tau_n^m}{1+\tau_n^m}\pi_{1n}\right) = 0
$$

Further

$$
\sum_{n\neq 1}^{N} \frac{\gamma_x - \gamma_n}{1+\tau_n^m}\pi_{1n} = u_c - \gamma_x \pi_{11}
$$

FOC over τ_{xn}

$$
\sum_{i\neq 1}^{N} \gamma_i \left[\sum_{m\neq 1} \frac{\partial \pi_{m,i}}{\partial \tau_n^x} x_m \right] + \gamma_x \frac{1}{(1+\tau_n^x)^2}\pi_{n1}x_n + \gamma_x \sum_{i\neq 1}^{N} \frac{\tau_i^x}{1+\tau_i^x}\frac{\partial \pi_{i1}}{\partial \tau_n^x} x_i = 0
$$

plugging into derivatives

$$
\sum_{i\neq 1}^{N} \gamma_i \left[\theta \pi_{n,i}\pi_{n1}x_n\right] + \gamma_x \frac{1}{(1+\tau_n^x)}\pi_{n1}x_n - \gamma_x \frac{\tau_n^x}{1+\tau_n^x}\theta\pi_{n1}(1-\pi_{n1})x_n = 0
$$

Hence the optimal export tax

$$
1+\tau_n^x = \frac{[1+\theta(1-\pi_{n1})]}{\theta \sum_{i\neq 1}(1-\gamma_i/\gamma_x)\pi_{ni}}
$$

FOC over τ_n^m

$$
\begin{aligned}
&-\gamma_P \frac{\pi_{1n}}{1+\tau_n^m} - \gamma_n \frac{\pi_{1n}}{\left(1+\tau_n^m\right)^2} x_1 \\
&+\gamma_n \frac{1}{1+\tau_n^m} \frac{\partial \pi_{1n}}{\partial \tau_n^m} x_1 + \sum_{i \neq \{1,n\}} \gamma_i \frac{1}{1+\tau_i^m} \frac{\partial \pi_{1i}}{\partial \tau_n^m} x_1 + \gamma_x \frac{1}{\left(1+\tau_n^m\right)^2} \pi_{1n} x_1 + \gamma_x \sum_{i \neq 1}^{N} \frac{\tau_i^m}{1+\tau_i^m} \frac{\partial \pi_{1i}}{\partial \tau_n^m} x_1 = 0
\end{aligned}
$$

plugging in derivatives

$$
\begin{aligned}
&-\gamma_P \frac{\pi_{1n}}{1+\tau_n^m} - \gamma_n \frac{\pi_{1n}}{\left(1+\tau_n^m\right)^2} x_1 - \gamma_n \frac{1}{1+\tau_n^m} x_1 \theta \frac{1}{1+\tau_n^m} \pi_{1n}\left(1-\pi_{1n}\right) + \sum_{i \neq \{1,n\}} \gamma_i \frac{1}{1+\tau_i^m} x_1 \theta \frac{1}{1+\tau_n^m} \pi_{1i} \pi_{1n} \\
&+\gamma_x \frac{1}{\left(1+\tau_n^m\right)^2} \pi_{1n} x_1 - \gamma_x \frac{\tau_n^m}{1+\tau_n^m} \theta \frac{1}{1+\tau_n^m} \pi_{1n}\left(1-\pi_{1n}\right) x_1 + \gamma_x \sum_{i \neq \{1,n\}}^{N} \frac{\tau_i^m}{1+\tau_i^m} x_1 \theta \frac{1}{1+\tau_n^m} \pi_{1i} \pi_{1n} = 0
\end{aligned}
$$

Further $u_c = \gamma_P / x_1$

$$
\begin{aligned}
&-u_c + \sum_{i \neq \{1,n\}} \gamma_i \theta \pi_{1i} + \left(\gamma_x - \gamma_n\right) \frac{1}{\left(1+\tau_n^m\right)} \left[1 + \theta\left(1-\pi_{1n}\right)\right] \\
&-\gamma_x \theta\left(1-\pi_{1n}\right) + \sum_{i \neq \{1,n\}}^{N} \left(\gamma_x - \gamma_i\right) \frac{\tau_i^m}{1+\tau_i^m} \theta \pi_{1i} = 0
\end{aligned}
$$

Hence the optimal import tariff

$$
\frac{1}{1+\tau_n^m} = \frac{u_c + \gamma_x \left[\theta \pi_{11} + \sum_{i \neq \{1,n\}}^{N} \left(\frac{1-\gamma_i/\gamma_x}{1+\tau_i^m}\right) \theta \pi_{1i}\right]}{\left(\gamma_x - \gamma_n\right)\left[1 + \theta\left(1-\pi_{1n}\right)\right]}
$$

Combined with FOC over x_1

$$
\frac{1}{1+\tau_n^m} = \frac{\left(\gamma_x - \gamma_n\right) \frac{\pi_{1n}}{1+\tau_n^m} + \sum_{i \neq \{1,n\}}^{N} \left(\frac{\gamma_x - \gamma_i}{1+\tau_i^m}\right)(1+\theta) \pi_{1i} + \gamma_x (1+\theta) \pi_{11}}{\left(\gamma_x - \gamma_n\right)\left[1 + \theta\left(1-\pi_{1n}\right)\right]}
$$

Further

$$
\frac{\gamma_x - \gamma_n}{1+\tau_n^m}\left(1-\pi_{1n}\right) = \sum_{i \neq \{1,n\}}^{N} \left(\frac{\gamma_x - \gamma_i}{1+\tau_i^m}\right) \pi_{1i} + \gamma_x \pi_{11}
$$

$$
\frac{\gamma_x - \gamma_n}{1+\tau_n^m} = \sum_{i \neq \{1\}}^{N} \frac{\gamma_x - \gamma_i}{1+\tau_i^m} \pi_{1i} + \gamma_x \pi_{11}
$$

Combined with FOC over x_1

$$
\frac{1}{1+\tau_n^m} = \frac{u_c}{\gamma_x - \gamma_n}
$$

Plugging it back to FOC over x_1

$$u_c + \sum_{n \neq 1}^{N} \gamma_n \frac{u_c}{\gamma_x - \gamma_n} \pi_{1n} = \gamma_x \left(\pi_{11} + \sum_{n \neq 1}^{N} \frac{u_c}{\gamma_x - \gamma_n} \pi_{1n} \right)$$

Further

$$\gamma_x = u_c$$

Final on τ_n^m

$$\tau_n^m = -\frac{\gamma_n}{u_c} \tag{A.1}$$

Final on τ_{xn}

$$1 + \tau_n^x = \frac{[1 + \theta(1 - \pi_{n1})]}{\theta \sum_{i \neq 1} (1 + \tau_i^m) \pi_{ni}} \tag{A.2}$$

this finishes the proof of optimal import tariff and export tax in Proposition 1.

FOC over w_1

$$\begin{aligned} &- \gamma_P \frac{\pi_{11}}{w_1} + \sum_{n \neq 1}^{N} \gamma_n \frac{1}{1 + \tau_n^m} \frac{\partial \pi_{1n}}{\partial w_1} x_1 + \sum_{n \neq 1}^{N} \gamma_n \sum_{m \neq 1}^{N} \frac{\partial \pi_{mn}}{\partial w_1} x_m \\ &+ \gamma_x L_1 + \gamma_x \sum_{i \neq 1}^{N} \frac{\tau_i^x}{1 + \tau_i^x} \frac{\partial \pi_{i1}}{\partial w_1} x_i + \gamma_x \sum_{i \neq 1}^{N} \frac{\tau_i^m}{1 + \tau_i^m} \frac{\partial \pi_{1i}}{\partial w_1} x_1 = 0 \end{aligned}$$

Plugging in derivatives

$$\begin{aligned} &- \gamma_P \pi_{11} + \sum_{n \neq 1}^{N} \gamma_n \frac{1}{1 + \tau_n^m} \theta \pi_{1n} \pi_{11} x_1 + \sum_{n \neq 1}^{N} \gamma_n \sum_{m \neq 1}^{N} \theta \pi_{mn} \pi_{m1} x_m + \gamma_x w_1 L_1 \\ &- \gamma_x \sum_{i \neq 1}^{N} \frac{\tau_i^x}{1 + \tau_i^x} \theta \pi_{i1} (1 - \pi_{i1}) x_i + \gamma_x \sum_{i \neq 1}^{N} \frac{\tau_i^m}{1 + \tau_i^m} \theta \pi_{1i} \pi_{11} x_1 = 0 \end{aligned}$$

Final on w_1:

$$\begin{aligned} &\sum_{n \neq 1}^{N} \gamma_n \left[\left(\frac{1}{1 + \tau_n^m} \theta \pi_{1n} \pi_{11} x_1 + \sum_{m \neq 1}^{N} \theta \pi_{mn} \pi_{m1} x_m \right) \right] \\ &+ \gamma_x \left[w_1 L_1 + \left(- \sum_{i \neq 1}^{N} \frac{\tau_i^x}{1 + \tau_i^x} \theta \pi_{i1} (1 - \pi_{i1}) x_i + \sum_{i \neq 1}^{N} \frac{\tau_i^m}{1 + \tau_i^m} \theta \pi_{1i} \pi_{11} x_1 \right) \right] = u_c x_1 \pi_{11} \end{aligned}$$

FOC over w_n for $n \neq 1$

$$
\begin{aligned}
&-\gamma_P \frac{\pi_{1n}}{w_n} + \gamma_x \sum_{i \neq 1}^{N} \frac{\tau_i^x}{1+\tau_i^x} \frac{\partial \pi_{i1}}{\partial w_n} x_i + \gamma_x \frac{\tau_n^x}{1+\tau_n^x} \pi_{n1} \frac{x_n}{w_n} \\
&+ \gamma_x \sum_{i \neq 1}^{N} \frac{\tau_i^m}{1+\tau_i^m} \frac{\partial \pi_{1i}}{\partial w_n} x_1 + \sum_{i \neq 1} \sum_{m \neq 1}^{N} \gamma_i \frac{\partial \pi_{m,i}}{\partial w_n} x_m + \sum_{i \neq 1} \gamma_i \pi_{n,i} \frac{x_n}{w_n} + \sum_{i \neq 1} \gamma_i \frac{1}{1+\tau_i^m} \frac{\partial \pi_{1,i}}{\partial w_n} x_1 - \gamma_n \frac{x_n}{w_n} = 0
\end{aligned}
$$

Plugging in derivatives

$$
\begin{aligned}
&-\gamma_P \pi_{1n} + \gamma_x \sum_{i \neq 1}^{N} \frac{\tau_i^x}{1+\tau_i^x} \theta \pi_{i1} \pi_{in} x_i + \gamma_x \frac{\tau_n^x}{1+\tau_n^x} \pi_{n1} x_n + \gamma_x \sum_{i \neq \{1,n\}}^{N} \frac{\tau_i^m}{1+\tau_i^m} \theta \pi_{1i} \pi_{1n} x_1 \\
&-\gamma_x \frac{\tau_n^m}{1+\tau_n^m} \theta \pi_{1n} (1-\pi_{1n}) x_1 + \sum_{i \neq \{1,n\}} \sum_{m \neq 1}^{N} \gamma_i \theta \pi_{mi} \pi_{mn} x_m - \sum_{m \neq 1}^{N} \gamma_n \theta \pi_{mn} (1-\pi_{mn}) x_m + \sum_{i \neq 1} \gamma_i \pi_{n,i} x_n \\
&+ \sum_{i \neq \{1,n\}} \gamma_i \frac{1}{1+\tau_i^m} \theta \pi_{1i} \pi_{1n} x_1 - \gamma_n \frac{1}{1+\tau_n^m} \theta \pi_{1n} (1-\pi_{1n}) x_1 - \gamma_n x_n = 0
\end{aligned}
$$

Final on w_n:

$$
\begin{aligned}
&-\gamma_P \pi_{1n} + \gamma_x \sum_{i \neq 1}^{N} \frac{\tau_i^x}{1+\tau_i^x} \theta \pi_{i1} \pi_{in} x_i + \gamma_x \frac{\tau_n^x}{1+\tau_n^x} \pi_{n1} x_n + \gamma_x \sum_{i \neq 1}^{N} \frac{\tau_i^m}{1+\tau_i^m} \theta \pi_{1i} \pi_{1n} x_1 - \gamma_x \frac{\tau_n^m}{1+\tau_n^m} \theta \pi_{1n} x_1 \\
&+ \sum_{i \neq 1} \sum_{m \neq 1}^{N} \gamma_i \theta \pi_{mi} \pi_{mn} x_m - \sum_{m \neq 1}^{N} \gamma_n \theta \pi_{mn} x_m + \sum_{i \neq 1} \gamma_i \pi_{n,i} x_n + \sum_{i \neq 1} \gamma_i \frac{1}{1+\tau_i^m} \theta \pi_{1i} \pi_{1n} x_1 - \gamma_n \frac{1}{1+\tau_n^m} \theta \pi_{1n} x_1 - \gamma_n x_n = 0
\end{aligned}
$$

B Characterization of Markov Policy

We normalize the price of final goods as 1 and denote countries by i, n. The evolution of technology is given by

$$
T_{nt+1} = (1-\delta) T_{nt} + \alpha_n \sum_{i=1}^{N} \left(\pi_{ni,t}\right)^{1-\rho} \left(T_{it}\right)^{\rho}. \tag{A.3}
$$

Note that Ramsey and Markov problems are the same, given that there are no forward-looking constraints like a worker-researcher choice constraint under endogenous technology accumulation.

At period 0, the Home country government chooses the sequence of $\{\tau_{nt}^x, \tau_{nt}^m\}$ to maximize the present value of utility subject to the private equilibrium:

$$
\max \sum_{t=0}^{\infty} \beta^t u(x_{1t})
$$

Subject to for any period:

$$T_{nt+1} = (1-\delta)T_{nt} + \alpha_n \sum_{i=1}^{N} (\pi_{nit})^{1-\rho} (T_{it})^{\rho}, \quad (\gamma_{Tn}, \quad N)$$

$$P_{1t} = \left[T_{1t} w_{1t}^{-\theta} + \sum_{n \neq 1} T_{nt} (w_{nt}(1+\tau_{nt}^{m}) d_{1nt})^{-\theta} \right]^{-\frac{1}{\theta}} = 1 \quad (\gamma_P)$$

$$x_{1t} = w_{1t} L_{1t} + \sum_{i \neq 1}^{N} \frac{\tau_{it}^{x}}{1+\tau_{it}^{x}} \pi_{i1t} (w_{it} L_{it}) + \sum_{i \neq 1}^{N} \frac{\tau_{it}^{m}}{1+\tau_{it}^{m}} \pi_{1it} x_{1t}, \quad (\gamma_x)$$

$$w_{nt} L_{nt} = \sum_{m \neq 1}^{N} \pi_{mnt} x_{mt} + \frac{1}{1+\tau_{nt}^{m}} \pi_{1nt} x_{1t}, \quad (\gamma_n, \quad (N-1), n > 1)$$

where

$$x_{it} = w_{it} L_{it}$$

$$P_{it} = \left[T_{1t} (w_{1t}(1+\tau_{it}^{x}) d_{i1,t})^{-\theta} + \sum_{n \neq 1} T_{nt} (w_{nt} d_{in,t})^{-\theta} \right]^{-\frac{1}{\theta}}$$

$$\pi_{11,t} = \frac{T_1 w_1^{-\theta}}{T_{1t} w_{1t}^{-\theta} + \sum_{n \neq 1} T_{nt} (w_{nt}(1+\tau_{nt}^{m}) d_{1n,t})^{-\theta}}$$

$$\pi_{i1,t} = \frac{T_{1t} (w_{1t}(1+\tau_{it}^{x}) d_{i1,t})^{-\theta}}{T_{1t} (w_{1t}(1+\tau_{it}^{x}) d_{i1,t})^{-\theta} + \sum_{n \neq 1} T_{nt} (w_{nt} d_{in,t})^{-\theta}}$$

$$\pi_{in,t} = \frac{T_{nt} (w_{nt} d_{in,t})^{-\theta}}{T_{1t} (w_{1t}(1+\tau_{it}^{x}) d_{i1,t})^{-\theta} + \sum_{m \neq 1} T_{mt} (w_{mt} d_{im,t})^{-\theta}}$$

$$\pi_{1i,t} = \frac{T_{it} (w_{it}(1+\tau_{it}^{m}) d_{1i,t})^{-\theta}}{T_{1t} w_{1t}^{-\theta} + \sum_{n \neq 1} T_{nt} (w_{nt}(1+\tau_{nt}^{m}) d_{1n,t})^{-\theta}}$$

Note that $\sum_n \pi_{in,t} = 1$ for any i in period t.

Recursively problem can be written as

$$V(\{T_n\}) = \max_{\{T_n', w_n, x_n, \tau_{nt}^{x}, \tau_{nt}^{m}\}} u(x_1) + \beta V(\{T_n'\})$$

Subject to

$$T'_n = (1-\delta)T_n + \alpha_n \sum_{i=1}^{N} (\pi_{ni})^{1-\rho} (T_i)^{\rho}, \quad (\gamma_{Tn}, \quad N) \tag{A.4}$$

$$P_1 = \left[T_1 w_1^{-\theta} + \sum_{n\neq 1} T_n (w_n(1+\tau_n^m) d_{1n})^{-\theta} \right]^{-\frac{1}{\theta}} = 1 \quad (\gamma_P) \tag{A.5}$$

$$x_1 = w_1 L_1 + \sum_{i\neq 1}^{N} \frac{\tau_i^x}{1+\tau_i^x} \pi_{i1} (w_i L_i) + \sum_{i\neq 1}^{N} \frac{\tau_i^m}{1+\tau_i^m} \pi_{1i} x_1, \quad (\gamma_x) \tag{A.6}$$

$$w_n L_n = \sum_{m\neq 1}^{N} \pi_{mn} x_m + \frac{1}{1+\tau_n^m} \pi_{1n} x_1, \quad (\gamma_n, \quad (N-1), n>1) \tag{A.7}$$

B.1 Proof of Proposition 2

This section provides the proof of Lerner symmetry in our model (Lerner (1936), Costinot and Werning (2019)). Given $\{\tau_{it}^m + 1, \tau_{it}^x + 1\}$ where $i \neq 1$, let $\mathcal{E}(\tau_{it}^m + 1, \tau_{it}^x + 1)$ denote the set of $\{T_{nt+1}, T_{nt}, \pi_{1n,t}, \pi_{mn,t}, \frac{w_{nt}}{P_{nt}}, \frac{x_{nt}}{P_{nt}}\}$ that form an equilibrium. We say that from $\{\tau_{it}^m + 1, \tau_{it}^x + 1\}$ to $\{\check{\tau}_{it}^m + 1, \check{\tau}_{it}^x + 1\}$ is neutral if $\mathcal{E}(\tau_{it}^m + 1, \tau_{it}^x + 1) = \mathcal{E}(\check{\tau}_{it}^m + 1, \check{\tau}_{it}^x + 1)$. This captures neutrality because the equilibrium allocations and welfare obtainable with import tariffs and export taxes $\{\tau_{it}^m + 1, \tau_{it}^x + 1\}$ and $\{\check{\tau}_{it}^m + 1, \check{\tau}_{it}^x + 1\}$ are the same.

We assume $\check{\tau}_{it}^m + 1 = \lambda_t(\tau_{it}^m + 1)$ and $\check{\tau}_{it}^x + 1 = (\tau_{it}^x + 1)/\lambda_t$. We guess the allocations $\{\check{T}_{nt+1}, \check{T}_{nt}, \check{\pi}_{1n,t}, \check{\pi}_{in,t}, \frac{\check{w}_{nt}}{\check{P}_{nt}}, \frac{\check{x}_{nt}}{\check{P}_{nt}}\}$ in the new equilibrium have the following relations with allocations in the old equilibrium:

$\check{T}_{nt+1} = T_{nt+1}, \check{T}_{nt} = T_{nt}, \check{\pi}_{1n,t} = \pi_{1n,t}, \check{\pi}_{in,t} = \pi_{in,t}, \check{P}_{1t} = P_{1t} = 1, \check{P}_{it} = P_{it}/\lambda_t, \check{w}_{1t} = w_{1t}, \check{w}_{it} = w_{it}/\lambda_t, \check{x}_{1t} = x_{1t}, \check{x}_{it} = x_{it}/\lambda_t$.

We then verify the following equations can be satisfied under new equilibrium allocations.

Evolution of technology

$$\check{T}_{nt+1} = (1-\delta)T_{nt} + \alpha_n \sum_{i=1}^{N} (\pi_{ni,t})^{1-\rho} (T_{it})^{\rho} = T_{nt+1}$$

Price index

$$\check{P}_{1t} = \left[T_{1t} w_{1t}^{-\theta} + \sum_{n\neq 1} T_{nt} (\frac{w_{nt}}{\lambda_t} \lambda_t (1+\tau_{nt}^m) d_{1nt})^{-\theta} \right]^{-\frac{1}{\theta}} = P_{1t} = 1$$

$$\check{P}_{it} = \left[T_{1t} (w_{1t} \frac{1+\tau_{it}^x}{\lambda_t} d_{i1t})^{-\theta} + \sum_{n\neq 1} T_{nt} (\frac{w_{nt}}{\lambda_t} d_{int})^{-\theta} \right]^{-\frac{1}{\theta}} = \frac{P_{it}}{\lambda_t}$$

Market clearing conditions ($n \neq 1$)

$$\check{w}_{nt}L_{nt} = \sum_{i\neq 1}^{N} \pi_{in,t}\frac{x_{it}}{\lambda_t} + \frac{1}{\lambda_t(1+\tau_{nt}^m)}\pi_{1nt}x_{1t} = \frac{w_{nt}}{\lambda_t}L_{nt}$$

Trade share

$$\begin{aligned}
\check{\pi}_{11t} &= \frac{T_{1t}w_{1t}^{-\theta}}{T_{1t}w_{1t}^{-\theta} + \sum_{n\neq 1} T_{nt}(\frac{w_{nt}}{\lambda_t}\lambda_t(1+\tau_{nt}^m)d_{1nt})^{-\theta}} = \pi_{11t} \\
\check{\pi}_{i1t} &= \frac{T_{1t}(w_{1t}\frac{(1+\tau_{it}^x)}{\lambda_t}d_{i1t})^{-\theta}}{T_{1t}(w_{1t}\frac{(1+\tau_{it}^x)}{\lambda_t}d_{i1t})^{-\theta} + \sum_{n\neq 1} T_{nt}(\frac{w_{nt}}{\lambda_t}d_{int})^{-\theta}} = \pi_{i1t} \\
\check{\pi}_{int} &= \frac{T_{nt}(\frac{w_{nt}}{\lambda_t}d_{int})^{-\theta}}{T_{1t}(w_{1t}\frac{(1+\tau_{it}^x)}{\lambda_t}d_{i1t})^{-\theta} + T_{nt}(\frac{w_{nt}}{\lambda_t}d_{int})^{-\theta} + \sum_{m\neq\{1,n\}} T_{mt}(\frac{w_{mt}}{\lambda_t}d_{imt})^{-\theta}} = \pi_{int} \\
\check{\pi}_{1it} &= \frac{T_{it}(\frac{w_{it}}{\lambda_t}\lambda_t(1+\tau_{it}^m)d_{1it})^{-\theta}}{T_{1t}w_{1t}^{-\theta} + T_{it}(\frac{w_{it}}{\lambda_t}\lambda_t(1+\tau_{it}^m)d_{1it})^{-\theta} + \sum_{n\neq\{1,i\}} T_{nt}(\frac{w_{nt}}{\lambda_t}\lambda_t(1+\tau_{nt}^m)d_{1nt})^{-\theta}} = \pi_{1it}
\end{aligned}$$

Foreign's expenditure

$$\check{x}_{it} = \frac{w_{it}}{\lambda_t}L_{it} = \frac{x_{it}}{\lambda_t}$$

Home's expenditure

$$\check{x}_{1t} = w_{1t}L_{1t} + \sum_{i\neq 1}^{N}(1 - \frac{\lambda_t}{1+\tau_{it}^x})\pi_{i1t}\left(\frac{w_{it}}{\lambda_t}L_{it}\right) + \sum_{i\neq 1}^{N}(1 - \frac{1}{\lambda_t(1+\tau_{it}^m)})\pi_{1it}x_{1t}$$

If $\check{x}_{1t} = x_{1t}$, then

$$\sum_{i\neq 1}^{N}\frac{\tau_{it}^x}{1+\tau_{it}^x}\pi_{i1t}\left(w_{it}L_{it}\right) + \sum_{i\neq 1}^{N}\frac{\tau_{it}^m}{1+\tau_{it}^m}\pi_{1it}x_{1t} = \sum_{i\neq 1}^{N}\frac{1-\lambda_t+\tau_{it}^x}{\lambda_t(1+\tau_{it}^x)}\pi_{i1t}w_{it}L_{it} + \sum_{i\neq 1}^{N}\frac{\lambda_t - 1 + \lambda_t\tau_{it}^m}{\lambda_t(1+\tau_{it}^m)}\pi_{1it}x_{1t}$$

Further

$$\sum_{i\neq 1}^{N}\pi_{i1t}w_{it}L_{it} = \sum_{i\neq 1}^{N}\frac{1}{1+\tau_{it}^m}\pi_{1it}x_{1t}$$

This is the market clearing condition for Home, which is always true, ensuring that the home expenditure equation can be satisfied under new equilibrium allocations.

Since the equations in the new equilibrium are identical to those in the old equilibrium, we confirm that the allocations we deduced indeed satisfy the conditions of the new equilibrium. This completes the proof of tax neutrality in this diffusion model.

B.2 First order conditions

For ease of notation, we define the weighted average of quality of insights in country n as

$$I_n = \sum_{i=1}^{N} \left(\pi_{ni}\right)^{1-\rho} \left(T_i\right)^{\rho}$$

FOC over x_1

$$u_c + \sum_{n\neq 1}^{N} \gamma_n \frac{1}{1+\tau_n^m}\pi_{1n} - \gamma_x \left(1 - \sum_{n\neq 1}^{N} \frac{\tau_n^m}{1+\tau_n^m}\pi_{1n}\right) = 0$$

FOC over τ_n^x

$$\sum_{i=1}^{N} \gamma_{Ti}\alpha_i \sum_{m=1}^{N} (1-\rho)\left(\pi_{im}\right)^{-\rho}\left(T_m\right)^{\rho} \frac{\partial \pi_{im}}{\partial \tau_n^x} + \sum_{i\neq 1}^{N} \gamma_i \left[\sum_{m\neq 1} \frac{\partial \pi_{mi}}{\partial \tau_n^x} x_m\right]$$
$$+ \gamma_x \frac{1}{(1+\tau_n^x)^2}\pi_{n1}x_n + \gamma_x \sum_{i\neq 1}^{N} \frac{\tau_i^x}{1+\tau_i^x}\frac{\partial \pi_{i1}}{\partial \tau_n^x} x_i = 0$$

plugging into derivatives

$$\gamma_{Tn}\alpha_n(1-\rho)\theta \left[\sum_{m\neq 1}^{N} \left(\pi_{nm}\right)^{-\rho}\left(T_m\right)^{\rho}\pi_{nm}\pi_{n1} - \left(\pi_{n1}\right)^{-\rho}\left(T_1\right)^{\rho}\pi_{n1}\left(1-\pi_{n1}\right)\right]$$
$$+ \sum_{i\neq 1}^{N} \gamma_i \left[\theta \pi_{ni}\pi_{n1}x_n\right] + \gamma_x \frac{1}{(1+\tau_n^x)}\pi_{n1}x_n - \gamma_x \frac{\tau_n^x}{1+\tau_n^x}\theta\pi_{n1}(1-\pi_{n1})x_n = 0$$

Hence the optimal export taxes satisfy

$$1+\tau_n^x = \frac{\gamma_x\left[1+\theta(1-\pi_{n1})\right]}{\gamma_x\theta\sum_{m\neq 1}(1-\gamma_m/\gamma_x)\pi_{nm} + \gamma_{Tn}(1-\rho)\theta\frac{1}{x_n}\alpha_n\left[\left(\pi_{n1}/T_1\right)^{-\rho} - I_n\right]}, \tag{A.8}$$

this finishes the proof of optimal export tax in Proposition 3.

FOC over τ_n^m

$$\sum_{i=1}^{N} \gamma_{Ti}\alpha_i \sum_{m=1}^{N} (1-\rho)\left(\pi_{im}\right)^{-\rho}\left(T_m\right)^{\rho} \frac{\partial \pi_{im}}{\partial \tau_n^m} - \gamma_P \frac{\pi_{1n}}{1+\tau_n^m} - \gamma_n \frac{\pi_{1n}}{(1+\tau_n^m)^2}x_1$$
$$+ \gamma_n \frac{1}{1+\tau_n^m}\frac{\partial \pi_{1n}}{\partial \tau_n^m}x_1 + \sum_{i\neq\{1,n\}} \gamma_i \frac{1}{1+\tau_i^m}\frac{\partial \pi_{1i}}{\partial \tau_n^m}x_1 + \gamma_x \frac{1}{(1+\tau_n^m)^2}\pi_{1n}x_1 + \gamma_x \sum_{i\neq 1}^{N} \frac{\tau_i^m}{1+\tau_i^m}\frac{\partial \pi_{1i}}{\partial \tau_n^m}x_1 = 0$$

plugging in derivatives

$$
\begin{aligned}
&\gamma_{T1}\alpha_1(1-\rho)\left(1+\tau_n^m\right)^{-1}\left[\sum_{m\neq n}^{N}\left(\pi_{1m}\right)^{-\rho}\left(T_m\right)^{\rho}\theta\pi_{1m}\pi_{1n}-\left(\pi_{1n}\right)^{-\rho}\left(T_n\right)^{\rho}\theta\pi_{1n}(1-\pi_{1n})\right]-\gamma_P\frac{\pi_{1n}}{1+\tau_n^m}\\
&-\gamma_n\frac{\pi_{1n}}{\left(1+\tau_n^m\right)^2}x_1-\gamma_n\frac{1}{1+\tau_n^m}x_1\theta\frac{1}{1+\tau_n^m}\pi_{1n}\left(1-\pi_{1n}\right)+\sum_{i\neq\{1,n\}}\gamma_i\frac{1}{1+\tau_i^m}x_1\theta\frac{1}{1+\tau_n^m}\pi_{1i}\pi_{1n}\\
&+\gamma_x\frac{1}{\left(1+\tau_n^m\right)^2}\pi_{1n}x_1-\gamma_x\frac{\tau_n^m}{1+\tau_n^m}\theta\frac{1}{1+\tau_n^m}\pi_{1n}\left(1-\pi_{1n}\right)x_1+\gamma_x\sum_{i\neq\{1,n\}}^{N}\frac{\tau_i^m}{1+\tau_i^m}x_1\theta\frac{1}{1+\tau_n^m}\pi_{1i}\pi_{1n}=0
\end{aligned}
$$

Further $u_c=\gamma_P/x_1$

$$
\begin{aligned}
&\gamma_{T1}(1-\rho)\frac{1}{x_1}\theta\alpha_1\left[I_1-\left(\pi_{1n}\right)^{-\rho}\left(T_n\right)^{\rho}\right]-u_c+\sum_{m\neq\{1,n\}}\gamma_m\theta\pi_{1m}\\
&+\left(\gamma_x-\gamma_n\right)\frac{1}{\left(1+\tau_n^m\right)}\left[1+\theta\left(1-\pi_{1n}\right)\right]-\gamma_x\theta\left(1-\pi_{1n}\right)+\sum_{i\neq\{1,n\}}^{N}\left(\gamma_x-\gamma_i\right)\frac{\tau_i^m}{1+\tau_i^m}\theta\pi_{1i}=0
\end{aligned}
$$

Hence the optimal import tariffs satisfy

$$
\frac{1}{1+\tau_n^m}=\frac{u_c+\gamma_x\left[\theta\pi_{11}+\sum_{i\neq\{1,n\}}^{N}\left(\frac{1-\gamma_i/\gamma_x}{1+\tau_i^m}\right)\theta\pi_{1i}\right]+\gamma_{T1}(1-\rho)\frac{1}{x_1}\theta\alpha_1\left[\left(\pi_{1,n}\right)^{-\rho}\left(T_n\right)^{\rho}-I_1\right]}{\left(\gamma_x-\gamma_n\right)\left[1+\theta\left(1-\pi_{1n}\right)\right]} \tag{A.9}
$$

Combine FOC over τ_n^m and FOC over x_1:

$$
((\gamma_x-\gamma_n)\frac{1}{1+\tau_n^m}-u_c)(1+\theta)x_1=\gamma_{T1}(1-\rho)\theta\alpha_1\left[\left(\pi_{1n}\right)^{-\rho}\left(T_n\right)^{\rho}-I_1\right] \tag{A.10}
$$

For country 1, it has

$$
(\gamma_x-u_c)(1+\theta)x_1=\gamma_{T1}(1-\rho)\theta\alpha_1\left[\left(\pi_{11}\right)^{-\rho}\left(T_1\right)^{\rho}-I_1\right] \tag{A.11}
$$

Combining Equation (A.10) and (A.11), **the optimal import tariffs satisfy**

$$
\frac{1}{1+\tau_n^m}=\frac{\gamma_x}{\gamma_x-\gamma_n}+\gamma_{T1}\frac{(1-\rho)\theta\alpha_1}{(\gamma_x-\gamma_n)(1+\theta)x_1}\left[\left(\pi_{1n}\right)^{-\rho}\left(T_n\right)^{\rho}-\pi_{11}^{-\rho}\left(T_1\right)^{\rho}\right] \tag{A.12}
$$

this finishes the proof of optimal tariff in Proposition 3.

FOC over w_1

$$\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\sum_{m=1}^{N}(1-\rho)\left(\pi_{im}\right)^{-\rho}\left(T_m\right)^{\rho}\frac{\partial\pi_{im}}{\partial w_1}-\gamma_P\frac{\pi_{11}}{w_1}+\sum_{n\neq 1}^{N}\gamma_n\frac{1}{1+\tau_n^m}\frac{\partial\pi_{1n}}{\partial w_1}x_1$$
$$+\sum_{n\neq 1}^{N}\gamma_n\sum_{m\neq 1}^{N}\frac{\partial\pi_{mn}}{\partial w_1}x_m+\gamma_x L_1+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\frac{\partial\pi_{i1}}{\partial w_1}x_i+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\frac{\partial\pi_{1i}}{\partial w_1}x_1=0$$

Plugging in derivatives

$$\sum_{i=1}^{N}\gamma_{Ti}\alpha_i(1-\rho)\left[\sum_{m\neq 1}^{N}\left(\pi_{im}\right)^{-\rho}\left(T_m\right)^{\rho}\theta\pi_{im}\pi_{i1}-\left(\pi_{i1}\right)^{-\rho}\left(T_1\right)^{\rho}\theta\pi_{i1}(1-\pi_{i1})\right]-\gamma_P\pi_{11}+\sum_{n\neq 1}^{N}\gamma_n\frac{1}{1+\tau_n^m}\theta\pi_{1n}\pi_{11}x_1$$
$$+\sum_{n\neq 1}^{N}\gamma_n\sum_{m\neq 1}^{N}\theta\pi_{mn}\pi_{m1}x_m+\gamma_x w_1L_1-\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\theta\pi_{i1}(1-\pi_{i1})x_i+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\theta\pi_{1i}\pi_{11}x_1=0$$

Final on w_1:

$$\sum_{n=1}^{N}\gamma_{Tn}(1-\rho)\theta\pi_{n1}\alpha_n\left[I_n-\left(\pi_{n1}\right)^{-\rho}\left(T_1\right)^{\rho}\right]+\sum_{n\neq 1}^{N}\gamma_n\left[\left(\frac{1}{1+\tau_n^m}\theta\pi_{1n}\pi_{11}x_1+\sum_{m\neq 1}^{N}\theta\pi_{mn}\pi_{m1}x_m\right)\right]$$
$$+\gamma_x\left[w_1L_1+\left(-\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\theta\pi_{i1}(1-\pi_{i1})x_i+\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\theta\pi_{1i}\pi_{11}x_1\right)\right]=u_c x_1\pi_{11}$$

FOC over w_n for $n\neq 1$

$$\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\sum_{m=1}^{N}(1-\rho)\left(\pi_{im}\right)^{-\rho}\left(T_m\right)^{\rho}\frac{\partial\pi_{im}}{\partial w_n}-\gamma_P\frac{\pi_{1n}}{w_n}+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\frac{\partial\pi_{i1}}{\partial w_n}x_i+\gamma_x\frac{\tau_n^x}{1+\tau_n^x}\pi_{n1}\frac{x_n}{w_n}$$
$$+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\frac{\partial\pi_{1i}}{\partial w_n}x_1+\sum_{i\neq 1}\sum_{m\neq 1}^{N}\gamma_i\frac{\partial\pi_{mi}}{\partial w_n}x_m+\sum_{i\neq 1}\gamma_i\pi_{n,i}\frac{x_n}{w_n}+\sum_{i\neq 1}\gamma_i\frac{1}{1+\tau_i^m}\frac{\partial\pi_{1i}}{\partial w_n}x_1-\gamma_n\frac{x_n}{w_n}=0$$

Plugging in derivatives

$$\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\sum_{m\neq n}^{N}(1-\rho)\left(\pi_{im}\right)^{-\rho}\left(T_m\right)^{\rho}\theta\pi_{im}\pi_{in}-\sum_{i=1}^{N}\gamma_{Ti}\alpha_i(1-\rho)\left(\pi_{in}\right)^{-\rho}\left(T_n\right)^{\rho}\theta\pi_{in}(1-\pi_{in})$$
$$-\gamma_P\pi_{1n}+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\theta\pi_{i1}\pi_{in}x_i+\gamma_x\frac{\tau_n^x}{1+\tau_n^x}\pi_{n1}x_n+\gamma_x\sum_{i\neq\{1,n\}}^{N}\frac{\tau_i^m}{1+\tau_i^m}\theta\pi_{1i}\pi_{1n}x_1$$
$$-\gamma_x\frac{\tau_n^m}{1+\tau_n^m}\theta\pi_{1n}(1-\pi_{1n})x_1+\sum_{i\neq\{1,n\}}\sum_{m\neq 1}^{N}\gamma_i\theta\pi_{mi}\pi_{mn}x_m-\sum_{m\neq 1}^{N}\gamma_n\theta\pi_{mn}(1-\pi_{mn})x_m+\sum_{i\neq 1}\gamma_i\pi_{ni}x_n$$
$$+\sum_{i\neq\{1,n\}}\gamma_i\frac{1}{1+\tau_i^m}\theta\pi_{1i}\pi_{1n}x_1-\gamma_i\frac{1}{1+\tau_n^m}\theta\pi_{1n}(1-\pi_{1n})x_1-\gamma_n x_n=0$$

Final on w_n:

$$\sum_{i=1}^{N}\gamma_{Ti}(1-\rho)\pi_{in}\theta\alpha_i\left[I_i-(\pi_{in})^{-\rho}(T_n)^{\rho}\right]-\gamma_P\pi_{1n}+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\theta\pi_{i1}\pi_{in}x_i+\gamma_x\frac{\tau_n^x}{1+\tau_n^x}\pi_{n1}x_n$$
$$+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\theta\pi_{1i}\pi_{1n}x_1-\gamma_x\frac{\tau_n^m}{1+\tau_n^m}\theta\pi_{1n}x_1+\sum_{i\neq 1}\sum_{m\neq 1}^{N}\gamma_i\theta\pi_{mi}\pi_{mn}x_m-\sum_{m\neq 1}^{N}\gamma_n\theta\pi_{mn}x_m+\sum_{i\neq 1}\gamma_i\pi_{ni}x_n$$
$$+\sum_{i\neq 1}\gamma_i\frac{1}{1+\tau_i^m}\theta\pi_{1i}\pi_{1n}x_1-\gamma_n\frac{1}{1+\tau_n^m}\theta\pi_{1n}x_1-\gamma_n x_n=0$$

FOC over T_1

$$-\gamma_{T1,-1}+\beta\Big\{(1-\delta)\gamma_{T1}+\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\rho\,(\pi_{i1})^{1-\rho}\,(T_1)^{\rho-1}+\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\sum_{m=1}^{N}(1-\rho)\,(\pi_{im})^{-\rho}\,(T_m)^{\rho}\,\frac{\partial\pi_{im}}{\partial T_1}$$
$$+\gamma_P\frac{1}{\theta}\frac{\pi_{11}}{T_1}+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\frac{\partial\pi_{i1}}{\partial T_1}x_i+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\frac{\partial\pi_{1i}}{\partial T_1}x_1+\sum_{i\neq 1}\gamma_i\sum_{m\neq 1}^{N}\frac{\partial\pi_{mi}}{\partial T_1}x_m+\sum_{i\neq 1}\gamma_i\frac{1}{1+\tau_i^m}\frac{\partial\pi_{1i}}{\partial T_1}x_1\Big\}=0$$

Plugging in derivatives

$$-\gamma_{T1,-1}T_1+\beta\Big\{(1-\delta)\gamma_{T1}T_1+\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\rho\,(\pi_{i1})^{1-\rho}\,(T_1)^{\rho}-\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\sum_{m=1}^{N}(1-\rho)\,(\pi_{im})^{-\rho}\,(T_m)^{\rho}\,\pi_{i1}\pi_{im}$$
$$+\sum_{i=1}^{N}\gamma_{Ti}\alpha_i(1-\rho)\,(\pi_{i1})^{-\rho}\,(T_1)^{\rho}\,\pi_{i1}+\gamma_P\frac{1}{\theta}\pi_{11}+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\pi_{i1}(1-\pi_{i1})x_i-\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\pi_{11}\pi_{1i}x_1$$
$$-\sum_{i\neq 1}\gamma_i\sum_{m\neq 1}^{N}\pi_{m1}\pi_{mi}x_m-\sum_{i\neq 1}\gamma_i\frac{1}{1+\tau_i^m}\pi_{11}\pi_{1i}x_1\Big\}=0$$

Final on T_1:

$$-\gamma_{T1,-1}T_1+\beta\Big\{(1-\delta)\gamma_{T1}T_1+\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\,(\pi_{i1})^{1-\rho}\,(T_1)^{\rho}-\sum_{i=1}^{N}\gamma_{Ti}\pi_{i1}(1-\rho)\alpha_iI_i+\gamma_P\frac{1}{\theta}\pi_{11}$$
$$+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\pi_{i1}(1-\pi_{i1})x_i-\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\pi_{11}\pi_{1i}x_1-\sum_{i\neq 1}\gamma_i\sum_{m\neq 1}^{N}\pi_{m1}\pi_{mi}x_m-\sum_{i\neq 1}\gamma_i\frac{1}{1+\tau_i^m}\pi_{11}\pi_{1i}x_1\Big\}=0$$

FOC over T_n

$$-\gamma_{Tn,-1}+\beta\Big\{(1-\delta)\gamma_{Tn}+\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\rho\,(\pi_{in})^{1-\rho}\,(T_n)^{\rho-1}+\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\sum_{m=1}^{N}(1-\rho)\,(\pi_{im})^{-\rho}\,(T_m)^{\rho}\,\frac{\partial\pi_{im}}{\partial T_n}$$
$$+\gamma_P\frac{1}{\theta}\frac{\pi_{1n}}{T_n}+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\frac{\partial\pi_{i1}}{\partial T_n}x_i+\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\frac{\partial\pi_{1i}}{\partial T_n}x_1+\sum_{i\neq 1}\gamma_i\sum_{m\neq 1}^{N}\frac{\partial\pi_{mi}}{\partial T_n}x_m+\sum_{i\neq 1}\gamma_i\frac{1}{1+\tau_i^m}\frac{\partial\pi_{1i}}{\partial T_n}x_1\Big\}=0$$

Plugging in derivatives

$$-\gamma_{Tn,-1}T_n+\beta\Big\{(1-\delta)\gamma_{Tn}T_n+\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\rho\left(\pi_{i,n}\right)^{1-\rho}\left(T_n\right)^{\rho}-\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\sum_{m=1}^{N}(1-\rho)\left(\pi_{im}\right)^{-\rho}\left(T_m\right)^{\rho}\pi_{im}\pi_{in}$$

$$+\sum_{i=1}\gamma_{Ti}\alpha_i(1-\rho)\left(\pi_{in}\right)^{-\rho}\left(T_n\right)^{\rho}\pi_{i,n}+\gamma_P\frac{1}{\theta}\pi_{1n}-\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\pi_{i1}\pi_{in}x_i-\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\pi_{1i}\pi_{1n}x_1$$

$$+\gamma_x\frac{\tau_n^m}{1+\tau_n^m}\pi_{1n}x_1-\sum_{i\neq 1}\gamma_i\sum_{m\neq 1}^{N}\pi_{mi}\pi_{mn}x_m+\gamma_n\sum_{m\neq 1}^{N}\pi_{mn}x_m-\sum_{i\neq 1}\gamma_i\frac{1}{1+\tau_i^m}\pi_{1i}\pi_{1n}x_1+\gamma_n\frac{1}{1+\tau_n^m}\pi_{1n}x_1\Big\}=0$$

Final on T_n:

$$-\gamma_{Tn,-1}T_n+\beta\Big\{(1-\delta)\gamma_{Tn}T_n+\sum_{i=1}^{N}\gamma_{Ti}\alpha_i\left(\pi_{i,n}\right)^{1-\rho}\left(T_n\right)^{\rho}-\sum_{i=1}^{N}\gamma_{Ti}\pi_{i,n}(1-\rho)\alpha_i I_i$$

$$+\gamma_P\frac{1}{\theta}\pi_{1n}-\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\pi_{i1}\pi_{in}x_i-\gamma_x\sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\pi_{1i}\pi_{1n}x_1+\gamma_x\frac{\tau_n^m}{1+\tau_n^m}\pi_{1n}x_1$$

$$-\sum_{i\neq 1}\gamma_i\sum_{m\neq 1}^{N}\pi_{mi}\pi_{mn}x_m+\gamma_n\sum_{m\neq 1}^{N}\pi_{mn}x_m-\sum_{i\neq 1}\gamma_i\frac{1}{1+\tau_i^m}\pi_{1i}\pi_{1n}x_1+\gamma_n\frac{1}{1+\tau_n^m}\pi_{1n}x_1\Big\}=0$$

C Proof of Corollary 1

For the case of two countries, the optimal export tax is derived from the FOC over τ_2^x:

$$\frac{\gamma_x x_2}{1+\tau_2^x}-\gamma_x\frac{\tau_2^x}{1+\tau_2^x}\theta\pi_{22}x_2-\gamma_2\theta\pi_{22}x_2-\gamma_{T_2}(1-\rho)\theta\alpha_2\pi_{22}((\frac{T_1}{\pi_{21}})^{\rho}-(\frac{T_2}{\pi_{22}})^{\rho})=0$$

Optimal export tax:

$$\frac{1}{1+\tau_2^x}=\frac{(\gamma_x-\gamma_2)\theta\pi_{22}x_2+\gamma_{T_2}(1-\rho)\theta\alpha_2\pi_{22}\left[(\frac{T_1}{\pi_{21}})^{\rho}-(\frac{T_2}{\pi_{22}})^{\rho}\right]}{\gamma_x(1+\theta\pi_{22})x_2}$$

To derive the optimal import tariff, we combine the FOC over τ_2^m and FOC over x_1
FOC over τ_2^m:

$$\frac{1}{1+\tau_2^m}=\frac{(u_c+\gamma_x\theta\pi_{11})x_1-\gamma_{T_1}(1-\rho)\theta\pi_{11}\alpha_1((\frac{T_1}{\pi_{11}})^{\rho}-(\frac{T_2}{\pi_{12}})^{\rho})}{(\gamma_x+\gamma_2)(1+\theta\pi_{11})x_1}$$

FOC over x_1:

$$u_c=\gamma_x(1-\frac{\tau_2^m}{1+\tau_2^m}\pi_{12})-\gamma_2\frac{1}{1+\tau_2^m}\pi_{12}$$

Optimal import tariff:

$$\frac{1}{1+\tau_2^m} = \frac{\gamma_x}{\gamma_x - \gamma_2} + \frac{\gamma_{T_1}(1-\rho)\theta\alpha_1\pi_{11}\left[(\frac{T_2}{\pi_{12}})^\rho - (\frac{T_1}{\pi_{11}})^\rho\right]}{(\gamma_x-\gamma_2)(1+\theta)\pi_{11}x_1}$$

According to the tax neutrality in Proposition 2, we can normalize one variable without affecting real allocations.

1) By normalizing $\tau_2^x = 0$, we get

$$\gamma_2 = \frac{-\gamma_x x_2 + \gamma_{T_2}(1-\rho)\theta\alpha_2\pi_{22}\left[(\frac{T_1}{\pi_{21}})^\rho - (\frac{T_2}{\pi_{22}})^\rho\right]}{\theta\pi_{22}x_2}$$

$$\frac{1}{1+\tau_2^m} = \frac{1}{\gamma_x - \gamma_2}(\gamma_x + \frac{\gamma_{T_1}(1-\rho)\theta\alpha_1\pi_{11}\left[(\frac{T_2}{\pi_{12}})^\rho - (\frac{T_1}{\pi_{11}})^\rho\right]}{(1+\theta)\pi_{11}x_1})$$

2) By normalizing $\tau_2^m = 0$, we get

$$\gamma_2 = -\frac{\gamma_{T_1}(1-\rho)\theta\alpha_1\pi_{11}\left[(\frac{T_2}{\pi_{12}})^\rho - (\frac{T_1}{\pi_{11}})^\rho\right]}{(1+\theta)\pi_{11}x_1}$$

$$\frac{1}{1+\tau_2^x} = \frac{(\gamma_x-\gamma_2)\theta\pi_{22}x_2 + \gamma_{T_2}(1-\rho)\theta\alpha_2\pi_{22}\left[(\frac{T_1}{\pi_{21}})^\rho - (\frac{T_2}{\pi_{22}})^\rho\right]}{\gamma_x(1+\theta\pi_{22})x_2}$$

3) By normalizing $\gamma_2 = -\frac{\gamma_x}{\theta\pi_{22}}$, we get Equation (10) and Equation (11):

$$\frac{1}{1+\tau_2^x} = 1 + \frac{\gamma_{T_2}(1-\rho)\theta\frac{1}{\gamma_x x_2}\alpha_2\pi_{22}\left[(\frac{T_1}{\pi_{21}})^\rho - (\frac{T_2}{\pi_{22}})^\rho\right]}{1+\theta\pi_{22}}$$

$$\frac{1}{1+\tau_2^m} = \frac{\theta\pi_{22}}{1+\theta\pi_{22}}(1 + \frac{\gamma_{T_1}(1-\rho)\theta\alpha_1\pi_{11}\left[(\frac{T_2}{\pi_{12}})^\rho - (\frac{T_1}{\pi_{11}})^\rho\right]}{\gamma_x(1+\theta)\pi_{11}x_1})$$

To back out multipliers γ_x, γ_{T_1} and γ_{T_2}, we use the following three equations.

1. Combining the FOC on T_1 and T_2:

$$\sum_{n=1}^{2}\gamma_{T_n}T_n\theta(1-\beta+\beta\delta(1-\rho)) = \beta u_c x_1$$

2. Combining the FOC on w_2 and T_2:

$$-\gamma_2\pi_{21}x_2 - \frac{\gamma_{T_2}T_2\theta}{\beta} + \gamma_x\frac{\tau_x}{1+\tau_x}\pi_{21}x_2 + (1-\delta)\gamma_{T_2}T_2\theta + \sum_{n=1}^{2}\gamma_{T_n}\alpha_n\pi_{n2}^{1-\rho}\rho T_2^\rho\theta = 0$$

3. Combining the FOC on x_1 and τ_2^m:

$$(u_c - \gamma_x)(1+\theta)x_1 = -\gamma_{T_1}(1-\rho)\theta\pi_{12}\alpha_1((\frac{T_1}{\pi_{11}})^\rho - (\frac{T_2}{\pi_{12}})^\rho)$$

D Computing Optimal Policies at Steady State

1. We guess $\{w_n, T_n, \tau_n^x, \tau_n^m\}$ and assume $\tau_2^x = 0$. The total number of unknow is $N + N + 2(N-1) - 1$.

2. We find $\{\pi_{ni}, x_n, P_n\}$

$$P_1 = \left[T_1(w_1 d)^{-\theta} + \sum_{n\neq 1} T_n(w_n(1+\tau_n^m)d)^{-\theta}\right]^{-\frac{1}{\theta}} \qquad (\gamma_P)$$

$$x_1 = w_1 L_1 + \sum_{i\neq 1}^{N} \frac{\tau_i^x}{1+\tau_i^x}\pi_{i1}\left(w_i L_i\right) + \sum_{i\neq 1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\pi_{1i}x_1, \quad (\gamma_x)$$

$$x_i = w_i L_i$$

3. We find multipliers $1 + (N-1) + N : \{\gamma_x, \gamma_n, \gamma_{Tn}\}$, by setting $\gamma_N = 0$

FOC over T_1

$$\gamma_x \sum_{i\neq 1}^{N}\left(\frac{\tau_i^x}{1+\tau_i^x}\pi_{i1}(1-\pi_{i1})x_i - \frac{\tau_i^m}{1+\tau_i^m}\pi_{11}\pi_{1i}x_1\right) + \sum_{i\neq 1}\gamma_i\left[\frac{\tau_i^m}{1+\tau_i^m}\pi_{11}\pi_{1i}x_1 - \sum_{m=1}^{N}\pi_{m1}\pi_{mi}x_m\right]$$
$$-\left(\frac{1}{\beta} - 1 + \delta\right)\gamma_{T1}T_1 + \sum_{i=1}^{N}\gamma_{Ti}\left[\alpha_i\left(\pi_{i,1}\right)^{1-\rho}\left(T_1\right)^\rho - (1-\rho)\delta\pi_{i1}T_i\right] = -u_c x_1\frac{1}{\theta}\pi_{11}$$

FOC over T_n

$$-\left(\frac{1}{\beta} - 1 + \delta\right)\gamma_{Tn}T_n + \sum_{i=1}^{N}\gamma_{Ti}\left[\alpha_i\left(\pi_{i,n}\right)^{1-\rho}\left(T_n\right)^\rho - (1-\rho)\delta\pi_{i,n}T_i\right]$$
$$+\gamma_x\left[\sum_{i\neq 1}^{N}\left(-\frac{\tau_i^x}{1+\tau_i^x}\pi_{i1}\pi_{in}x_i - \frac{\tau_i^m}{1+\tau_i^m}\pi_{1i}\pi_{1n}x_1\right) + \frac{\tau_n^m}{1+\tau_n^m}\pi_{1n}x_1\right]$$
$$+\gamma_n\left(\sum_{m=1}^{N}\pi_{mn}x_m - \frac{\tau_n^m}{1+\tau_n^m}\pi_{1n}x_1\right) + \sum_{i\neq 1}\gamma_i\left(\frac{\tau_i^m}{1+\tau_i^m}\pi_{1i}\pi_{1n}x_1 - \sum_{m=1}^{N}\pi_{mi}\pi_{m,n}x_m\right) = -u_c x_1\frac{1}{\theta}\pi_{1n}$$

FOC over x_1

$$u_c + \sum_{n\neq 1}^{N}\gamma_n\frac{1}{1+\tau_n^m}\pi_{1n} - \gamma_x\left(1 - \sum_{n\neq 1}^{N}\frac{\tau_n^m}{1+\tau_n^m}\pi_{1n}\right) = 0$$

We have a condition for the tariff for $n=2$, the following holds:

$$\begin{aligned}&u_c-\sum_{i\neq\{1,n\}}^{N}(\gamma_x-\gamma_i)\frac{\tau_i^m}{1+\tau_i^m}\theta\pi_{1i}+\gamma_x\theta(1-\pi_{1n})-\sum_{m\neq\{1,n\}}\gamma_m\theta\pi_{1m}\\&-\gamma_{T1}(1-\rho)\frac{1}{x_1}\theta\alpha_1\left[I_1-(\pi_{1n})^{-\rho}(T_n)^\rho\right]=\frac{1}{1+\tau_n^m}(\gamma_x-\gamma_n)\left[1+\theta(1-\pi_{1n})\right]\end{aligned}$$

Reorganize

$$\begin{aligned}&\gamma_{T1}(1-\rho)\frac{1}{x_1}\theta\alpha_1\left[I_1-(\pi_{1,n})^{-\rho}(T_n)^\rho\right]+\gamma_x\left(\sum_{i\neq\{1,n\}}^{N}\frac{\tau_i^m}{1+\tau_i^m}\theta\pi_{1i}-\theta(1-\pi_{1n})+\frac{1}{1+\tau_n^m}\left[1+\theta(1-\pi_{1n})\right]\right)\\&+\sum_{i\neq\{1,n\}}^{N}\gamma_i\left(\frac{1}{1+\tau_i^m}\theta\pi_{1i}\right)-\frac{1}{1+\tau_n^m}\gamma_n\left[1+\theta(1-\pi_{1n})\right]=u_c\end{aligned}$$

or

$$\begin{aligned}&\gamma_{T1}(1-\rho)\frac{1}{x_1}\theta\alpha_1\left[I_1-(\pi_{1,n})^{-\rho}(T_n)^\rho\right]+\gamma_x\left(\sum_{i\neq1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\theta\pi_{1i}-\theta+\frac{1+\theta}{1+\tau_n^m}\right)\\&+\sum_{i\neq1}^{N}\gamma_i\left(\frac{1}{1+\tau_i^m}\theta\pi_{1i}\right)-\frac{1+\theta}{1+\tau_n^m}\gamma_n=u_c\end{aligned}$$

FOC over w_n for $n>3$

$$\begin{aligned}&\sum_{i=1}^{N}\gamma_{Ti}(1-\rho)\pi_{in}\theta\alpha_i\left[I_i-(\pi_{in})^{-\rho}(T_n)^\rho\right]+\sum_{i\neq1}\gamma_i\left[\left(\sum_{m\neq1}^{N}\theta\pi_{mi}\pi_{mn}x_m+\frac{1}{1+\tau_i^m}\theta\pi_{1i}\pi_{1n}x_1+\pi_{ni}x_n\right)\right]\\&+\gamma_x\left[\sum_{i\neq1}^{N}\frac{\tau_i^x}{1+\tau_i^x}\theta\pi_{i1}\pi_{in}x_i+\sum_{i\neq1}^{N}\frac{\tau_i^m}{1+\tau_i^m}\theta\pi_{1i}\pi_{1n}x_1+\frac{\tau_n^x}{1+\tau_n^x}\pi_{n1}x_n-\frac{\tau_n^m}{1+\tau_n^m}\theta\pi_{1n}x_1\right]\\&-\gamma_n\left[\left(\sum_{m\neq1}^{N}\theta\pi_{mn}x_m+\frac{1}{1+\tau_n^m}\theta\pi_{1n}x_1\right)+x_n\right]=u_cx_1\pi_{1n}\end{aligned}$$

4. We check whether the following equations holds. The total number of equations is $N+N+2(N-1)-1$.

$$P_1=1$$

$$\sum_{m=1}^{N}\pi_{nm}x_n=\sum_{m\neq1}^{N}\pi_{mn}x_m+\frac{1}{1+\tau_n^m}\pi_{1,n}x_1,\quad(\gamma_n,\quad(N-1),n>1)$$

$$\delta T_n=\alpha_n\sum_{i=1}^{N}(\pi_{ni})^{1-\rho}(T_i)^\rho,\quad(\gamma_{Tn},\quad N)$$

$$1+\tau_n^x=\frac{\gamma_x\left[1+\theta(1-\pi_{n1})\right]}{\gamma_x\theta\sum_{m\neq1}(1-\gamma_m/\gamma_x)\pi_{nm}+\gamma_{Tn}(1-\rho)\theta\alpha_n\frac{1}{x_n}\left[(\pi_{n1}/T_1)^{-\rho}-I_n\right]}$$

$$1+\tau_n^m = \frac{(\gamma_x - \gamma_n)\left[1+\theta(1-\pi_{1n})\right]}{u_c + \gamma_x \left[\theta\pi_{11} + \sum_{i\neq\{1,n\}}^{N} \left(\frac{1-\gamma_i/\gamma_x}{1+\tau_i^m}\right)\theta\pi_{1i}\right] + \gamma_{T1}(1-\rho)\frac{1}{x_1}\theta\alpha_1 \left[(\pi_{1n})^{-\rho}(T_n)^{\rho} - I_1\right]}, n > 3$$

E Suggestive Evidence: Learning Through Imports

In this section, we show some patterns in our data sample that motivate our paper. We first show technology convergence across countries. The dispersion of technology has been falling. We further propose one potential explanation for convergence: technology diffusion through trade. Using panel data with trade and patent citations, we find that higher citations of a country's patent are associated with larger imports from that country in the past. This finding shows the explanation of technology diffusion through trade is promising.

Data Source Our empirical analysis uses data on trade, National Accounts, and patents. The data on trade in goods is sourced from BACI, CEPII's database based on COMTRADE, which provides a harmonized world trade matrix for values at the HS 6-digit level of the Harmonized System of 1992 (5699 products) for 253 countries.

We obtain the real national account data from Penn World Table 10.1 (PWT 10.1) from 2000 to 2016. We start with a sample of 169 countries, where the total import value in those 169 countries accounts for 98% of the total import in all countries in 2016. We select the 19 largest countries based on their GDP in 2016, and group all other countries into the category of the rest of the world. The import value of these top 19 countries accounts for about 80% of the total imports in those 169 countries in 2016. We use real GDP, physical capital (K), and employment (emp) in PWT 10.1 of these countries.

Patent citations come from the European Patent Office (EPO) data. We only include patents from China that belong to the manufacturing sectors, identified by ISIC rev3-2digit codes ranging from 15 to 36. Additionally, we focus on the years between 2000 and 2010, which are defined as the year when the patent application was filed. In the case of a patent from China with multiple inventors, we distribute the patent and citations equally among the inventors, considering their respective contributions. We then associate each inventor with their corresponding country. We aggregate the number of citations within a specific country-IPC-year combination. To map the country-IPC-year measures to the country-sector-year level, we utilize the IPC-sector mapping provided in Lybbert and Zolas (2014).

Technology Convergence In an Eaton-Kortum trade model, an underlying technology is associated with the observed domestic expenditure share π_{ii} and real income per capita w_i/p_i of a country. Specifically, for each country i, the technology is given by

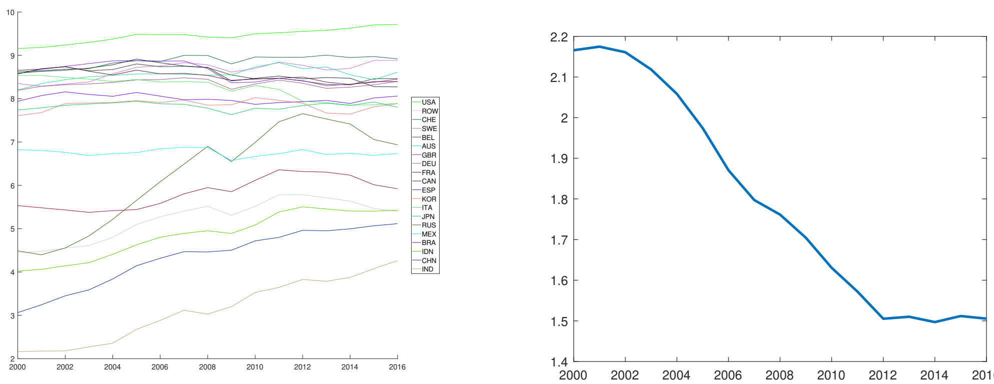
$$T_{it} = \pi_{ii} \left(\frac{w_{it}}{p_{it}} \right)^{\theta}. \tag{A.13}$$

In the EK model, real income per capita equals real GDP per input in consumer price.

Following Buera and Oberfield (2020), we measure the composite input with $K^{\zeta} emp^{1-\zeta}$ where K is capital, emp employment, and ζ capital share. The real GDP, physical capital (K), and employment (emp) are from the PWT 10.1. We choose the capital share ζ to be 0.36 to match the corporate labor share in the US calculated by Karabarbounis and Neiman (2014). The Domestic expenditure share π_{ii} is constructed using the bilateral trade data. The Frechet parameter θ is chosen to be 4, consistent with the trade elasticity estimated from Simonovska and Waugh (2014).

Panel (a) of Figure A-1 plots the logged technology across our 20 countries from 2000 to 2016. On average, developed countries have higher technology development than developing countries. However, developing countries experience faster technology growth. Moreover, the dispersion of technology across countries falls over time, and the standard deviation decreases from around 2.2 to 1.5, as Panel (b) shows. Hence, Figure A-1 indicates a technology convergence.

Figure A-1: Technology Covergence



(a) log(T) (b) Standard Deviation of log(T)

Note: The left panel plots the logged technology backed out using equation (A.13) for each of the 20 countries in our sample. The right panel plots the standard deviation of cross-country technologies in each period from 2000 to 2016.

There are various reasons for technology convergence in Pane (b). One potential one is learning through trade. After 2000, many countries adopted trade liberalization, which not only brought more trade but also technology diffusions through trade across countries. As a result, technology development has become less dispersed across countries. Given that it is challenging to measure technology diffusion, below, we provide suggestive evidence for this channel by documenting a positive relationship between imports and patent citations.

Trade and Technology Diffusion Here, we explore the relationship between trade and technology diffusion. Some literature papers utilize patent citation data to indicate knowledge diffusion (Cai and Li (2019), Acemoglu, Akcigit, and Kerr (2016)). The hypothesis is that when firms in China import from country c, they uncover the underlying technology embedded in the imported goods. Firms further improve upon the technology from country c and cite more the patents from country c. To see the potential of such an explanation, we consider the following panel regression:

$$\log(citation_{cjt}) = \beta_1 \log(import_{cjt-1}) + \beta_2 \log(export_{cjt-1}) + \delta_c + \delta_j + \delta_t + \varepsilon_{cjt}$$

where $citation_{cjt}$ is the number of patent citations that China cites from country c in sector j in year t, $import_{cjt-1}$ is the value of China's import from country c in sector j in year $t-1$, and $export_{cjt-1}$ is the value of China's export to country c in sector j in year $t-1$. We control the country, sector, and time-fixed effects.

Table A-1 reports the regression results using different groups of countries that trade with China. Column (1) uses the top 50 countries that China imported from in 2000, and Column (2) and (3) use the top 40 and top 30 of China's trading partners, respectively. We also consider the group of advanced countries using the IMF definition, OECD high-income countries, and G7 countries.

All results demonstrate a positive relationship between patent citation and import: when China imports more from a country c in the past, it also cites more patents from country c. Exports and patent citations, however, exhibit a negative relationship. Thus, a mechanism of learning from imports is consistent with our empirical findings of positively correlated imports and patent citations.

Table A-1: Regression: Trade on Patent Citations

	(1)	(2)	(3)	(4)	(5)	(6)
	Top50	Top40	Top30	IMF advanced	OECD high income	G7
$\log(import_{cjt-1})$	0.052***	0.058***	0.061***	0.061***	0.053***	0.059***
	(0.010)	(0.012)	(0.015)	(0.015)	(0.012)	(0.029)
$\log(export_{cjt-1})$	-0.041***	-0.045***	-0.046***	-0.046***	-0.082***	-0.011
	(0.011)	(0.012)	(0.014)	(0.016)	(0.019)	(0.040)
FE	country, sector, year					
Obs	11000	8800	6600	9020	7480	1540

Note: Cluster in country. Top50 means only keeping the top 50 countries that China imported from in 2000, similar to the Top 40 and Top 30 countries. IMF advanced means only keeping IMF-advanced countries in the sample.

In summary, we find technological convergence across countries. Such convergency could arise from technology diffusion through imports. Our second empirical finding suggests this explanation is promising. Moreover, many trade disputes are on technology and spillover, it is a natural question to ask the policy implication when a Home country considers technology diffusion and would like to maximize its own utility. In the paper, we derive the dynamic optimal policies with international technology diffusion.