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# Optimal trade policy with international technology diffusion ☆

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ABSTRACT

We study optimal dynamic trade policies in an Eaton–Kortum model with technology diffusion through trade. Trade affects technology by determining the distribution from which potential producers draw their insights. Our theory shows that optimal policies capture dynamic motives for a country to alter global technology. These policies take into account selection effects and country endowments that affect the degree and quality of diffusion. We provide explicit formulas showing that a country should subsidize imports that raise domestic learning quality and reduce export taxes when higher foreign productivity benefits the home country and increased exports improve foreign learning. We quantify these dynamic policies and their welfare implications using cross-country data.

## 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, as well as suggestive empirical evidence that learning from importing holds in the data.[4] 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.

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[1] Large literature suggested a strong relationship between openness and growth, for example, Ben-David (1993), Coe and Helpman (1995), Frankel and Romer (1999) and Sachs (1995). We also find technology convergence across countries during our sample periods, see Online Appendix H.

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

[3] For example, Eaton and Kortum (2006). Cai et al. (2022b) quantifies the cross-country and cross-sector interactions among trade, innovation, and knowledge diffusion.

[4] Theoretical and quantitative exercises include Alvarez et al. (2013), Buera and Oberfield (2020), Cai et al. (2022a), and Santacreu (2015). Empirical evidence see Coe and Helpman (1995), Grossman and Helpman (1991), MacGarvie (2006) and Sjöholm (1996). See Keller (2010) for a review.

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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 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. Without diffusion, Home's optimal policy would consist of imposing an import tariff to manipulate its terms of trade in its favor. Export tax can be set to zero according to Lerner symmetry. With diffusion, Home has an extra motive to manipulate trade to affect technological diffusion both domestically and abroad. Foreign technology affects Home: a higher level of Foreign technology makes its goods cheaper but reduces Home's exports and thus tax revenue and income. However, better foreign technology diffuses to Home through imports, ultimately improving Home's future technology. If the overall effect is that higher Foreign technology is good for Home and exporting more to Foreign improves Foreign technology, Home would want to lower its export tax, relative to 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 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) (henceforth BO), which extends (Eaton and Kortum, 2002) (henceforth EK) 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 and foreign sellers. Trade affects the creation and diffusion of ideas by determining the distribution from which potential 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 a 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.

As diffusion is through the goods sold to Home markets, selection matters. Both trade costs and foreign endowment affect selection. Higher trade costs result in lower imports, leading to reduced learning from foreign markets. Moreover, higher trade costs lead to the selection of more productive foreign producers to sell to the home country, thereby improving the quality of learning. The endowment of foreign countries also matters for selection. Importing from a low-wage country results in a lower quality of learning, as the home country imports from sellers with 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.

To understand the nature of externality and incentives for policies, we start with the problem of a central planner who cares about the weighted sum of the welfare of all countries. Under the EK model, due to tax neutrality, cross-country import tariffs and international transfers are sufficient tax instruments for the planner. Without diffusion, the world market equilibrium is efficient, and the planner has no incentives to impose import tariffs or export taxes. With diffusion, to correct the externality arising from technology diffusion, the optimal tariffs include a diffusion wedge, which increases with the relative insight embodied in imports. For example, If country A's import from country B improves A's technology, the diffusion wedge is positive, and the planner would subsidize A's imports from B.

We then 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 include greater diffusion benefits than the domestic quality afforded at Home, then Home should subsidize imports from that country. It can also choose export taxes 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 tariffs and export taxes jointly.

Based on the multi-country setup, we use data to quantitatively study optimal unilateral trade policies for the U.S. and China, and the implied welfare impact. We compute the optimal trade policies for both the balanced growth path and the transition to it.[5]

[5] Our model is isomorphic to the detrended semi-endogenous growth model in BO, which assumes the growth rate of innovation efficiency is exogenously driven by population growth. The two models would prescribe the same optimal policies in both the transition and the long run. In the calibration, we consider the economy to be on a balanced growth path in 2016, the last year of our data sample. When Home implements a path of optimal dynamic policies, technologies change and slowly accumulate to the new balanced growth path.

We calibrate the model to 20 countries, including the nineteen largest countries, based on their GDP in 2016, and the rest of the world. The exogenous innovation efficiencies for each of the 20 countries and the diffusion parameter $\rho$ are calibrated jointly using the national account and trade data from 2000 to 2016. The calibrated innovation efficiencies, on average, are higher for countries with higher real GDP per input.

Under the 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 countries. The reason is that by imposing import tariffs, the U.S. 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 U.S. and see a decline in technology. Trade costs affect 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 different. Chinese policies are more beneficial for China than U.S. ones are for the U.S. since China is less efficient and can learn more. China 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.

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 differential tariffs across countries to take advantage of foreign technologies. As a result, import tariffs are less dispersed. The impact of higher U.S. wages dominates, leading to a fall in other countries' imports and 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 U.S. and see technology and welfare gains.

To further study the policy impacts of technology diffusion, we consider two experiments. In the first one, Home overlooks the benefits of learning and treats technology exogenously. As the government does not consider technology diffusion, the optimal policy yields smaller gains than the baseline for the U.S. and results in a loss for China. The second experiment explores alternative values of diffusion parameters. As diffusion increases, the optimal tariffs and export taxes become more dispersed across countries.

Our model does not consider endogenous innovation. If innovations were chosen endogenously by innovators, diffusion would impact competition, affecting returns to innovators and subsequently influencing innovation and long-run growth. In such a scenario, the Home government would consider the endogenous response of innovation when choosing policies. This aspect is studied in the work of Bai et al. (2023) and Santacreu (2024). Furthermore, Bai et al. (2023) demonstrates that a Home government would use country-sector-specific tariffs, export taxes, and sometimes domestic policies to influence foreign innovation incentives and, consequently, technology. The current paper focuses on quantitative analysis of technology diffusions. In general, government policies play a role in different market structures and innovation processes, including intertemporal diffusion. In an open economy, these considerations intertwine with the terms of trade considerations, leading to a complex scenario that warrants separate consideration of each element for a comprehensive understanding.

Our paper proceeds as follows. Section 2 sets up the multi-country dynamic theoretical framework. Section 3 studies the optimal policies of a central planner and those of the Home government, and Section 4 uses data to quantitatively study optimal unilateral trade policies for the U.S. and China and the implied welfare impact. Section 5 concludes.

## 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 $\beta$ 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 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 and foreign sellers.

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 $\theta$, and the evolution of the scale of the Frechet, that is, the stock of knowledge, evolves according to[6]

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

where $\alpha_n$ 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. $\left(T_{it}/\pi_{ni,t}\right)^{\rho}$ reflects the average quality of insights country $n$ draws from $i$ through imports, where $\rho$ 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 similar to those in Eaton and Kortum (2002). Without loss of generality, we normalize the Home price $P_{1t} = 1$ for any period $t$. We now define the world market equilibrium.

**Definition 1** (*World Market Equilibrium*)**.** The world market equilibrium consists of consumption $\{C_{nt}\}$, technology $\{T_{nt}\}$, expenditures $\{x_{nt}\}$, prices $\{P_{nt}\}$, and wages $\{w_{nt}\}$ such that, for each country $n$ in each period $t$, consumers maximize expected discounted utility, with constraints $P_{nt}C_{nt} = x_{nt}$; technology evolves according to (1); markets clear: $w_{nt}L_{nt} = \sum_{i\neq n}^{N} \pi_{in,t}x_{it} + \pi_{nn,t}x_{nt}$, where expenditures are given by $x_{nt} = w_{nt}L_{nt}$ and trade shares satisfying $\pi_{ni,t} = \frac{T_{it}(w_{it}d_{ni,t})^{-\theta}}{T_{nt}w_{nt}^{-\theta}+\sum_{j\neq n}T_{jt}(w_{jt}d_{nj,t})^{-\theta}}$. The consumer prices are given by $P_{nt} = \left[T_{nt}w_{nt}^{-\theta} + \sum_{i\neq n} T_{it}(w_{it}d_{ni,t})^{-\theta}\right]^{-\frac{1}{\theta}}$.

*Evidence of diffusion:* There are extensive works documenting learning through imports, as reviewed in Keller (2010, 2021).[7] We also provide empirical evidence of this mechanism at work in Online Appendix H. In our sample period, we find a positive relationship between patent citations and imports: when China imports more from country $n$ in the past, it also cites more patents from country $n$. Thus, the assumption of learning from imports is consistent with our empirical findings of positively correlated imports and patent citations.

## 3. Optimal policies

This section studies optimal policies. To understand the nature of inefficiency and incentives for policies, we start with a central planner's problem, where the only externality is the technology diffusion through imports. We then study Home's unilateral optimal policies. From the Home government's perspective, there are two types of externalities: the technology diffusion and the traditional terms-of-trade externality.

We assume that governments lack knowledge about each good's productivity but know the technology distributions. Under this assumption, country-specific export taxes and tariffs are the finest policy instruments, and they are sufficient to address the externalities stemming from import-induced technology diffusions and terms of trade.[8]

### 3.1. Central planner problem

Consider a world social planner whose goal is to maximize global welfare, measured as a weighted sum across nations: $\sum_{n=1}^{N} \lambda_n u(\frac{x_{nt}}{P_{nt}})$ with $\lambda_n$ capturing the planner's weight on country $n$. The planner can use all trade policy instruments: (1) the import tariff $\tau^m_{ni,t}$ and export tax $\tau^x_{in,t}$ between each pair of countries, where $\tau^m_{ni,t}$ is the tariff imposed on country $n$'s imports of country $i$'s goods, and $\tau^x_{in,t}$ the export tax on country $n$'s export to country $i$. (2) international transfers $\{\kappa_{nt}\}$ across countries with $\sum_{n=1}^{N} \kappa_{nt} = 0$.

At period 0, the planner chooses the sequence of $\left\{\tau^m_{ni,t}, \tau^x_{in,t}, \kappa_{nt}\right\}$ to solve the following problem:

$$\max \sum_{t=0}^{\infty} \beta^t \sum_{n=1}^{N} \lambda_n u\left(\frac{x_{nt}}{P_{nt}}\right) \tag{2}$$

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

[7] Research shows trade facilitates technology diffusion: A country's productivity depends on both domestic and foreign R&D through trade (Coe and Helpman, 1995), with evidence of import-related R&D spillovers (Acharya and Keller, 2009). Patent citation analyses demonstrate imports' role in technology transfer (Sjöholm, 1996; MacGarvie, 2006). Using French data, Aghion et al. (2023) show countries cite more French patents after French firms start exporting there.

[8] The assumption of not knowing individual goods' productivity is consistent with the underlying assumption in Eaton and Kortum (2002) (EK) and Buera and Oberfield (2020). In these frameworks, goods are ex-ante identical, drawing ideas from the same distribution. Thus, ex-ante, a planner has no incentive to impose goods-specific taxes. While ex-post, the planner may consider subsidizing certain goods if it knows their productivity. However, the beauty of the EK model lies in the assumption that only the probability (or shares) of country $n$ imported from country $i$ is known, while the specific goods imported from country $i$ remain unknown. Without this assumption, computing the equilibrium would be a challenging task in a multi-country setup, requiring the comparison of goods' prices in different countries. Therefore, we maintain this assumption, and country-specific export taxes and tariffs are the finest policy instruments.

subject to the zero total transfers $\sum_{n=1}^{N} \kappa_{nt} = 0$ and the private equilibrium under the planner's taxes and transfers, characterized by the technology evolution (1), markets clearing conditions

$$w_{nt} L_{nt} = \sum_{i \neq n}^{N} \frac{1}{1+\tau^x_{in,t}} \frac{1}{1+\tau^m_{in,t}} \pi_{in,t} x_{it} + \pi_{nn,t} x_{nt}, \quad \forall n, t, \tag{3}$$

the definition of expenditures

$$x_{nt} = w_{nt} L_{nt} + \sum_{i \neq n}^{N} \frac{\tau^m_{ni,t}}{1+\tau^m_{ni,t}} \pi_{ni,t} x_{nt} + \sum_{i \neq n}^{N} \frac{\tau^x_{in,t}}{1+\tau^x_{in,t}} \frac{1}{1+\tau^m_{in,t}} \pi_{in,t} x_{it} + \kappa_{nt}, \quad \forall n, t, \tag{4}$$

trade shares $\pi_{ni,t} = \frac{T_{it}(w_{it}(1+\tau^x_{ni,t})(1+\tau^m_{ni,t})d_{ni,t})^{-\theta}}{T_{nt} w_{nt}^{-\theta} + \sum_{j \neq n} T_{jt}(w_{jt}(1+\tau^x_{nj,t})(1+\tau^m_{nj,t})d_{nj,t})^{-\theta}}$ and consumer prices

$$P_{nt} = \left[ T_{nt} w_{nt}^{-\theta} + \sum_{i \neq n} T_{it} (w_{it}(1+\tau^x_{ni,t})(1+\tau^m_{ni,t})d_{ni,t})^{-\theta} \right]^{-\frac{1}{\theta}}, \forall n, t. \tag{5}$$

Online Appendix A writes the central planner's problem recursively. Below, we establish that some of these taxes are redundant.

**Definition 2.** Let $\Gamma = \{(1+\tau^m_{ni,t}, 1+\tau^x_{in,t}, \kappa_{nt}) : \forall n, i, t\}$ be a set of policies. Two policies $\Gamma$ and $\check{\Gamma}$ are neutral if the allocations and welfare of the world market equilibrium under $\Gamma$ and $\check{\Gamma}$ are the same.

**Proposition 1** (*Tax Neutrality*). *Two sets of central government policies $\Gamma = \{(1+\tau^m_{ni,t}, 1+\tau^x_{in,t}, \kappa_{nt}) : \forall n, i, t\}$ and $\check{\Gamma} = \{(1+\check{\tau}^m_{ni,t}, 1+\check{\tau}^x_{in,t}, \check{\kappa}_{nt}) : \forall n, i, t\}$ are neutral if $1+\check{\tau}^m_{ni,t} = \frac{\xi_{it}}{\xi_{nt}} \mu_{ni,t}(1+\tau^m_{ni,t})$, $1+\check{\tau}^x_{ni,t} = \frac{1+\tau^x_{ni,t}}{\mu_{ni,t}}$, and $\check{\kappa}_{nt} = \frac{1}{\xi_{nt}} \left[ \kappa_{nt} + \sum_{i \neq n}^{N} \frac{\xi_{nt}/\xi_{it} - \mu_{ni,t}}{\mu_{ni,t}(1+\tau^m_{ni,t})} \pi_{ni,t} x_{nt} + \sum_{i \neq n}^{N} \frac{\mu_{in,t}-1}{\mu_{in,t}(1+\tau^m_{in,t})} \pi_{in,t} x_{it} \right]$ for any constants $\mu_{ni,t} > 0$ for any $i \neq n$ and $\xi_{nt} > 0$ for any $n$, where the trade shares and expenditures $\{\pi_{ni,t}, x_{nt}\}$ are from the world market equilibrium under policy $\Gamma$.*

**Proof.** Online Appendix A.2. This proposition shows that tax neutrality holds, similar to Lerner (1936) and Costinot and Werning (2019). First, two policies are equivalent if they have the same product of $(1+\tau^m_{ni,t})(1+\tau^x_{ni,t})$ under some transfers. This implies that the planner can equally utilize either the tariff of country $n$ on country $i$'s goods or the export tax of country $i$ on its export to country $n$, as both taxes equally impact the price from $i$ to $n$. Thus, all export taxes can be normalized to zero. For any policy $\Gamma$, we can set $\mu_{ni,t} = 1+\tau^x_{ni,t}$ and $\check{\tau}^x_{ni,t} = 0$. Second, by further adjusting $\{\frac{\xi_{it}}{\xi_{nt}}\}$, we can set the tariffs of country $n$ on other countries' goods to zero or normalize the tariffs imposed on country $n$'s goods to zero, or make all transfers $\{\kappa_{nt}\}$ zero. In all the cases, we remove $N-1$ policy instruments.

In summary, there are total $2N(N-1)+N-1$ policy instruments including $N(N-1)$ import tariffs, $N(N-1)$ export taxes, and $N-1$ transfers. Proposition 1 indicates that for any policy $\Gamma$, we can use $\mu_{ni,t}$ to remove $N(N-1)$ export taxes and use $\{\frac{\xi_{it}}{\xi_{nt}}\}$ to further remove $N-1$ import tariffs or transfers. Hence, the planner only needs to use $N(N-1)$ instruments to manipulate $N(N-1)$ trade flows $\{\pi_{ni,t}\}$.

**Proposition 2** (*Central Planner's Optimal Policy under No Diffusion*). *Without technology diffusion ($\rho = 0$), the central planner can set all import tariffs and export taxes to zero, $\tau^m_{ni} = \tau^x_{ni} = 0$, for any $n, i$, with transfers.*

**Proof.** Online Appendix A.3. Without technology diffusion, $\rho = 0$, technology accumulation (1) becomes $T_{n,t+1} = (1-\delta)T_{nt} + \alpha_n$, and thus technologies evolves exogenously. Taking as given countries' technologies, the central planner solves the optimal policies in a static way. In the absence of externalities from technology diffusions, the planner has no incentive to implement differential tariffs or export taxes to affect trade flows, as such taxes are distortionary. With tax neutrality, the planner can further set all taxes and tariffs to zero.

**Corollary 1.** *Without technology diffusion, the world market equilibrium in Definition 1 is efficient.*

Corollary 1 is a straightforward application of Proposition 2. Given that the planner does not impose any import tariffs or export taxes, the world market equilibrium consists of the same allocations as the planner's problem under some weights. With technology diffusions, the world market equilibrium is not efficient anymore, and the planner has incentives to use trade policies to correct the diffusion externality.

**Proposition 3** (*Central Planner's Optimal Policy under Technology Diffusion*). *With technology diffusion, the central planner can use transfers to set the optimal policies as*

$$\frac{1}{1+\tau^m_{in,t}} = 1 + \gamma_{Ti,t} \frac{(1-\rho)\theta\alpha_i}{\gamma_{xi,t}(1+\theta)x_{it}} \left[ \left( \frac{T_{nt}}{\pi_{in,t}} \right)^{\rho} - \left( \frac{T_{it}}{\pi_{ii,t}} \right)^{\rho} \right], \quad \textit{for } i \neq n \tag{6}$$

*or equivalently by tax neutrality, the planner can optimally set $\tau^m_{in,t} = \tau^x_{ni,t} = 0$ for $i > n$ and the rest $N(N-1)/2$ import tariffs and $N(N-1)/2$ export taxes as*

$$\frac{1}{1+\tau^m_{in,t}} = 1 + \gamma_{Ti,t}\frac{(1-\rho)\theta\alpha_i}{\gamma_{xi,t}(1+\theta)x_{it}}\left[\left(\frac{T_{nt}}{\pi_{in,t}}\right)^\rho - \left(\frac{T_{it}}{\pi_{ii,t}}\right)^\rho\right], \quad \text{for } i<n, \tag{7}$$

$$\frac{1}{1+\tau^x_{ni,t}} = 1 + \gamma_{Tn,t}\frac{(1-\rho)\theta\alpha_n}{\gamma_{xn,t}(1+\theta)x_{nt}}\left[\left(\frac{T_{it}}{\pi_{ni,t}}\right)^\rho - \left(\frac{T_{nt}}{\pi_{nn,t}}\right)^\rho\right] \quad \text{for } i<n, \tag{8}$$

*where $\gamma_{Tn,t}$, $\gamma_{xn,t}$ are the multipliers of the central planner's optimization problem (2), with $\gamma_{Tn,t}$ being the multiplier on country $n$'s technology accumulation (1), and $\gamma_{xn,t}$ the multiplier on country $n$'s expenditure Eq. (4).*

**Proof.** Online Appendix A.3. With technology diffusion, the central planner is incentivized to manipulate trade flows to influence technology accumulation worldwide. It uses global trade policies to dictate the relative prices of goods and expenditures. This is why the multipliers on expenditures $\{\gamma_{xn,t}\}$ appear in the tariff formulae. Moreover, the planner chooses these policies in a dynamic way. The technology-accumulation multiplier $\gamma_{Tn,t}$ reflects the central planner's incentive in choosing $T_{n,t+1}$, which in turn affects the planner's future decision-making regarding $T_{n,t+s}$ for $s>1$. Thus, $\gamma_{Tn,t}$ and all future multipliers $\gamma_{Tn,t+s}$ are jointly determined. In sum, current trade policies affect technology accumulations and future trade policies, which in turn shape the current policies through $\gamma_{Tn,t}$.

Furthermore, the second term in the tariff formula (6) works as a diffusion wedge, compared to the zero optimal tariffs under no diffusion. This wedge reveals the central planner's incentive to correct externalities arising from international technology diffusions. When shutting down diffusion with $\rho=0$, the second term becomes zero, generating zero optimal tariffs as in Proposition 2. Moreover, a positive wedge implies a positive externality from diffusion and leads to import subsidies ($\tau^m<0$).

This diffusion wedge is positive when $\gamma_{Tn,t}[(\frac{T_{it}}{\pi_{ni,t}})^\rho - (\frac{T_{nt}}{\pi_{nn,t}})^\rho]>0$. In this case, the central planner would like to subsidize country $n$'s imports from country $i$. The term $(\frac{T_{it}}{\pi_{ni,t}})^\rho - (\frac{T_{nt}}{\pi_{nn,t}})^\rho$ captures the relative import quality of country $n$ from country $i$, namely the quality of insights embodied in the goods that country $n$ imports from country $i$, relative to country $n$'s domestic quality of insights. If this relative import quality is positive and $\gamma_{Tn,t}\geq 0$, importing from country $i$ is beneficial from idea learning. In this case, country $n$'s tariff on the country $i$'s goods needs to be lowered. Equivalently, by tax neutrality, the central planner can also lower country $i$'s export tax on country $n$, as shown in (8), so that country $n$ can learn from $i$.

### 3.2. Unilateral optimal trade policies

We now examine the unilateral policies of the Home country (country 1), assuming that foreign governments are passive. Specifically, the Home government can impose country-specific export taxes $\tau^x_{n1,t}$ and import tariffs $\tau^m_{1n,t}$ for any country $n>1$ at any period $t$. Home, however, cannot set trade policies and transfers for other countries, and $\tau^m_{ni,t}=\tau^x_{in,t}=\kappa_{nt}=0$ for any $i,n\neq 1$. For simplicity, we drop the subscription 1 in the trade policies. Let $\tau^m_{nt}$ and $\tau^x_{nt}$ be the import tariffs and export taxes on country $n$ imposed by the Home country, respectively.

The government in the Home country chooses trade policies to maximize the aggregate of Home consumers' lifetime utilities, subject to the world market equilibrium given by Definition 1 with $\tau^m_{ni,t}=\tau^x_{in,t}=\kappa_{nt}=0$ for any $i,n\neq 1$. Equivalently, Home chooses the sequence $\{\tau^x_{nt},\tau^m_{nt}\}^\infty_{t=0}$ and private allocations and prices to solve the following problem

$$\max \sum_{t=0}^{\infty}\beta^t u(C_{1t}) \tag{9}$$

subject to the evolution of technology (1), the market clearing conditions (3), Home and Foreigns' expenditure (4), and the normalization of Home price index, for any period $t$.

Note that the Ramsey and Markov problems are equivalent here, given that there are no forward-looking constraints.[9] Online Appendix B.1 specifies the recursive problem of the Home government and characterizes the optimal policies with first-order conditions. We first provide the property of tax neutrality and then proceed to present the key findings.

**Proposition 4** (*Tax Neutrality in Unilateral Problem*)**.** *Consider two sets of Home government trade policies $\Gamma=\{(1+\tau^m_{nt},1+\tau^x_{nt}) : \forall n\neq 1\}$ and $\check{\Gamma}=\left\{\left(\mu_t\left(1+\tau^m_{nt}\right),\frac{1+\tau^x_{nt}}{\mu_t}\right) : \forall n\neq 1\right\}$ for any sequence of positive constant $\{\mu_t\}^\infty_{t=0}$. The welfare and allocation of the world market equilibrium under $\Gamma$ and $\check{\Gamma}$ are the same. In addition, the prices $w_{nt}(\Gamma)=w_{nt}(\check{\Gamma})/\mu_t$, $P_{nt}(\Gamma)=P_{nt}(\check{\Gamma})/\mu_t$ and expenditure $x_{nt}(\Gamma)=x_{nt}(\check{\Gamma})/\mu_t$ for $n>1$ and any $t$.*

**Proof.** Online Appendix B.2. This proposition shows that under technology diffusion, tax neutrality holds. As a result, we can always normalize one of the taxes to zero in each period $t$. In the two-country case, there is only one tariff and one export tax, and we can normalize either export tax or import tariff to zero. In this case, tax neutrality implies that import tariff and export tax are equivalent (thus Lerner symmetry). However, in the models with multiple countries, we can only set *one* of taxes equal to zero. The import tariff and export tax within each country are no longer equivalent.

[9] Bai et al. (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.

As a reference, we first characterize the optimal policies when technology is exogenous. The problem becomes static, and thus, we omit the time $t$ subscript for notational convenience.

**Proposition 5** (*Unilateral Policy with Exogenous Technology*). *When technology is exogenous ($\rho = 0$), optimal unilateral trade policies consist of a country-specific import tariff and country-specific export taxes. Specifically,*

$$\tau_n^m = -\frac{\gamma_n}{u_c}, \qquad 1 + \tau_n^x = \frac{1 + \theta(1 - \pi_{n1})}{\theta \sum_{i \neq 1}(1 + \tau_i^m)\pi_{ni}}. \tag{10}$$

*where $\gamma_n$ is the multiplier on country $n$'s market clearing condition (3) and satisfy the system of equations (A.25) in the online appendix. In the case of two countries $N = 2$, optimal policies can be $\tau_2^x = 0$ and $1 + \tau_2^m = \frac{1+\theta\pi_{22}}{\theta\pi_{22}}$.*

**Proof.** Online Appendix B.3. The overall level of optimal tariffs and export taxes are not uniquely pinned down due to tax neutrality, and we can set zero tariffs or export taxes for one country. $\gamma_n$ is the multiplier on the market clearing condition (3) for country $n$ and optimal tariffs show Home uses country-specific tariffs to manipulate relative wages.

Export taxes are used to exploit the country's monopoly power and manipulate the terms of trade. For example, if all foreign countries are symmetric, we can normalize one of the tariffs to zero, and all tariffs would be zero under symmetry equilibrium. We can further simplify the export tax formula (10) to $1 + \tau_n^x = \frac{1+\theta(1-\pi_{n1})}{\theta(1-\pi_{n1})}$, which increases with $\pi_{n1}$. Thus, the export tax for a particular country rises with the market power (and exports) of the Home country's goods in that country. This pattern of trade policies is consistent with the one proposed by Costinot et al. (2015), where the government can manipulate relative prices in its favor by limiting the supply of its export goods. In general, when dealing with multiple asymmetric countries, Home employs country-specific tariffs to manipulate relative wages and imposes country-specific export taxes to exploit its market power. All trade policies are jointly determined.

Comparing Home's unilateral policy (10) and the central planner's policy outlined in Proposition 2. Without technology diffusion, the world market equilibrium is efficient, and the planner can utilize international transfers to set all import tariffs to zero. In contrast, the Home government would like to manipulate the terms of trade, and it uses country-specific tariffs to affect relative wages across countries. In addition, the Home government is incentivized to manipulate its market power and hence uses country-specific export taxes.

In the case of two countries, export tax and import tariff is equivalent, and Home can optimally impose export tax $\tau_2^x = 0$ and import tariff $\tau_2^m = \frac{1}{\theta\pi_{22}}$ according to Proposition 5. 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 6** (*Unilateral Policy with Technology Diffusion*). *With technology diffusion, the unilateral optimal import tariff and export tax satisfy*

$$\frac{1}{1+\tau_{nt}^m} = \frac{\gamma_{xt}}{\gamma_{xt} - \gamma_{nt}} + \gamma_{T1,t}\frac{(1-\rho)\theta\alpha_1}{(\gamma_{xt} - \gamma_{nt})(1+\theta)x_{1t}}\left[\left(\frac{T_{nt}}{\pi_{1n,t}}\right)^\rho - \left(\frac{T_{1t}}{\pi_{11,t}}\right)^\rho\right] \tag{11}$$

$$\frac{1}{1+\tau_{nt}^x} = \frac{\theta\sum_{i\neq 1}(1 - \gamma_{it}/\gamma_{xt})\pi_{ni,t} + \frac{(1-\rho)\theta}{\gamma_{xt}x_{nt}}\alpha_n\gamma_{Tn,t}\left[\left(\frac{T_{1t}}{\pi_{n1,t}}\right)^\rho - I_{nt}\right]}{1 + \theta(1 - \pi_{n1,t})} \tag{12}$$

*where $\gamma_{Tn,t}$, $\gamma_{nt}$, $\gamma_{xt}$ are the multipliers of the government's optimization problem (9), with $\gamma_{Tn,t}$ being the multiplier on country $n$'s technology accumulation (1), $\gamma_{nt}$ the multiplier on country $n$'s market clearing condition (3), and $\gamma_{xt}$ being the multiplier on Home expenditure Eq. (4) with $n = 1$.*

**Proof.** Online Appendix B.4. With technology diffusion, the incentive to exploit the country's monopoly power still presents as the expenditure country $n$ on country 1 goods, $\pi_{n1}$, showing up in the export tax formula (12). Most importantly, the Home government is incentivized to manipulate trade to influence technologies worldwide. However, the Home government has to respect the market equilibrium. That is the reason the multipliers $\{\gamma_{Tn,t}\}$ on technology accumulation and $\{\gamma_{nt}\}_{n>1}$ on the market clearing conditions show up in the tax formulae.

Moreover, as in the central planner case, the Home government chooses these policies in a dynamic way. $\gamma_{Tn,t}$ 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 $\gamma_{Tn,t}$. When there are no diffusions, $\rho = 0$, the government cannot use policies to manipulate the exogenous technology accumulation. In this case, optimal policies of (11)–(12) are the same as (10) in the exogenous case.

The import tariff formula (11) encompasses both the static terms of trade and the central-planner formula (6) with $i = 1$. When picking import tariffs on country $n$, Home government considers its import quality from $n$ relative to its own domestic quality of insight, i.e. $\left(\frac{T_{nt}}{\pi_{1n,t}}\right)^\rho - \left(\frac{T_{1t}}{\pi_{11,t}}\right)^\rho$. If this relative import quality is positive and $\gamma_{T1,t} \geq 0$, importing from country $n$ is beneficial from idea learning. In this case, the Home government would lower the tariff on the country $n$'s goods.

The export tax formula (12) encompasses both the incentives to leverage static monopoly power, as seen in the exogenous technology case (10), and the incentives to manipulate trade flows due to technology diffusion, as observed in the central planner case (8). Unlike the central planner, the Home government can only control the inflow and outflow of trade in its own country, i.e., $\pi_{1n,t}$ or $\pi_{n1,t}$, and it does not have direct influence over the trade flows between any other two countries, such as $\pi_{nj,t}$ for $n \neq 1$ and $j \neq 1$. Thus, Home cannot fully dictate other countries' technologies. As a result, Home only considers its export quality of insight $T_{1t}/\pi_{n1,t}$ to country $n$ relative to country $n$'s average quality of insights $I_{nt}$, which encapsulates country $n$'s own domestic insight and its imported insights from all other countries. In addition, the central planner can directly control every bilateral trade flow and can set the export tax from country 1 to country $n$ solely based on export quality of insight $T_{1t}/\pi_{n1,t}$ to country $n$ relative to country $n$'s domestic insight $T_{nt}/\pi_{nn,t}$. Nevertheless, when Home's exported goods to country $n$ exhibit a better quality of insights, the export tax to country $n$ should be reduced relative to the terms of trade effect, in either case.

**A Simple Case with Two Countries.** This section examines 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 relative 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 $\alpha_2$ and varying diffusion parameter $\rho$.

**Corollary 2.** *With two countries, the unilateral optimal import tariffs and export taxes under technology diffusion satisfy*

$$\frac{1}{1+\tau_2^m} = \frac{\theta\pi_{22}}{1+\theta\pi_{22}}\left\{1+(1-\rho)\frac{\theta}{1+\theta}\frac{\alpha_1}{\gamma_x x_1}\gamma_{T_1}\left[(\frac{T_2}{\pi_{12}})^\rho - (\frac{T_1}{\pi_{11}})^\rho\right]\right\} \tag{13}$$

$$\frac{1}{1+\tau_2^x} = 1+(1-\rho)\frac{\theta\pi_{22}}{1+\theta\pi_{22}}\frac{\alpha_2}{\gamma_x x_2}\gamma_{T_2}\left[\left(\frac{T_1}{\pi_{21}}\right)^\rho - \left(\frac{T_2}{\pi_{22}}\right)^\rho\right], \tag{14}$$

**Proof.** Online Appendix B.5. The proof is a straightforward application of Proposition 6 with $N = 2$ and normalizing $\gamma_2 = -\frac{\gamma_x}{\theta\pi_{22}}$.

According to the tax neutrality in Proposition 4, we can set one tax to zero. In a two-country case, we can normalize $\tau_2^m = 0$ and solve for $\gamma_2$ and $\tau_2^x$; or $\tau_2^x = 0$ and solve $\gamma_2$ and tariff $\tau_2^m$; 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 $\tau_2^m = \frac{1}{\theta\pi_{22}}$ 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 (14), which is no longer zero, and the tariff (13), which include an additional term besides $\tau_2^m = \frac{1}{\theta\pi_{22}}$.

The incentive to manipulate technology using taxes is encapsulated in the diffusion wedges. The multipliers $\gamma_{T_n}$ for $n = 1, 2$ are associated with the constraints of technology accumulation (1). We label $(\frac{T_2}{\pi_{12}})^\rho - (\frac{T_1}{\pi_{11}})^\rho$ as Home's *relative import quality*. A positive value implies that Home learns more from importing than from domestic sellers.

Let us first consider why Foreign technology matters for Home. First, as Home imports from Foreign, a higher level of foreign technology makes its goods cheaper; Second, a more productive Foreign lowers the relative wages of Home due to competition; Third, a more productive Foreign induces Home to export less and reduce its tax revenue and income. Fourth, 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 Eq. (13). 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.

Fig. 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 $\alpha_2$ to rise from 0.1 to 0.2 and examine the consequent optimal policy.[10] 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 (Fig. 1(a)). The increase in $\alpha_2$ also improves the U.S. relative import quality as $(\frac{T_2}{\pi_{12}})^\rho - (\frac{T_1}{\pi_{11}})^\rho$ increases (Panel (e)). As a result, the U.S. lowers import tariffs (Panel (b)). In this example, when $\alpha_2$ 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 $\frac{1}{\theta\pi_{22}}$ 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., $(\frac{T_1}{\pi_{21}})^\rho > (\frac{T_2}{\pi_{22}})^\rho$, 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 $\alpha_2$ is higher. Even though China's relative import quality is increasing (Panel (f)), $\gamma_{T_2}$ has been decreasing. This competitive force dominates the increasing learning effect and reverses the fall in export taxes, as shown in Panel (c).

[10] 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 $L_1 = 1$, $L_2 = 3$.

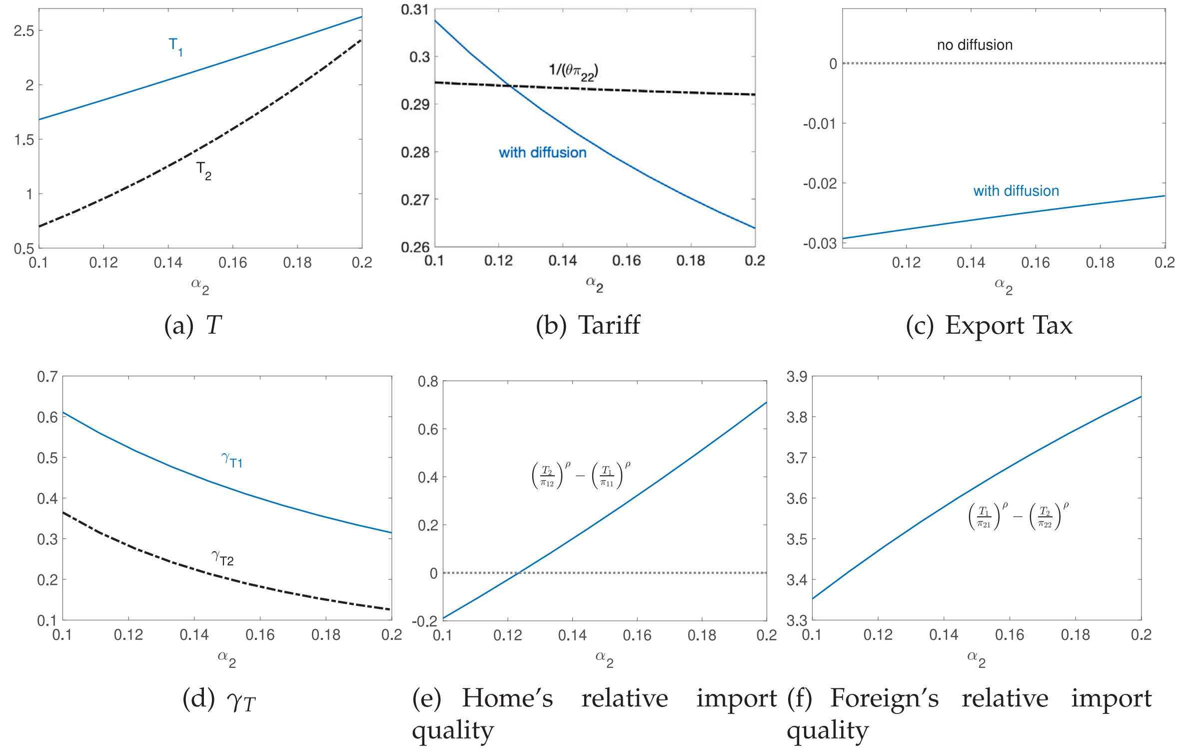



**Fig. 1.** Optimal Policies with Increasing Foreign Efficiency.
**Note:** This figure plots the Home optimal policies and the associated equilibrium at the steady state when we vary Foreign country's arrival rates $\alpha_2$. Home's relative import quality is defined as $(T_2/\pi_{12})^\rho - (T_1/\pi_{11})^\rho$, and Foreign's relative import quality is $(T_1/\pi_{21})^\rho - (T_2/\pi_{22})^\rho$. $\gamma_{T_1}$ and $\gamma_{T_2}$ are the multipliers on technology accumulations (1).

## 4. 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.

### 4.1. Sample selection

Real national account data, including real GDP, physical capital, and employment, comes from PWT 10.01. The data on trade in goods is obtained from BACI 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.

First, as in Dekle et al. (2007) (DEK), to mitigate the effect of entrepot trade, we combine some economies into a single entity. Specifically, we combine (1) Belgium, Luxembourg, and the Netherlands into BEL, (2) Indonesia, Malaysia, Singapore, and Thailand into IDN, and (3) China and Hong Kong into CHN. Second, we rank economies according to their GDP in 2016, and we choose the largest 19 economies and group all other countries into the rest of the world (ROW). In addition, we move Turkey, Saudi Arabia, and Argentina into ROW due to the poor data quality of price indices in these countries. In the end, our 19 largest countries include the USA, CHN (China/HK), Japan, Germany, United Kingdom, France, India, IDN(Indonesia/Malaysia/Singapore/Thailand), Italy, Brazil, Canada, Republic of Korea, BEL(Belgium/Luxembourg/Netherlands), Australia, Russian Federation, Spain, Mexico, Switzerland and Sweden. The final sample of countries in our quantitative analysis thus consists of a balanced panel of 20 countries, including ROW.

### 4.2. Parameterization

The parameters comprise those that are common across countries—such as the Fréchet parameter $\theta$, technology depreciation $\delta$, and the diffusion parameter $\rho$—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 10.01. The capital share $\zeta$ is chosen to be 0.36 to match the corporate labor share in the U.S. 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

$$d_{in} = \frac{P_i}{P_n}\left(\frac{\pi_{nn}}{\pi_{in}}\right)^{\frac{1}{\theta}}. \tag{15}$$

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 $\delta$, 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 $\gamma$, hence the scale of the Frechet distribution $T_t$ grows asymptotically at $\frac{\gamma}{1-\rho}$. In their model, technology evolves according to

$$\tilde{T}_{it+1} = \tilde{T}_{it} + \tilde{\alpha}_{it}\left[\pi_{iit}^{1-\rho}\tilde{T}_{it}^{\rho} + \sum_{n\neq i}\pi_{int}^{1-\rho}\tilde{T}_{nt}^{\rho}\right]. \tag{16}$$

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 Eq. (16) becomes Eq. (1) in our model with $\delta = \gamma/(1-\rho)$.[11] We choose the population growth rate $\gamma$ 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 $\rho$ using an iterative method, which involves two steps. In the first step, for any given $\rho$, we back out the country-specific arrival rates $\boldsymbol{\alpha} = (\alpha_1, \ldots, \alpha_n)$ using the year 2016 data, assuming the economy is on a balanced growth path. In the second step, with the backed-out $\boldsymbol{\alpha}$, we use the nonlinear least-squares method to estimate the diffusion parameter $\rho$ using the panel data from 2000–2016. We repeat the two steps until we find the fixed point of $\rho$ and $\boldsymbol{\alpha}$.

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

$$\frac{\gamma}{1-\rho}\tilde{T}_{i,2016} = \alpha_i\left[\pi_{ii,2016}^{1-\rho}\tilde{T}_{i,2016}^{\rho} + \sum_{n\neq i}\pi_{in,2016}^{1-\rho}\tilde{T}_{n,2016}^{\rho}\right], \tag{17}$$

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 real $GDP$, capital, and employment data from PWT 10.01.

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

$$\tilde{T}_{it+1} = \tilde{T}_{it} + \frac{\alpha_i}{1-\gamma/(1-\rho)}e^{\gamma(t-2016)}\left[\pi_{iit}^{1-\rho}\tilde{T}_{it}^{\rho} + \sum_{n\neq i}\pi_{int}^{1-\rho}\tilde{T}_{nt}^{\rho}\right], \tag{18}$$

where we plug the relation $\tilde{\alpha}_{it} = \frac{\alpha_i}{1-\frac{\gamma}{1-\rho}}e^{-\gamma(t-2016)}$ into Eq. (16). We continue these two steps until the estimated $\rho$ is the same as that in the first step. The estimated $\rho = 0.4985$ is statistically significant at the 1% level. We use $\rho = 0.5$ in our baseline when computing the Home government's optimal dynamic policies.

Fig. 2 plots the backed-out arrival rates $\alpha$ for each of the 20 countries. We order the countries by the level of real GDP per input, while ROW is always placed last.[12] On average, the arrival rates are higher for countries with higher real GDP per input; the U.S. has the highest $\alpha$, and China and India are the least efficient in innovating. However, $\{\alpha_i\}$ and real GDP per input are not perfectly correlated for two reasons. First, in equilibrium, $\left(\frac{w_{it}}{P_{it}}\right)^{\theta} = \frac{T_{it}}{\pi_{ii,t}}$, hence real GDP per input ($w_i/P_i$) not only depends on a country's own technology $T_i$ but also trade $1-\pi_{ii}$. An open economy can enlarge the state of technology by importing other countries' goods. Second, a country's $T_i$ not only depends on the country's own $\alpha_i$ but also trade and diffusions hence others $\alpha_j$.

**Goodness of fit.** First, we compare the model implications with the data in 2016, for domestic share of expenditure $\pi_{ii}$, real GDP per input ($w_i/P_i$), and consumer price indices $P_i$. Figure A-3 in Online Appendix E shows that the model matches the data tightly, country by country. Note that the calibration of $\{\alpha_i, d_{ni}\}$ helps match $N + N(N-1)$ endogenous variables. Hence, among the $2N + N(N-1)$ endogenous variables $\{\pi_{ni}, w_i/P_i, P_i\}$, there are still $N$ of them can be used for out-of-sample examination.

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

[12] Note that we choose the 20 countries with the largest GDP, and when we show the results, we order them by real GDP per input (a moment we use in the calibration) because it positively relates to $\alpha_i$, which the equilibrium $T_i$ and optimal policies largely depend on.

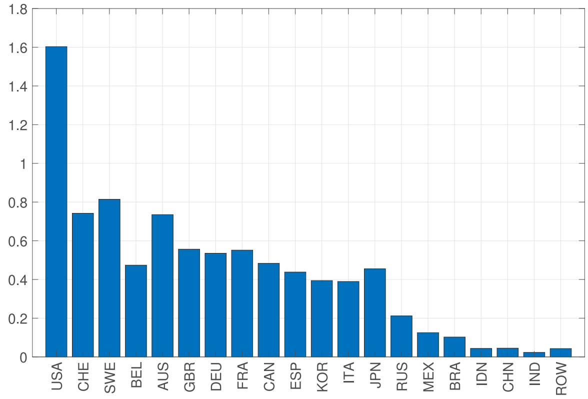



**Fig. 2.** Arrival Rates Across Countries. **Note:** This figure plots the calibrated arrival rates in 2016 with 20 countries and technology diffusion $\rho = 0.5$.

Second, although the estimated $\rho$ is significant at the 1% level, the model cannot explain most of the fluctuation of annual growth with constant $\{\alpha_i\}$. Nonetheless, the model captures key features of the average growth of real GDP per input between 2000 and 2016. See Figure A-4 of Online Appendix E. The average growth of real GDP per input in the model is 0.62%, close to 0.81% in the data. Furthermore, the model and data are highly correlated, with a correlation of 0.97, meaning that high-growth countries in the data also have high growth in the model. Lastly, the model accounts for about 37% of the observed growth variation across countries.[13]

**Discussion on calibrating $\rho$.** Our $\rho = 0.5$ 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 $\rho$ is about 0.6. First, in their calculation, $\gamma = 1\%$, which is the average population growth rate in the U.S. 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 on the BGP using Eq. (17) and $\alpha_{US,2000}$ using Eq. (18). Given the growth rate of $\alpha$ as the population growth rate 1%, only when $\rho = 0.6$, the accumulated growth of $\alpha$ 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 $\rho$.

It is worth noting that we do not view our contribution as identifying the diffusion parameter $\rho$, even though we propose an alternative method to calibrate 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 $\rho$ 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 on a balanced growth path at the end of the sample period, the year 2016. In the analysis, the parameter values remain at the 2016 level, including the calibrated $\rho$ and $\gamma$, arrival rates of ideas $\alpha_i$, 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. 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.

### *4.3. 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 Eqs. (11) and (12) in Proposition 6. Proposition 4 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. Online Appendix C describes our computation algorithm and the system of equations that characterizes the optimal policies and the associated world equilibrium.

Consider optimal trade policies in the long run, as shown in Fig. 3. At the new BGP, 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

[13] One way to generate the observed annual growth rates is to introduce country-specific, time-varying arrival rates $\alpha_{it}$. However, it is challenging to distinguish time-varying $\alpha$ from diffusion parameter $\rho$. Additional data or assumptions are needed to tackle this issue.

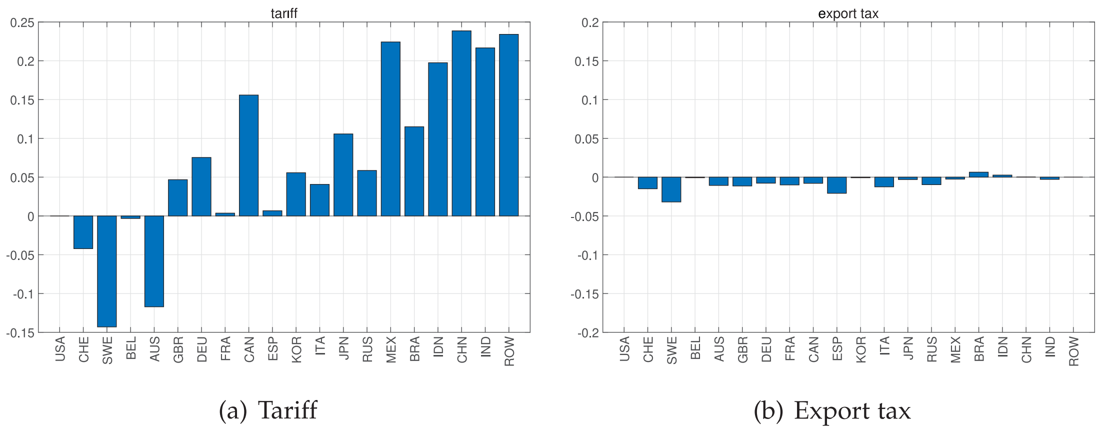



**Fig. 3.** U.S. Optimal Policies with Diffusion ($\rho = 0.5$), 20 Countries, Steady State.
**Note:** This figure plots U.S. optimal trade policies at the steady state in the model with 20 countries and technology diffusion $\rho = 0.5$.

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.

As a reference, we also compute optimal policies with no technology diffusions by setting $\rho = 0$. In this exercise, we do not recalibrate $\alpha_n$ since the goal is to compare with U.S. optimal policies under no technology diffusion. Figure A-5 in the online appendix plots the U.S. optimal policies with $\rho = 0$. Export taxes and import tariffs come from Eq. (10) of Proposition 5 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.

Comparing the optimal policies with and without technology diffusions, 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 relative import quality from more productive countries. The amount of export taxes that the 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 new balanced growth path. Figure A-7 in the online appendix shows the transition path of the 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.

On the transition path, other countries' $T$ fall relative to the U.S. (Fig. 4). 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, generating an increase in U.S wages and a relative fall in all other countries' wages. As a result of higher relative U.S. wages, imports from the U.S. fall, and other countries learn less from the U.S. This results in lower levels of technology in those countries. See Figure A-8 and A-9 in Online Appendix F.

On the other hand, the fact that the U.S. technology improves over time (first panel of Fig. 4), 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 $\alpha$ 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 A-10 in Online Appendix F 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%

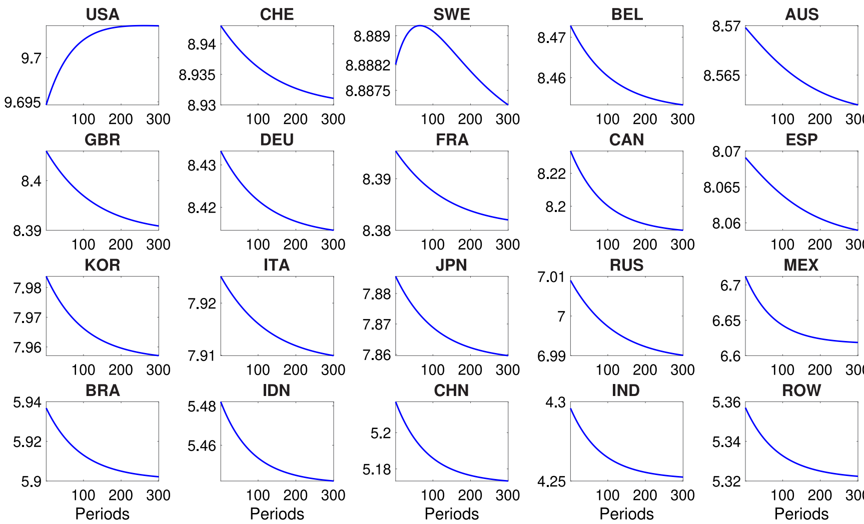



**Fig. 4.** Technology during Transition under U.S. Optimal Policies.
**Note:** This figure plots the transition path of logged technology under the U.S. optimal dynamic trade policies with technology diffusion, $\rho = 0.5$.

**Table 1**
U.S. optimal policies.

| 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 |

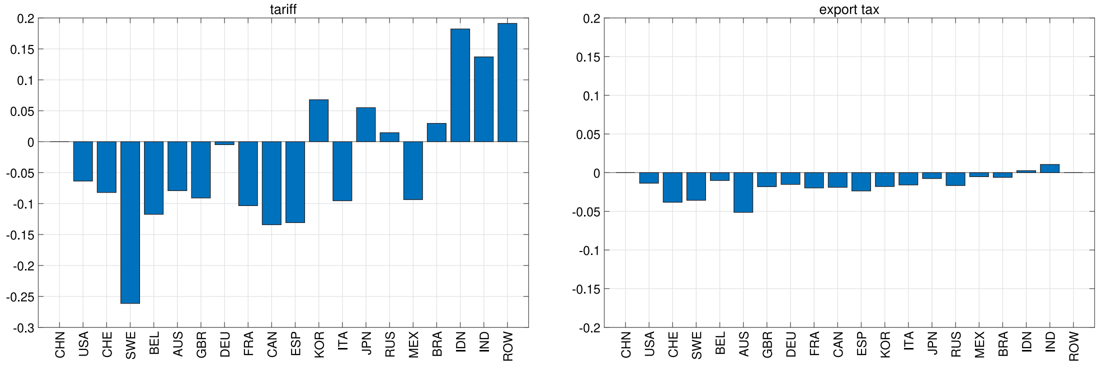
**Note:** This table summarizes U.S. optimal export taxes and tariffs on the other 19 countries and the associated equilibrium technology and consumption at the steady state, relative to the initial private equilibrium, as well as the change in consumption equivalence considering the whole transition path and the steady state. We rank the countries by real GDP per input in 2016.

from 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.

### *4.4. Unilateral optimal dynamic policies of China*

We next examine optimal policies from China's perspective, shown in Fig. 5. The export tax on ROW is again normalized to zero. Since China has a low arrival rate $\alpha$ among the 20 countries shown in Fig. 2, it is heavily incentivized to subsidize its




(a) Tariff (b) Export tax

**Fig. 5.** China Optimal Policies with Diffusion ($\rho = 0.5$), 20 Countries, Steady State.
**Note:** This figure plots China's optimal trade policies at the steady state in the model with 20 countries with technology diffusion.

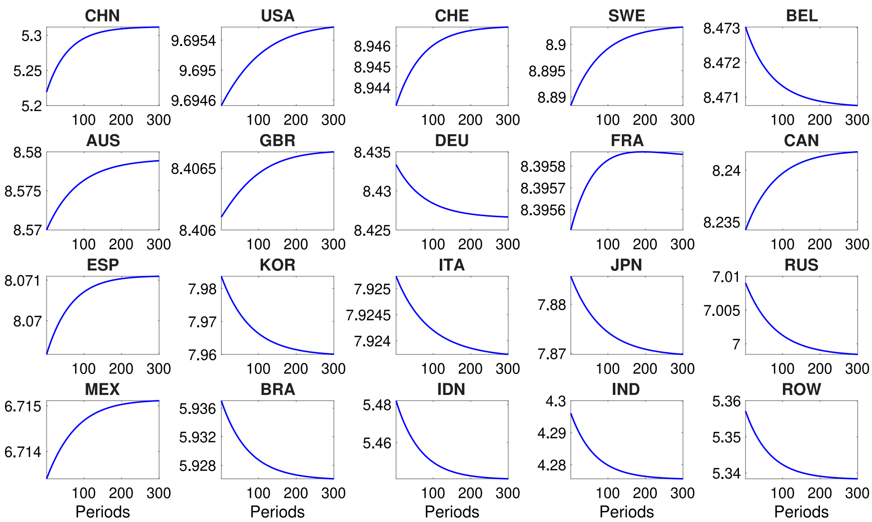



**Fig. 6.** Technology during Transition under China's Optimal Policies.
**Note:** This figure plots technology during transition under China's optimal trade policies with technology diffusion.

imports—especially from countries with high efficiency. The export taxes for most countries are lower than those in the exogenous technology/no diffusion case (see Figure A-6 in the online appendix), reflecting its incentive to let other countries learn from the high quality of insights derived from its exports. It may seem puzzling given China's low levels of technology among the 20 countries. However, 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.

**Optimal Policies of China during Transition and Welfare.** Similar to the U.S. case, China initially imposes export taxes and import subsidies close to their steady-state levels (see Figure A-11 in the online appendix). The overall level of subsidies leads to a decline in China's technological gap with others, shown in Fig. 6, causing import subsidies to fall over time—indicating China's catching up.

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.

**Table 2**
China optimal policies.

| 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 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.

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. 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, causing the former to start to import more from China (as shown in Figure A-12 and A-13 in Online Appendix F). As explained above, importing more from China does not 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 $\alpha$, benefit from improved learning.

Due to these two forces, the advanced economies' technology increases on 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 A-13 of Online Appendix F and they also benefit from the dramatic technological improvement in China.

Figure A-14 in Online Appendix F 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.

### *4.5. Policy impact of technology diffusion*

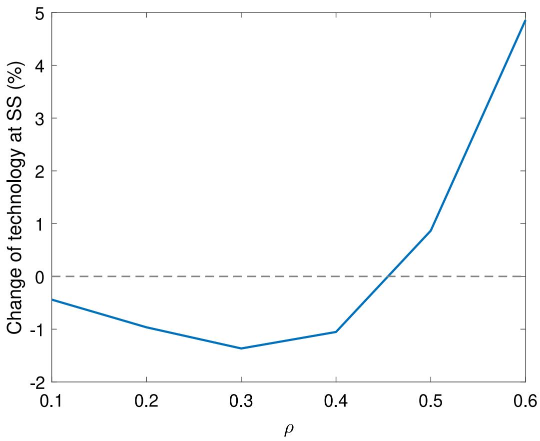
To gain deeper insights into the policy impacts of technology diffusion, we carry out two types of experiments. First, we compare the baseline optimal policies with those developed under exogenous technologies. Second, we perform a robustness analysis by examining various values of the diffusion parameter $\rho$.

In the first experiment, we assume that Home either overlooks the benefits of learning or mistakenly perceives the real world as lacking such diffusions. The optimal policies are the same as in a case with exogenous technology (refer to the 'Exogenous Technology' rows in Tables 3). The variance in policies across countries is significantly smaller than the baseline. Following this policy, Home's technology and real consumption both decrease in the long run. As Home does not consider technology diffusion, the policy can potentially generate welfare loss. We find that this optimal trade policy yields much smaller gains than the baseline

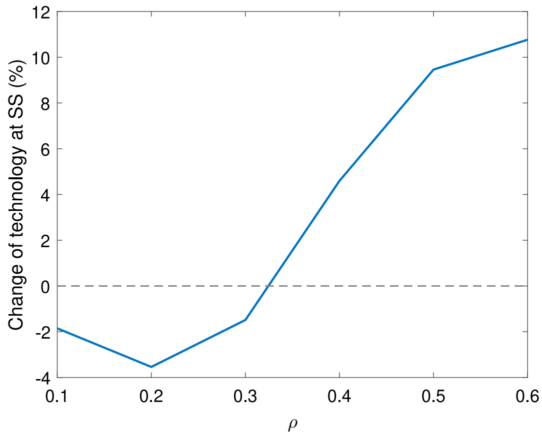
**Table 3**
Optimal policies: Baseline versus exogenous technology.

| | Mean $\tau^x$ at SS(%) | Std $\tau^x$ at SS | Mean $\tau^m$ at SS(%) | Std $\tau^m$ at SS | Change of technology at SS(%) | Change of real consumption at SS(%) | Change of consumption equivalence(%) |
|---|---|---|---|---|---|---|---|
| *US optimal policies* | | | | | | | |
| Baseline | −0.73 | 0.90 | 7.73 | 11.43 | 0.87 | 0.35 | 0.18 |
| Exogenous Technology | −0.07 | 0.48 | 25.38 | 0.98 | −6.35 | −1.36 | 0.06 |
| *China optimal policies* | | | | | | | |
| Baseline | −1.58 | 1.46 | −3.05 | 11.80 | 9.46 | 2.20 | 0.31 |
| Exogenous Technology | −0.42 | 0.63 | 25.76 | 0.94 | −16.30 | −3.74 | −0.40 |

**Note:** The upper panel of this table summarizes U.S. optimal policies (mean and standard deviation) on the other 19 countries and the U.S. technology and consumption at the new steady state, relative to the initial market equilibrium, as well as the change in consumption equivalence. The lower penal presents China's optimal policies. In the 'Exogenous Technology' case, the home government treats technology exogenously.




(a) Home country—-U.S.




(b) Home country—-China

**Fig. 7.** Technology Change after Optimal Policies: Varying $\rho$.
**Note:** Panel(a) plots the U.S. percentage change of technology (compared to the private equilibrium) at steady state under U.S. optimal trade policies with technology diffusion for different $\rho$. Panel (b) plots the technology changes under China's optimal policies.

for the U.S. and results in a loss for China. Due to static terms of trade consideration and large import tariffs, China experiences reduced learning, leading to technology and welfare losses.

In the second experiment, we show how policies and welfare change under alternative diffusion parameters. For each $\rho$, we calibrate $\{\alpha_n\}$ using Eq. (17) so that the world private equilibrium on the balanced growth path is consistent with the year 2016 panel data. We then proceed to conduct analyses of the optimal policies of the U.S. and China. Results are shown in Table A-1 and A-2 in Online Appendix F. When $\rho$ increases from 0.4 to 0.6, optimal trade policies for both the U.S. 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.

However, the changes in Home's technology resulting from its optimal policies are not monotonic with respect to $\rho$. Fig. 7 depicts the percentage change in technology for the U.S. and China at steady state across various values of $\rho$ under their optimal trade policies relative to the private equilibrium. For low levels of $\rho$, the change in technology is negative, while it becomes increasingly positive as $\rho$ rises. There are two opposing forces at play: the conventional terms of trade effect and the spillover from trade diffusion.

When $\rho$ is small, the terms of trade effect dominate. The policy-making country tends to raise import tariffs to exploit the benefit from terms of trade, resulting in reduced trade and diminished learning. As a result, technologies fall. As $\rho$ gets larger, the spillover effect begins to dominate. The policy-making 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. Therefore, the relationship between trade policies and technological changes exhibits a U-shaped pattern.

## 5. Conclusion

This paper studies optimal dynamic policies in an economy with international technology diffusion. We derive theoretical results to explain why and how a country has incentives to manipulate technological diffusion to alter technology levels both at home and abroad. Export taxes can be used to influence foreign technology levels, while import policies depend on the learning benefits from foreign goods. This technological diffusion channel complements traditional terms-of-trade motives for trade policy.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jinteco.2024.104038.

## Data availability

Optimal Trade Policy with International Technology Diffusion (Reference data) (Mendeley Data)

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