Technological Rivalry and Optimal Dynamic Policy in an Open Economy

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Abstract

What policy options does a country have in response to emerging technologies in a global economy? To address this question, we investigate optimal dynamic policies in an open economy where technology is endogenously accumulated through innovation. Our key insight is that even when private innovation allocations are (Pareto) efficient, a country has incentives to influence foreign innovation efforts across sectors and over time. We derive explicit expressions for optimal taxes linked to both an intratemporal and an intertemporal motive to manipulate foreign technology. To affect forward-looking innovation decisions in Foreign, Home uses committed future trade policies (Ramsey) or innovation policies (Markov); to affect intratemporal prices, Home imposes higher tariffs in sectors where it has a comparative advantage.

Keywords: Endogenous Technology, Innovation, Trade, Optimal Dynamic Policies

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1 Introduction

Trade disputes are often driven by technological rivalry rather than trade itself. Historically, advancements in cutting-edge sectors have fueled national competition and protectionist measures, often disguised as trade wars. For instance, during the 1980s, both the U.S. and Japan heavily subsidized their domestic semiconductor industries to gain a competitive edge. More recently, the 2018 U.S.-China trade war highlighted technology as a core area of contention.[1]

This paper provides a framework to explore the nexus between trade policies and technological development in the context of globalization and competition. The spirit of the contest is captivatingly explored in Krugman (1994), which argues that developing countries' technological advancement can sometimes harm the interests of advanced economies, by becoming more productive in sectors in which rich countries have a comparative advantage. This simple yet powerful argument is based on a comparative static analysis of exogenous technology. However, it overlooks the possibility that one country may influence the innovation efforts of another, and it does not account for the costs associated with innovation. To revisit Krugman's thesis, we theoretically characterize optimal dynamic taxation within a workhorse Ricardian model that incorporates endogenous technological progress.

We show that a government has an incentive to manipulate innovation efforts in *other* countries across sectors and over time. We have two novel findings. First, even when private innovations are efficient and the government has access to a full set of trade policies, these tools are insufficient if the government *cannot* commit to its future policies. Trade policies can only be used to manipulate contemporaneous prices. To affect future prices, Home would need to adjust its own innovation efforts in order to shape Foreign's innovation incentives. Optimal policy thus includes domestic innovation policies. This rationale extends beyond traditional industrial policy, which typically justifies subsidizing or protecting specific sectors based on domestic externalities and spillovers. Second, to affect intratemporal prices, Home imposes higher tariffs in sectors where it holds comparative advantage, thereby discouraging Foreign innovation in those sectors. Meanwhile, Home

[1] During 2018 U.S.-China trade war, the U.S. increased restrictions and controls, while China implemented domestic policies to boost demand, procurement, and research in key technological sectors. Simultaneously, the U.S. enacted the America COMPETES Act of 2022, allocating $52 billion to its semiconductor industry.

uses heterogenous export taxes to exploit its market power as a seller.

To demonstrate these results, we extend the one-sector framework of Eaton and Kortum (2001) to a multi-country, multi-sector model. This model incorporates comparative advantage-based trade and endogenous technology accumulation through innovation. The model features Bertrand competition between producers for each goods, where each producer competes with all other producers in the world. The economy's government is benevolent and can choose a set of sector-specific domestic taxes/subsidies on innovation, as well as differential trade policies across sectors and trading partners. When choosing these policies, the government internalizes its choices on trade and technology development in its own country as well as in others. Other economies' government is taken to be passive in the benchmark scenario. We first consider Ramsey optimal policy, where Home can commit to a sequence of taxes, and then compare it to the Markov optimal policy.

We adopt this rich, dynamic model because it satisfies three key criteria. First, it incorporates a baseline Ricardian economy where private innovation is efficient, eliminating the need for traditional industrial-policy interventions in a closed economy. This enables us to isolate the novel mechanism driving the optimal policy. Second, the model's innovation process allows for explicit characterization of both sectoral and aggregate trade patterns—and, consequently, the optimal policy. This facilitates comparison with the standard workhorse Eaton and Kortum (2002) Ricardian model with exogenous technology. Additionally, the analytical characterization of individual researchers' expected profits allows for a more explicit formulation of dynamic optimal policies. Third, the enriched version of the model can accommodate many additional features of interest, for example, economies of scale, knowledge spillovers, or externalities.

Private innovation in the baseline economy is efficient. In the closed-economy setting, a planner would choose the same research allocation as the market. Openness itself does not affect the level of private innovation intensity: the increased foreign competition that spurs innovation is exactly offset by the larger foreign market effect that tends to reduce innovation effort. However, in the open economy environment, a Home planner has incentives to manipulate technology for both intertemporal and intratemporal terms of trade considerations. Home's planner recognizes that it can undertake actions to influence foreign profits and research returns, thereby discouraging foreign innovation efforts in certain sectors or redirecting them towards those that would be advantageous for Home.

To bring clarity to the disparate set of mechanisms, we build up our results by first zeroing in on a dynamic technology manipulation motive in a two-country, one-sector model that is absent intratemporal relative prices. Under tax neutrality (equivalent to Lerner symmetry in this two-country one-sector framework), Home can set the optimal tariff to zero and choose optimal export taxes. When Home increases export taxes, it depresses foreign real wages, which in turn raises foreign interest rates. Lower wages simultaneously reduce both the opportunity cost of current innovation and the benefits of past innovation. Higher interest rates have the opposite effect: they discourage current innovation while increasing returns on past innovation. If the Home country wants to stimulate current foreign innovation, when wage effects dominate, Home either increases current export taxes (lowers current wages) or reduces future export taxes (raises future wages and innovation return). When interest rate effects prevail, the Home country should implement the opposite policy.

Our theoretical framework yields an export tax formula comprising two elements: a classic element addressing static terms of trade and a novel component addressing dynamic terms of trade to influence foreign technology accumulation. Since current foreign innovation incentives respond to both current and future trade policies, time inconsistency emerges, generating distinct policies for the Ramsey and Markov governments.

Consider a case where Home's technology level is below steady state while Foreign is at steady state. For a Ramsey government who can commit to future policies, if lifetime consumption outweights consumption smoothing concerns, it will prefer Foreign to innovate more in earlier periods. When wage effects dominate, Home implements export taxes that initially exceed static case levels before declining below them. This creates a path of initially lower but subsequently higher foreign real wages. Through this mechanism, Home uses trade policies to encourage Foreign to allocate more resources to early-period innovation, thereby increasing Home's lifetime consumption. If consumption smoothing is more important, Home shifts future income to current periods as its future technology and income grow to steady state and are higher. Home would suppress foreign innovation, inducing Foreign to produce more in early periods.

The Markov government shares the same objectives as the Ramsey government but cannot commit to future policies. For example, in the scenario described above, while a Ramsey government would simultaneously raise current export taxes and lower future export taxes to stimulate foreign innovation, a Markov government cannot credibly promise lower future export taxes. As a result, Markov export taxes consistently exceed the static case and follow a steeper trajectory than Ramsey policies.

Our first key result is that in the absence of commitment mechanisms, trade policies would not be enough, and Markov policies would invoke domestic innovation policies even in the absence of any domestic externalities and even though they distort domestic innovation efforts. To induce desired foreign innovations, Home adjusts its own technology through innovation subsidies, altering the trajectory of Foreign's wages and interest rates. This, in turn, changes Foreign's innovation efforts and production.

The second key result is that when comparative advantage is introduced, there is a rich set of interweaving intratemporal mechanisms to alter relative prices and innovation. To uncover these different forces, we examine the model's long-run optimal policies. We prove that in the long run, Ramsey and Markov governments impose the same policies.

We begin with a two-country, multi-sector model. Our analysis yields two important insights. First, the Home government recognizes that individuals do not internalize the impact of their choices on sectoral prices. To correct these terms of trade externality, Home imposes sector-specific import tariffs to exploit its buyer power and sector-specific export taxes to leverage its seller power. Second, we derive an explicit formula connecting a country's optimal tariff in each sector to its comparative advantage: Home would want to improve its terms of trade by encouraging Foreign to do more research and enhance technology in sectors where Foreign holds a comparative advantage rather than competing in Home's strong sectors. Specifically, Home imposes higher tariffs in sectors with larger net exports relative to foreign production. By reducing demand for foreign goods in these sectors, the tariffs redirect foreigners' research efforts away from sectors that compete with Home's comparative advantage sectors.

Our heterogeneous import tariff findings differ significantly from the result of uniform optimal tariffs under exogenous technology, as analyzed in Costinot, Donaldson, Vogel, and Werning (2015). With exogenous technology, Home cannot effectively target specific sectors through tariffs because foreign supply prices are proportional to wages divided by exogenous sectoral productivity. Since perfect labor mobility equalizes foreign wages, sector-specific tariffs merely distort domestic prices without selectively affecting foreign supply prices, making uniform tariffs optimal.[2] However, with endogenous technology, Home can use sector-specific tariffs to influence foreign innovation incentives, thereby affecting foreign technologies and prices on a sector-by-sector basis.

Lastly, we characterize optimal policies in the general model with multiple sectors and multiple countries. The multi-country framework creates complex interlinkages across countries through the general equilibrium effect. Tariffs on one foreign country change equilibrium wages across all countries, thus affecting the demand and supply of all countries. As a result, even with exogenous technology, the Home country imposes both *country-specific* import tariffs and sector-country-specific export taxes. Furthermore, the elegant two-sector tariff formula derived under endogenous technology—prescribing higher tariffs in sectors with larger net exports—no longer applies in this more complex environment. However, Home's tariffs are, on average, higher for sectors with relatively higher net exports. Ultimately, optimal policies, multipliers, and allocations are jointly determined in equilibrium, reflecting the intricate interdependencies with multiple countries.

Our contribution is primarily theoretical, as a first attempt to understand the basic contours of optimal policy when there is technological evolution and competition. As such, our technical contribution is to theoretically characterize optimal dynamic policy and derive general results in a framework with elemental features, while providing explicit formulas that give rise to sharp predictions about the structure of optimal policy in special cases. The

[2] There is a large literature analyzing optimal trade policies under static frameworks. Bagwell and Staiger (1999) emphasize terms-of-trade manipulation and its implications for the WTO. Trade policy in simple general equilibrium or a partial equilibrium setting is explored in Gros (1987), and Broda, Limao, and Weinstein (2008), which show that the industry tariff is related to the foreign export supply elasticity. Demidova and Rodríguez-Clare (2009) characterizes optimal tariffs in a small economy, single industry, Melitz-Pareto setting. Ossa (2014) computes optimal tariffs across sectors, considering traditional, new trade, and political economy motives for protection. Trade policy analyzed in quantitative or new trade theories include Caliendo and Parro (2022); Costinot and Rodríguez-Clare (2014); Costinot et al. (2015); Demidova (2017); Lashkaripour and Lugovskyy (2023). Costinot, Rodríguez-Clare, and Werning (2020) characterizes optimal firm-level trade policy in a two-country-single-sector Melitz model.

emphasis on dynamic terms of trade manipulation is closely related to Costinot, Lorenzoni, and Werning (2014), which proposes a theory of capital controls as dynamic terms-of-trade manipulation in an endowment economy. By contrast, in our dynamic economy with endogenous technology, industrial policies serve as intertemporal trade policies. In general, our approach offers broader theoretical insights with dynamic implications, distinguishing it from quantitative approaches that compute welfare consequences under alternative policies.

Our paper sidesteps issues such as international technology diffusion or policy competition, although it provides a general setup and solution method that can nest cross-sector and cross-country innovation diffusion.[3] The paper is related to, but has little overlap with, the growth literature emphasizing the importance of innovation on long-run growth.

Our baseline model intentionally abstracts from domestic distortions and externalities.[4] This represents a significant departure from existing literature, where interventionist policies are typically justified by the presence of market failures, knowledge spillovers, or other distortions. In contrast, our analysis demonstrates that optimal dynamic policies can emerge from both static and dynamic terms-of-trade considerations and patterns of comparative advantage. Within this framework, industrial policies effectively function as intertemporal trade policies, creating a novel theoretical foundation for their implementation even in the absence of traditional market failures.

The paper proceeds as follows. Section 2 sets up the multi-country, multi-sector dynamic theoretical framework, while Section 3 zooms in on the dynamic technology manipulation motive in a one-sector model. Section 4 focuses on the intratemporal motive to manipulate

[3]There is already a large and expansive literature on the topic of international technology diffusion in the global economy, such as Arkolakis, Ramondo, Rodríguez-Clare, and Yeaple (2018), Atkeson and Burstein (2010), Bloom, Draca, and Van Reenen (2016), Buera and Oberfield (2020), Cai, Li, and Santacreu (2022), Eaton and Kortum (1999), Grossman and Helpman (1990), Grossman and Helpman (1993), Hsieh, Klenow, and Nath (2023), Perla, Tonetti, and Waugh (2021), and Somale (2021). Few consider optimal policy in these settings. One exception is Bai, Jin, Lu, and Wang (2025), who studies optimal trade policies in a framework as Buera and Oberfield (2020) with international diffusions through imports.

[4]Optimal policies in these contexts depend on assumptions of each theory—featuring either imperfect competition pricing, knowledge spillovers, congestion externalities, or creative destruction. For instance, Akcigit, Ates, and Impullitti (2019) explore policies with these features in an open economy with a one-sector model that does not have comparative advantage aspects to trade (and hence heterogeneous tariffs). Liu and Ma (2021) examine optimal innovation policy for a small open economy when there are cross-sector spillovers and externalities without dynamic considerations.

technology, and Section 5 concludes.

2 Theoretical Framework

2.1 Model

The baseline model extends the endogenous technology model in Eaton and Kortum (2001), henceforward EK2001, to one that features multiple sectors and countries, deriving unilateral optimal innovation and trade policies within this context.

The world has N countries and J sectors. We assume that country 1 is the Home country and study its unilateral optimal innovation and trade policies. We adopt a semi-primal approach where the Home government chooses innovation investment directly and implements this optimal choice with an innovation policy. The form of trade policies is specified explicitly, i.e., country-sector-specific export taxes $\tau^x_{i,j,t}$ and tariffs $\tau^m_{i,j,t}$ on the goods in sector $j \in [1, J]$ of country $i \in [2, N]$. In this section, we characterize the market equilibrium given Home's trade policies. In addition to export taxes and import tariffs, trade flows are subject to bilateral iceberg trade costs d_{ni} between country n and i.

All consumers' discount factor is ρ. Country n has a measure L_n of labor, which can freely flow into the production sector as a worker or the research sector as an innovator. Consumer preference in each country n is $\sum_{t=0}^{\infty} \rho^t u\left(C_{nt}\right)$, where the per period utility is given by $u(C) = C^{1-\sigma}/(1-\sigma)$. Final goods is a Cobb-Douglas function across the consumption of different sector $j \in J$ goods $C_n = \Pi_{j\in J}\left(C_{n,j}\right)^{\beta_j}$, where β_j is constant and reflects the share of sector j. Within a sector, there is a continuum of varieties of consumption goods, which are aggregated with a Cobb-Douglas function $C_{n,j} = \exp \int_0^1 \ln c_{nj}(\omega) d\omega$. All goods are tradable. Within each country, there are perfect financial markets. Across countries, consumers can only trade goods, and trade is balanced every period.

Innovation incentive and research decision. We start by explaining innovation efforts within each sector, as in the one-sector economy model of Eaton and Kortum (2001). All countries n are capable of producing any variety ω of good use labor and linear production technology with efficiency level $q_n(\omega)$, the distribution of which is endogenous and depends on the number of researchers and research productivity.

Researchers in country n and sector j draw ideas about how to produce goods in this sector. Each idea consists of the realization of two random variables. One is the good ω to which the idea applies, drawn from the uniform distribution over $[0,1]$. The other is the efficiency $q(\omega)$, drawn from a Pareto distribution with a parameter θ. The number of ideas per researcher is Poisson distributed with parameter $\alpha_{n,j}$, which reflects how effective the researchers are in the country n sector j's innovation process—-or, innovation efficiency.[5]

Let the measure of researchers in the country n sector j at period t be $L^r_{n,j,t}$, and the cumulative stock of ideas be $T_{n,j,t}$. Under a unit interval of varieties, the number of ideas for producing a specific good is Poisson distributed with parameter $T_{n,j,t}$. Ideas retire with probability δ and hence the evolution of the stock of ideas $T_{n,j,t}$ is[6]

$$T_{n,j,t} = (1-\delta)T_{n,j,t-1} + \alpha_{n,j}L^r_{n,j,t}. \tag{1}$$

Kortum (1997) proves that when the quality of idea is Pareto distributed, the distribution of technology efficiency frontier is a Frechet distribution with parameter $T_{n,j,t}$ and θ.

Firms engage in Bertrand competition: the lowest-cost producer of each good in each market claims the entire market for that good, charging a markup just enough to keep the second-lowest-cost producer out of the market. In equilibrium, the distribution of the markup is Pareto with the parameter θ. Since all firms selling in the market charge a markup drawn from the same distribution, total profits $\zeta_{n,j,t}$ of firms at period t are a constant share of total sales in that market.

Second, the profit of a firm in country n depends on whether it can outperform other firms in each market. The probability that a researcher in n and j draws a q that is the lowest price in market i at t is $\pi_{in,j,t}/T_{n,j,t}$. A firm innovates and surpasses the current

[5] In our baseline, the average number of ideas $\{\alpha_{n,j}\}$ in each sector and country are constant. One can let them endogenously depend on decreasing return to scale in innovation or domestic diffusion, for example, $\alpha_{n,j,t} = \bar{\alpha}_{n,j}(L^r_{n,j,t})^{\varepsilon-1}(T_{n,j,t-1})^{\eta}$ with a decreasing return to scale parameter $\varepsilon < 1$ and intertemporal diffusion η. Alternatively, the number of ideas can depend on foreign diffusion $\alpha_{n,j,t} = \bar{\alpha}_{n,j}(L^r_{n,j,t})^{\varepsilon-1}(T_{m,j,t-1})^{\eta}$ with $m \neq n$. Furthermore, it can be used to consider policies with input-output innovation structure across sectors, indicated by j and k, where $\alpha_{n,j,t} = \bar{\alpha}_{n,j}\prod_k (T_{n,k,t-1})^{\omega_{jk}}$.

[6] Note that our model is isomorphic to the detrended semi-endogenous growth model in EK2001, which assumes the growth rate of α_n is exogenously driven by population growth g_L. Since policies would not affect the exogenous growth rate, we use the detrended model.

set of ideas in its own country with probability $1/T_{n,j,t}$ at time t, but it must also be the cheapest source of a particular good in country i, with probability $\pi_{in,j,t}$.

Hence, the expected profit earned by a firm in country $n \neq 1$ is given by

$$\zeta_{n,j,t} = \frac{1}{T_{n,j,t}} \frac{1}{1+\theta} \left[\frac{1}{1+\tau^{m}_{n,j,t}} \pi_{1n,j,t} \beta_j x_{1t} + \sum_{i \neq 1} \pi_{in,j,t} \beta_j x_{it} \right] = \frac{1}{\theta} \frac{w_{nt} L^{p}_{n,j,t}}{T_{n,j,t}}, \tag{2}$$

where the expected profit takes into account Country 1's import tariffs $\tau^{m}_{n,j,t}$ on Country n's goods. The second equality holds because in equilibrium $1/(1+\theta)$ fraction of total sales goes to profit, and $\theta/(1+\theta)$ share goes to production labors. We can therefore replace the total sales of country n inside the bracket with $\frac{1+\theta}{\theta} w_{nt} L^{p}_{n,j,t}$ and obtain the second equality. Similarly, the expected profit earned by a firm in country 1 (Home country) at time t is:

$$\zeta_{1,j,t} = \frac{1}{T_{1,j,t}} \frac{1}{1+\theta} \left[\pi_{11,j,t} \beta_j x_{1t} + \sum_{i \neq 1} \frac{1}{1+\tau^{x}_{i,j,t}} \pi_{i1,j,t} \beta_j x_{it} \right] = \frac{1}{\theta} \frac{w_{1t} L^{p}_{1,j,t}}{T_{1,j,t}}, \tag{3}$$

which shows that the export tax of Home would affect Home firms' profit.

We can write the expected discounted value of an idea as

$$v_{n,j,t} = \sum_{s=t}^{\infty} [\rho(1-\delta)]^{s-t} \frac{u_{ns}}{u_{nt}} \frac{P_{nt}}{P_{ns}} \zeta_{n,j,s}, \tag{4}$$

where future profits are discounted with each country n's own endogenous discount factor $\rho^{s-t} \frac{u_{ns}}{u_{nt}} \frac{P_{nt}}{P_{ns}}$ and idea surviving rate $1-\delta$, with u_{ns} denoting marginal utility of consumption and P_{ns} consumer price at period s.

A researcher is motivated by the potential to generate ideas with value. Ex-ante, the researcher does not know how good the idea will be. Given the expected value of each idea is $v_{n,j,t}$, the average value of research at t is $\alpha_{n,j} v_{n,j,t}$. Free mobility across sectors ensures that the present value of the expected profits of being a researcher is equal to the wage of being a worker in the production sector w, i.e., $\alpha_{n,j} v_{n,j,t} = w_{nt}$ when $L^{r}_{n,j,t} \in [0, L_n]$. If in equilibrium $\alpha_{n,j} v_{n,j,t} < w_{nt}$, then $L^{r}_{n,j,t} = 0$.

Definition 1 (World Market Equilibrium)**.** *The world market equilibrium consists of an allocation of labor and consumption* $\left\{ L^{r}_{n,j,t}, L^{p}_{n,j,t}, C_{n,j,t} \right\}$, *technology* $\left\{ T_{n,j,t} \right\}$, *expenditures* $\{x_{nt}\}$, *prices*

$\{P_{n,t}\}$, and wages $\{w_{nt}\}$ such that consumers maximize expected discounted utility, firms maximize profits, and the free entry and market clearing conditions hold, for any period t, taking as given Home government's policies $\left\{\tau^m_{n,j,t}, \tau^x_{n,j,t}\right\}$.

1. *Free entry conditions for researchers in country n sector j:*[7]

$$\frac{w_{nt}}{\alpha_{n,j}} = \frac{1}{\theta}\frac{w_{nt}L^p_{n,j,t}}{T_{n,j,t}} + \rho(1-\delta)\frac{u_{n,t+1}/P_{n,t+1}}{u_{nt}/P_{nt}}\frac{w_{n,t+1}}{\alpha_{n,j}}, \quad (\forall n \in N, \forall j \in J) \tag{5}$$

2. *Evolution of technology*

$$T_{n,j,t} = \alpha_{n,j}L^r_{n,j,t} + (1-\delta)T_{n,j,t-1}, \quad (\forall n \in N, \forall j \in J), \tag{6}$$

3. *Goods market clearing conditions*

$$\frac{1+\theta}{\theta}w_{1t}L^p_{1,j,t} = \beta_j\left[\pi_{11,j,t}x_{1t} + \sum_{i\neq 1}\frac{1}{1+\tau^x_{i,j,t}}\pi_{i1,j,t}x_{it}\right], \tag{7}$$

$$\frac{1+\theta}{\theta}w_{nt}L^p_{n,j,t} = \beta_j\left[\frac{1}{1+\tau^m_{n,j,t}}\pi_{1n,j,t}x_{1t} + \sum_{i\neq 1}\pi_{in,j,t}x_{it}\right], \tag{8}$$

where the expenditures are given by

$$x_{1t} = \frac{1+\theta}{\theta}w_{1t}\sum_j L^p_{1,j,t} + \sum_{i\neq 1}^{N}\sum_{j=1}^{J}\beta_j\frac{\tau^x_{i,j,t}}{1+\tau^x_{i,j,t}}\pi_{i1,j,t}x_{it} + \sum_{i\neq 1}^{N}\sum_{j=1}^{J}\beta_j\frac{\tau^m_{i,j,t}}{1+\tau^m_{i,j,t}}\pi_{1i,j,t}x_{1t}, \tag{9}$$

$$x_{nt} = \frac{1+\theta}{\theta}w_{nt}\sum_j L^p_{n,j,t} \quad (\textit{for } n \neq 1), \tag{10}$$

[7] We derive the equation (5) in two steps. First, we write recursively the expected discounted value of an idea (4) as,

$$v_{n,j,t} = \frac{1}{\theta}\frac{w_{nt}L^p_{n,j,t}}{T_{n,j,t}} + \rho(1-\delta)\frac{u_{nt+1}}{u_{nt}}\frac{P_{nt}}{P_{nt+1}}v_{n,j,t+1},$$

which uses the profit definition from (2). Second, we use the free entry condition and write $w_{nt}/\alpha_{n,j} = v_{n,j,t}$ with $v_{n,j,t}$ from the above equation.

and the trade shares satisfy

$$\pi_{11,j,t} = \frac{T_{1,j,t} w_{1t}^{-\theta}}{T_{1,j,t} w_{1t}^{-\theta} + \sum_{n \neq 1} T_{n,j,t} (w_{nt}(1+\tau^m_{n,j,t}) d_{1n})^{-\theta}}, \tag{11}$$

$$\pi_{i1,j,t} = \frac{T_{1,j,t} (w_{1t}(1+\tau^x_{i,j,t}) d_{i1})^{-\theta}}{T_{1,j,t} (w_{1t}(1+\tau^x_{i,j,t}) d_{i1})^{-\theta} + \sum_{n \neq 1} T_{n,j,t} (w_{nt} d_{in})^{-\theta}}, \tag{12}$$

$$\pi_{in,j,t} = \frac{T_{n,j,t} (w_{nt} d_{in})^{-\theta}}{T_{1,j,t} (w_{1t}(1+\tau^x_{i,j,t}) d_{i1})^{-\theta} + \sum_{m \neq 1} T_{m,j,t} (w_{mt} d_{im})^{-\theta}}, \tag{13}$$

$$\pi_{1i,j,t} = \frac{T_{i,j,t} (w_{it}(1+\tau^m_{i,j,t}) d_{1i})^{-\theta}}{T_{1,j,t} w_{1t}^{-\theta} + \sum_{n \neq 1} T_{n,j,t} (w_{nt}(1+\tau^m_{n,j,t}) d_{1n})^{-\theta}}. \tag{14}$$

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

The consumer price of Home is given by

$$P_{1t} = \Pi_j \left[T_{1,j,t} w_{1t}^{-\theta} + \sum_{n \neq 1} T_{n,j,t} (w_{nt}(1+\tau^m_{n,j,t}) d_{1n})^{-\theta} \right]^{-\beta_j/\theta},$$

and the consumer price of country n *is*

$$P_{nt} = \Pi_j \left[T_{1,j,t} (w_{1t}(1+\tau^x_{n,j,t}) d_{n1})^{-\theta} + \sum_{m \neq 1} T_{m,j,t} (w_{mt} d_{nm})^{-\theta} \right]^{-\beta_j/\theta}.$$

4. *The labor market clearing conditions for each country* n

$$\sum_j \left(L^r_{n,j,t} + L^p_{n,j,t} \right) = L_n. \tag{15}$$

In the world market equilibrium, the market-clearing conditions and definition of expenditures imply that the balanced trade conditions hold.

Proposition 1. *Under zero export taxes and import tariffs, the world market equilibrium across sectors is efficient, and a world social planner would choose the same innovation allocation across sectors as in the market equilibrium.*

Proof. See Online Appendix A. The model has no distortions and externalities across sectors, nor international spillovers.[8] Specifically, innovation exhibits constant return across time $\alpha_{n,j}$, and the allocation between researchers and workers is efficient. Under Bertrand competition, the endogenous markup of each firm follows a distribution that is invariant over time and is independent of the destination to which the firm sells. As a result, aggregate markups are identical and constant across all sectors.

Our model with constant $\alpha_{n,j}$ and technology depreciation δ leads to a steady state in the long run, where technologies become constant for each country and each sector. Our model is isomorphic to the detrended semi-endogenous growth model in EK2001. The two models would prescribe the same optimal policies both during the transition and in the long run.

Define the research intensity in sector j of country n as $r_{n,j,t} \equiv \frac{L^r_{n,j,t}}{L_{n,j,t}}$, i.e., the fraction of researchers over total labor used in this sector. With this definition, we can rewrite the technology evolution (6) as $T_{n,j,t} = (1-\delta)T_{n,j,t-1} + \alpha_{n,j} r_{n,j,t} L_{n,j,t}$. At the steady state, the research intensity, labor, and technologies in each sector are constant. Specifically, $r_{n,j,t} = r_{n,j}$ at the steady state. Moreover, steady state conditions imply that the research intensity in each sector is independent of a country's size, research productivity, or trade openness.

Proposition 2. *At the steady state, with or without trade policies, the research intensity $r_{n,j}$ is constant and the same as in the closed economy for all sectors j in country n. Hence, research effort $L^r_{n,j} = r_{n,j} L_{n,j}$ is proportional to sectoral labor.*

Proof. See Online Appendix B. This proposition shows the feature of innovation in the extended *multi-sector* EK 2001, with or without trade policies. Accessing foreign markets increases the potential profits, but competition from foreign inventions decreases them. These two effects exactly cancel out, and the level of openness does not affect research intensity. However, the research level $r_{n,j} L_{n,j}$ does depend on size, research productivity, and openness. Thus, given the same level of research intensity $r_{n,j}$, more labor reallocated

[8] To apply the probabilistic framework from EK2001 and Eaton and Kortum (2002), we assume that governments observe the overall technology distributions but lack knowledge about productivity levels for individual goods. This informational constraint limits policymakers to sector-wide instruments rather than good-specific interventions. Since expected markups remain uniform and constant across all sectors under this framework, private research allocations are the same as a world central planner.

to the comparative advantage sector increases the total number of researchers in that sector, thereby raising its technology $T_{n,j}$.

We next present a result on tax neutrality, which establishes equivalency between different policies and allows for the normalization of certain export taxes and tariffs.

Proposition 3 (*Tax Neutrality*)**.** *Consider two sets of Home government trade policies* $\Gamma = \{(1+\tau^m_{n,j,t}, 1+\tau^x_{n,j,t}) : \forall n \neq 1, j, t\}$ *and* $\check{\Gamma} = \left\{\left(\lambda_t(1+\tau^m_{n,j,t}), \frac{1+\tau^x_{n,j,t}}{\lambda_t}\right) : \forall n \neq 1, j, t\right\}$ *for any sequence of positive constant* $\{\lambda_t\}_{t=0}^{\infty}$*. These policy sets are neutral in that the welfare and allocation of the world market equilibrium under* Γ *and* $\check{\Gamma}$ *are identical. Furthermore, the following relationships hold:* $w_{1t}(\Gamma) = w_{1t}(\check{\Gamma})$*,* $P_{1t}(\Gamma) = P_{1t}(\check{\Gamma})$*,* $w_{nt}(\Gamma) = w_{nt}(\check{\Gamma})/\lambda_t$*,* $P_{nt}(\Gamma) = P_{nt}(\check{\Gamma})/\lambda_t$ *and expenditure* $x_{nt}(\Gamma) = x_{nt}(\check{\Gamma})/\lambda_t$ *for* $n > 1$ *and any period* t*.*

Proof. See Online Appendix C. Proposition 3 shows tax neutrality holds as in Lerner (1936) and Costinot and Werning (2019). As a result, *one* of the tax levels remains undetermined. In the two-country and one-sector case, there is only one tariff and one export tax. Tax neutrality implies that the two are equivalent (thus Lerner symmetry), and hence, one can be set to zero in every period. However, in models with multiple countries or sectors, the import tariff and export tax are no longer equivalent within each country or industry. In such cases, tax neutrality dictates that only one specific tariff/export tax in a particular sector and country can be set to zero.

2.2 Optimal trade and innovation policies

The Home government chooses optimal unilateral trade policies and domestic innovation policies by maximizing Home households' lifetime utility. Foreigners are taken to be passive. We adopt a semi-primal approach that explicitly specifies trade policy instruments, comprising country-sector-specific import tariffs $\tau^m_{n,j}$ and export taxes $\tau^x_{n,j}$ directed at country $n \neq 1$. The optimal format of innovation policy—whether implemented through labor taxes, consumption taxes, sales taxes, or profit subsidies—emerges endogenously from our analysis. We derive optimal domestic innovation, summarized by $L^r_{1,j}$, and then examine how to implement it with domestic innovation policies.[9] The government rebates the tax

[9]The approach that the Home government directly chooses domestic innovation is similar to the primal approach in Costinot, Rodríguez-Clare, and Werning (2020) and Beshkar and Shourideh (2020), and we imple-

income to households in a lump-sum fashion.

We consider two types of government policies: Ramsey and Markov policies. The Ramsey government has the ability to commit to all its future policies at the beginning of time and chooses *a sequence of policies* to maximize utility, taking into account the private responses to the policies. In contrast, the Markov government cannot commit to future policies. In this case, the Home government chooses *current-period policies*, which are constrained to depend only on the current period's state. Private individuals react by taking current and future policies as given. While the government cannot commit, it correctly anticipates how future policies will be influenced by the current ones through the state of the economy.

Ramsey policy Under Ramsey optimal policies, the Home government commits to the path of policies. In period 0, taking as given the initial levels of technologies $\{T_{n,j,0}\}$, Home government chooses a sequence of $\left\{L^r_{1,j,t}, \tau^x_{n,j,t}, \tau^m_{n,j,t}\right\}_{t=0}^{\infty}$ to maximize the present value of utility

$$\max_{\left\{L^r_{1,j,t}, \tau^x_{n,j,t}, \tau^m_{n,j,t}\right\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \rho^t u(C_{1t}) \tag{16}$$

subject to the world market equilibrium characterized by foreign worker-researcher choices:

$$\frac{w_{nt}}{\alpha_{n,j}} \frac{u_{nt}}{P_{nt}} = \sum_{s=t}^{\infty} [\rho(1-\delta)]^{s-t} \frac{u_{ns}}{P_{ns}} \left(\frac{1}{\theta} \frac{w_{ns} L^p_{n,j,s}}{T_{n,j,s}} \right), \quad \text{for any } t,\, j,\, n \neq 1 \tag{17}$$

along with the resource constraints (6) - (15), and the normalization of Home price $P_{1t} = 1$ for any period t.

The Ramsey problem has no obvious recursive formulation since the foreign worker-research constraint (17) in each period t involves variables from all future periods $s \geq t$. To solve this problem, we extend the recursive contract approach of Marcet and Marimon (2019). The key to this approach is to define as part of the state the history of all multipliers

ment the Home government's optimal innovation using endogenously determined subsidies on innovation profits. The explicit specification of trade policy instruments shares similarities with Lashkaripour and Lugovskyy (2023). Since country-sector export taxes and tariffs are the full set of finest trade policy instruments in our model, it is easier to use them explicitly to write equilibrium conditions with multiple countries and sectors. Chari, Nicolini, and Teles (2023) also specifies the form of domestic and trade policies and studies a Ramsey problem to determine optimal policy levels.

on foreign worker-research constraints. The full recursive problem is presented in Online Appendix E.

Here, we briefly explain the approach to illustrate how the multipliers on foreign worker-research constraints emerge in the Ramsey government's problem. These multipliers ultimately appear in the optimal tax formula, revealing both the dynamic private equilibrium constraints faced by the Home government and highlighting its commitment challenges.

Specifically, let $\rho^t \gamma^v_{n,j,t}$ be the multiplier on foreign worker-research constraint (17). To make it clear, we present several intermediate steps below to explicitly show how these multipliers appear in the Ramsey government's problem. We can write the Lagrangian as (16) plus the sum of terms relating to the worker-research constraints of the form

$$\rho^t \gamma^v_{n,j,t} \left[\sum_{s=t}^{\infty} [\rho(1-\delta)]^{s-t} \frac{u_{ns}}{P_{ns}} \left(\frac{w_{ns} L^p_{n,j,s}}{\theta T_{n,j,s}} \right) - \frac{w_{nt}}{\alpha_{n,j}} \frac{u_{nt}}{P_{nt}} \right]$$

for all t, countries $n > 1$, and sectors $j \in J$, plus standard terms relating to the resource constraints (6)-(15). We can regroup terms and write the Lagrangian as

$$\sum_{t=0}^{\infty} \left[u(C_{1t}) + \sum_{n \neq 1} \sum_{j}^{J} \left(\Gamma^v_{n,j,t} \frac{w_{nt} L^p_{n,j,t}}{\theta T_{n,j,t}} - \gamma^v_{n,j,t} \frac{w_{nt}}{\alpha_{n,j}} \right) \frac{u_{nt}}{P_{nt}} \right] \tag{18}$$

plus standard terms relating to the resource constraints. Here the cumulative multiplier $\Gamma^v_{n,j,t} = \sum_{s=0}^{t} (1-\delta)^{t-s} \gamma^v_{n,j,s}$ summarizes all the past multipliers and captures Home government's past promises on policies that affect foreign innovation incentives through constraint (17). The cumulative multiplier can be written recursively as $\Gamma^v_{n,j,t} = (1-\delta)\Gamma^v_{n,j,t-1} + \gamma^v_{n,j,t}$.

We can now write the Ramsey problem recursively with the state variable as $\left\{ \Gamma^v_{n,j,-1}, T_{n,j,-1} \right\}$,

$$(Ramsey) \quad L\left(\left\{ \Gamma^v_{n,j,-1}, T_{n,j,-1} \right\} \right) = \inf_{\gamma^v_{n,j}} \sup_{\{L^r_{1,j}, \tau^x_{n,j}, \tau^m_{n,j}\}} u(C_{1t}) + \sum_{n \neq 1} \sum_{j}^{J} \left(\Gamma^v_{n,j} \frac{w_n L^p_{n,j}}{\theta T_{n,j}} - \gamma^v_{n,j} \frac{w_n}{\alpha_{n,j}} \right) \frac{u_n}{P_n}$$
$$+ \cdots + \rho L\left(\left\{ \Gamma^v_{n,j}, T_{n,j} \right\} \right)$$

where the omitted terms are related to the resource constraints. Online Appendix E shows the proof of the mapping between the original Ramsey problem and this recursive problem, and the derivations of the optimal conditions for the Ramsey policy.

Markov policy The non-commitment property of Markov policy allows us to write the problem in a recursive way. Here, we omit the time variable t for the current period and utilize a prime symbol to represent future values.

The Home government determines researchers in each sector j, taking into account foreign private innovation decisions and equilibrium production and trade. There are $N \times J$ state variables, i.e., the technologies $\{T_{n,j,-1}\}$ for all country n and sector j. Specifically, the government chooses $L^r_{1,j}$ with $j \in \{1, 2, .., J\}$, country-sector-specific import tariff $\tau^m_{n,j}$ and export taxes $\tau^x_{n,j}$ toward country $n > 1$ to solve the following problem:

$$(Markov) \quad V\left(\{T_{n,j,-1}\}\right) = \max_{\left\{L^r_{1,j}, \tau^x_{n,j}, \tau^m_{n,j}\right\}} u(C_1) + \rho V\left(\{T_{n,j}\}\right) \tag{19}$$

subject to the world market equilibrium characterized by the worker-researcher choice

$$\frac{w_n}{\alpha_{n,j}} = \frac{w_n L^p_{n,j}}{\theta T_{n,j}} + \rho(1-\delta)\frac{u'_n / P'_n}{u_n / P_n}\frac{w'_n}{\alpha_{n,j}}, \qquad (\gamma^r_{n,j} \quad J \times (N-1)) \tag{20}$$

the resource constraints (6) - (15), and $P_{1t} = 1$ for any t. The optimal conditions for the Markov policy are derived in Online Appendix F with $\gamma^r_{n,j}$ as the multiplier on constraint (20).

Both Markov and Ramsey governments consider the impact of their trade policies on the world private equilibrium. The major difference between them is that the Ramsey government decides on the entire path of policies honored in the future and internalizes that a policy at period t affects the constraint (17) for all periods. In contrast, the Markov government only chooses current policies $\left\{L^r_{1,j}, \tau^x_{n,j}, \tau^m_{n,j}\right\}$, but it recognizes that these policies affect the technology choice $\{T_{n,j}\}$, which in turn affect future marginal utility u'_n, prices P'_n, and value $v'_{n,j}$ that appear in the worker-researcher constraints of foreign countries (20). Thus, the Markov government indirectly affects future allocations and policies through current policies.

Note that establishing the existence and uniqueness of Ramsey and Markov policies is challenging due to the non-convexity property. The difficulty arises from the foreign worker-researcher constraints, which involve future allocations and values of foreign researchers, as illustrated by equations (17) or (20). This challenge is notably prevalent in much of the existing literature with limited enforcement, for example, Kehoe and Perri (2002). Establishing the uniqueness of optimal policies is challenging even for a static model, as pointed out by Lashkaripour and Lugovskyy (2023).[10] Thus, we assume the existence of a solution for both the Ramsey and Markov problem. We then proceed to characterize the optimal policies using first-order conditions.

3 Dynamic Technology Manipulation

We begin by examining how a government can influence foreign innovation to its advantage over time. To isolate this dynamic effect, we study a streamlined two-country, one-sector model. Our analysis yields two key findings. First, the Home government uses trade policies to address both static and dynamic terms of trade considerations. Second, when a Markov government cannot commit to future trade policies, it uses domestic innovation policies as an indirect tool to influence foreign innovation efforts over time. This finding contrasts sharply with outcomes under Ramsey policies.[11]

For reference, we first characterize optimal policies under exogenous technology. In this case, the worker-researcher constraint no longer applies to the equilibrium. Online Appendix D provides the complete setup and derivations of optimal conditions. The Home government solves a static problem and implements the following trade policies.

Proposition 4 (**Exogenous Technology, One Sector, Two Countries**)**.** *When technology is exogenous in a two-country, one-sector model, Home's optimal import tariffs and export taxes jointly satisfy* $(1+\tau_2^m)(1+\tau_2^x) = 1 + \frac{1}{\theta\pi_{22}}$. *Furthermore, according to tax neutrality, Home can optimally implement zero tariffs and set export tax at* $\tau_2^x = \frac{1}{\theta\pi_{22}}$.

Proof: Online Appendix D provides the proof for the general multi-country, multi-sector

[10] As stated in Lashkaripour and Lugovskyy (2023), '...the pseudo-uniqueness of the optimal policy formula is different from the uniqueness of the optimal policy equilibrium. Establishing the latter is a daunting task well beyond the scope of this paper.'

[11] Online Appendix K provides a simplified two-period model to further demonstrate our results.

exogenous technology case. By applying $N = 2, J = 1$ to the results, we derive this proposition. Intuitively, Home seeks to exploit its market power as both buyer and seller in international markets. In this single-sector model with sector-level trade policies, buyer and seller power merge into a unified market power, which is inversely related to two key factors: Foreign's expenditure share on its own goods (π_{22}) and trade elasticity θ.

When π_{22} increases, Foreign allocates more expenditure to its domestic goods and less to Home goods, reducing Home's seller power. As a result, Home's incentive to impose export taxes weakens. Meanwhile, a higher π_{22} implies a smaller share of Home's expenditure on Foreign goods under balanced trade conditions. With this reduced buyer power, Home has less leverage to depress its purchasing prices, resulting in lower optimal import tariffs. Furthermore, the Fréchet parameter θ controls trade elasticity. When θ is high, productivity dispersion is low, which makes trade flows more sensitive to price changes. When demand is more elastic, Home has less power to manipulate prices, leading to lower export taxes.

Following the tax neutrality established in Proposition 3, we set tariffs to zero without loss of generality. With zero tariffs, Home sets export taxes $\tau_2^x = \frac{1}{\theta \pi_{22}}$ to exploit its monopoly power as a seller in international markets.

In the next section, we demonstrate that with endogenous technology, the goal remains to exploit Home's market power. However, the Home government's policy incentives become more nuanced. Beyond the conventional motivation to influence static terms of trade, Home has additional incentives to manipulate foreign innovations over time.

3.1 Ramsey policies

A key insight from our analysis is that there is no need for domestic innovation policies under Ramsey policies, where the government can commit to future actions. Instead, the government can achieve its desired outcomes solely through a sequence of export taxes. The following proposition formally characterizes these optimal Ramsey policies.

Proposition 5 (Ramsey Policy). *Under the two-country, one-sector model, the optimal Ramsey policy is characterized by zero tariffs, and an export tax and domestic innovation condition that* *satisfy*

$$1+\tau^{x,R} = \frac{1+\theta\pi_{22}}{\theta\pi_{22} + \left(\gamma_2^v \frac{w_2}{\alpha_2} - \Gamma_2^v \frac{w_2 L_2^p}{\theta T_2}\right)(\sigma-1)\frac{u_{c_2}}{P_2}\frac{1}{u_{c_1} x_2}}, \tag{21}$$

$$\frac{w_1}{\alpha_1} = \frac{w_1 L_1^p}{\theta T_1} + \rho(1-\delta)\frac{u'_{c_1}/P'_1}{u_{c_1}/P_1}\frac{w'_1}{\alpha_1}. \tag{22}$$

In addition, $\gamma_2^v = \Gamma_2^v = 0$ at the steady state.

Proof. See Online Appendix G. In this two-country, one-sector framework, tax neutrality allows us to normalize import tariffs to zero. It is easy to see that the Ramsey innovation condition (22) aligns with that of the private market equilibrium (5). This implies that the Ramsey government does not impose any domestic taxes that would alter Home private innovation incentives. The rationale is straightforward: since Home innovation is efficient and the Home government only wants to take advantage of Foreign, under commitment, the government can achieve its desired intertemporal allocations through export taxes.

The export tax formula (21) reveals important insights about dynamic technology considerations. It differs from the formula under exogenous technology in Proposition 4: $1+\tau^x = \frac{1+\theta\pi_{22}}{\theta\pi_{22}}$ by including an additional term that captures dynamic effects. This term, $(\sigma-1)\left(\gamma_2^v \frac{w_2}{\alpha_2} - \Gamma_2^v \frac{w_2 L_2^p}{\theta T_2}\right)\frac{u_{c_2}}{P_2}/(u_{c_1} x_2)$ in the denominator of formula (21), depends not only on the current multiplier γ_2^v on the worker-research constraint (17) but also on the cumulative past commitments Γ_2^v, which enters the formula with an opposite sign. Hence, the presence of Γ_2^v dampens the impact of the current multiplier γ_2^v.

Why do both current and past cumulative multipliers matter? The period t export tax τ_t^x affects foreign innovation incentives not only in period t but also in all previous periods $s < t$. Such impact works through the foreign real wage w_{2t}/P_{2t}. A higher export tax τ_t^x raises the cost for foreign consumers to purchase home goods, leading to a higher foreign price P_{2t} and a lower real wage w_{2t}/P_{2t}. As w_{2t}/P_{2t} simultaneously represents both the cost of current innovation and the benefit of past innovation, τ_t^x affects innovation incentives for all the periods $s \leq t$.

To understand the mechanism more precisely, consider the worker-innovation constraint (17) or recursively (5) for the foreign country. Using the labor market clearing condition,

$L_2 = L^p_{2t} + L^r_{2t}$, the evolution of technology $T_{2t} = (1-\delta)T_{2t-1} + \alpha_2 L^r_{2t}$, along with the utility function $u(C_2) = C_2^{1-\sigma}/(1-\sigma)$, we can express the condition as:

$$1 - \frac{\alpha_2}{\theta}\frac{L_2 - L^r_{2t}}{(1-\delta)T_{2t-1} + \alpha_2 L^r_{2t}} = \rho(1-\delta)\left(\frac{C_{2t+1}}{C_{2t}}\right)^{-\sigma}\frac{w_{2t+1}/P_{2t+1}}{w_{2t}/P_{2t}}. \tag{23}$$

The left side captures the real cost of innovating: one minus current real profit, which depends on innovation L^r_{2t} and T_{2t-1} (the cumulative past innovations). The right side is the real benefit of innovating: discounted wage growth with the discount factor from households' marginal rates of substitution across time. We can define foreign real interest rate R_{2t} as the inverse of the discount factor, i.e., $1/R_{2t} = \rho(1-\delta)\left(\frac{C_{2t+1}}{C_{2t}}\right)^{-\sigma}$.

Innovation works as an investment: innovation is high under high wage growth or low real interest rate R_{2t}. In the foreign country, the real interest rate and wage growth are tightly linked since consumption depends directly on real wages ($C_{2t} = w_{2t}/P_{2t}L_2$). We can rewrite the equation (23) and the foreign interest rate as

$$1 - \frac{\alpha_2}{\theta}\frac{L_2 - L^r_{2t}}{(1-\delta)T_{2t-1} + \alpha_2 L^r_{2t}} = \rho(1-\delta)\left(\frac{w_{2t+1}/P_{2t+1}}{w_{2t}/P_{2t}}\right)^{1-\sigma}, \; R_{2t} = \frac{1}{\rho(1-\delta)}\left(\frac{w_{2t+1}/P_{2t+1}}{w_{2t}/P_{2t}}\right)^{\sigma}.$$

Thus, there is a tension: while high wage growth encourages innovation by increasing future returns, it also raises real interest rates, which discourage innovation by making current consumption more attractive. The net effect depends on the risk aversion parameter σ. When $\sigma < 1$, the wage effect dominates; when $\sigma > 1$, the interest rate effect prevails; and when $\sigma = 1$, these effects exactly offset each other.

Through its negative impact on foreign real wage w_{2t}/P_{2t}, export tax τ^x_t affects foreign innovation L^r_{2t} at period t. Moreover, w_{2t}/P_{2t} enters the worker-researcher constraints (17) for all $s < t$. Thus, export taxes create dynamic effects. A higher export tax in period t reduces the foreign real wage w_{2t}/P_{2t}, which:

- For $\sigma > 1$: reduces foreign current innovation but raises past innovation incentives,
- For $\sigma < 1$: increases foreign current innovation but lowers past innovation incentives,
- For $\sigma = 1$: does not affect foreign innovation.

This explains why the cumulative multiplier Γ^v_{2t} appears in the tax formula with the opposite sign of the current multiplier γ_2^v.

The sign of $\gamma_{2,t}^v$ reflects whether foreign innovation at period t improves Home welfare—higher lifetime consumption or a more smoothed path of consumption. A negative sign indicates that Home prefers to curb foreign innovation at period t. From Home's perspective, Foreign's innovation return—represented by the right-hand side of (17)—are too large relative to its associated innovation costs shown on the left-hand side of (17). To reduce these foreign innovation incentives, when $\sigma > 1$, Home increases the current export tax beyond the static terms-of-trade consideration, while reducing future export taxes below their static benchmark of $1/(\theta\pi_{22})$.

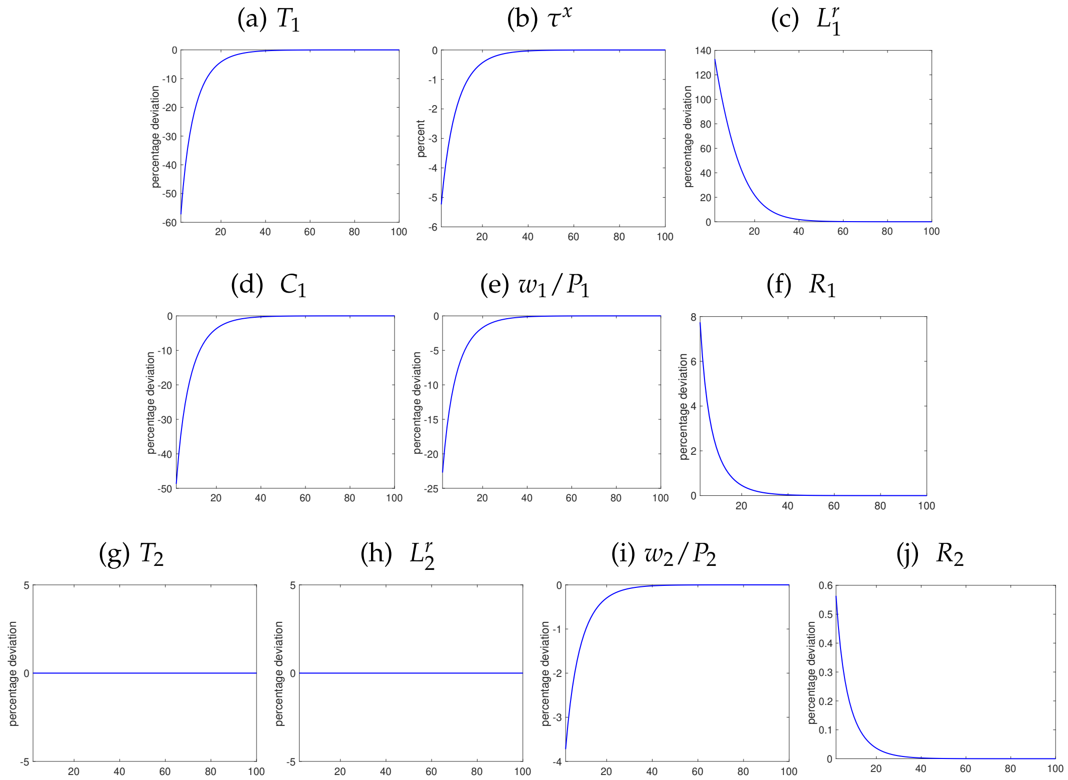
Numerical example We consider a numerical example where Home's technology begins below the steady state, while the foreign country's technology starts at its steady state value.[12] To illustrate the Home government's incentives in choosing policies, we compare optimal policies under three different preference specifications: logarithmic utility ($\sigma = 1$), linear utility ($\sigma = 0$), and a higher risk aversion case ($\sigma = 2.5$).

Figure 1 depicts the equilibrium under Home's optimal policy when $\sigma = 1$. In this case, Home's export taxes do not influence foreign innovation and technology, as shown in Figures 1h and 1g. As a result, Home imposes export taxes only to address the static terms of trade effect. The optimal policies and outcomes mirror those under the exogenous technology case. When starting with a low T_1, Home's innovation is above the steady-state level (Figure 1c), causing technology to increase over time (Figure 1a). As Home's technology improves, its exports to foreign countries increase, incentivizing the Home government to implement higher export taxes. Home's real wages, w_{1t}/P_{1t}, rise due to increased productivity, which elevates the marginal product of labor over time. Although Foreign's technology remains constant, its real wages (and thus consumption) initially fall below steady-state levels because of Home's low technology. Both countries experience initial interest rates above the steady-state level due to consumption growth over time. Eventually, all variables converge to their steady-state levels.

We next examine the case with linear preference $\sigma = 0$. To show Home government's

[12] In this example, $\theta = 2, \sigma = 2.5, \rho = 0.9, \delta = 0.02, \alpha_1 = 1, \alpha_2 = 0.9, d = 1.1$.

Figure 1: Optimal Trade Policy, Allocations, and Prices under $\sigma = 1$



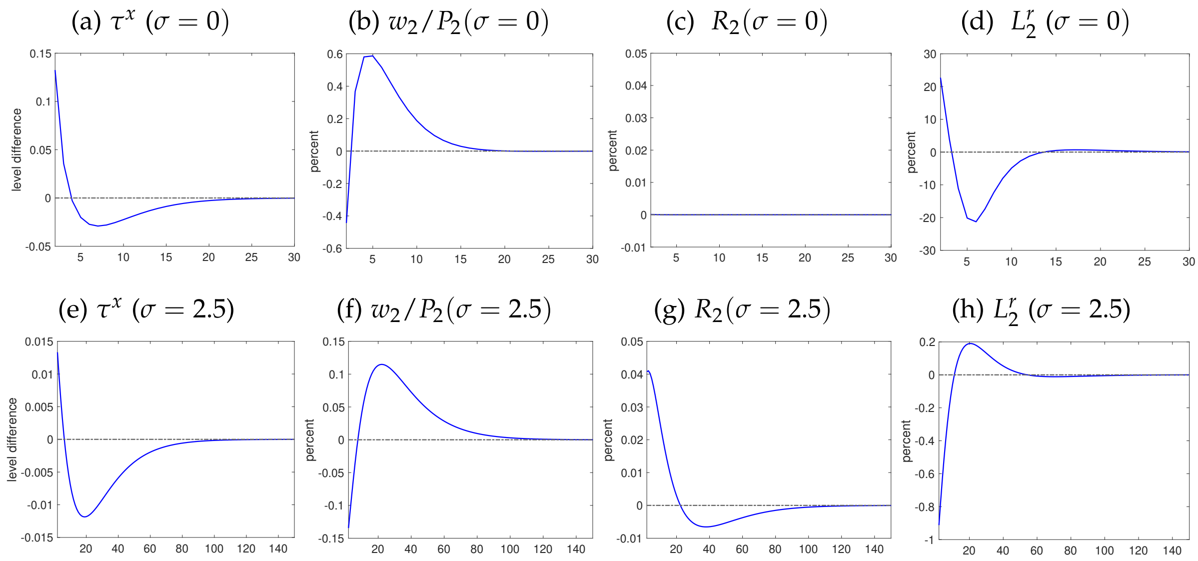
Note: These figures plot the percentage deviations of each variable relative to its steady state. τ^x is the export tax imposed by Home government, T_1 Home technology, L_1^r Home innovation labor, C_1 Home consumption, w_1/P_1 Home real wage, R_1 Home real interest rate.

dynamic incentives in choosing policies, we compare our endogenous technology model with a reference model that applies an export tax formula $1/\theta\pi_{22,t}$ for each period t, as in the exogenous technology case in Proposition 4. In this reference case, which we term "exogenous-T-tax", we solve for the private equilibrium under this exogenous tax formula. The upper panels of Figures 2 and 3 plot the percentage deviation of outcomes in our endogenous technology model from those of the reference model when $\sigma = 0$.

With linear preference, Home only cares about lifetime consumption but not consumption smoothing. Its objective is to stimulate higher foreign technology T_2 in the early periods to boost lifetime domestic consumption C_1. The Home government implements this through a dynamic export tax policy—initially setting higher export taxes followed by reductions below the levels in the exogenous-T-tax case, as shown in Figure 2a. While this tax sequence does not affect foreign real interest rates R_{2t} (Figure 2c), it generates a distinctive wage trajectory for Foreign: initially suppressed but subsequently elevated real wages w_{2t}/P_{2t} (Figure 2b) than the exogenous-T-tax case. This wage pattern stimulates innovation in the foreign country (Figure 2d), pushing T_2 above the exogenous tax case for an extended period and thereby raising Home consumption.

The higher export tax simultaneously depresses Home real wages (Figure 3a), which incentivizes domestic innovation, as shown in Figure 3c. The combined effect of increased innovation in both economies leads to expanded production. As a result, while Home consumption initially declines, it subsequently rises above the level in the exogenous-T-tax case. These figures illustrate how Home government uses trade policies to expand lifetime consumption: by pushing up both home and foreign innovation during early periods.

Figure 2: Dynamic Technology Manipulation: Trade Policies, Foreign Prices and Innovation



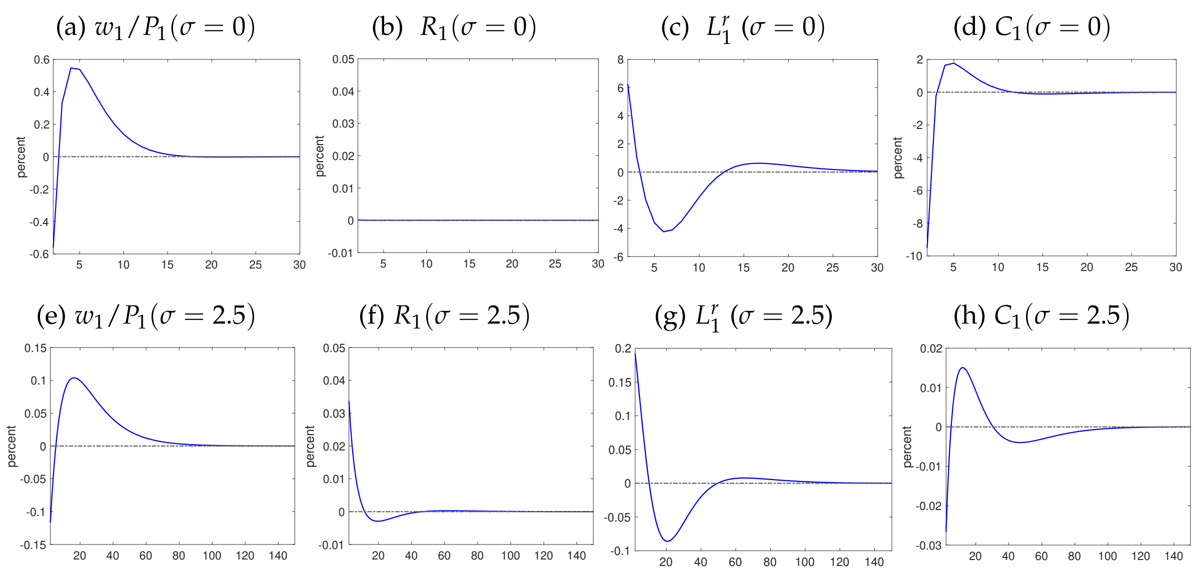
Note: Each figure plots the outcome differences between the Ramsey policy and outcomes under the reference exogenous-T-tax model, which applies the tax formula $1/(\theta\pi_{22,t})$ at each period t. τ^x is the export tax imposed by Home government, w_2/P_2 foreign wage, R_2 foreign real interest rate, L_2^r foreign innovation labor. The upper panels plot the relative outcome under $\sigma = 0$, and the lower panels plot the relative outcome under $\sigma = 2.5$.

The case with $\sigma = 0$ illustrates how governments can utilize trade policies to increase lifetime consumption. As σ increases, however, consumption smoothing becomes increasingly important. Given that technology T_1 is expected to be higher in the future, the Home government would like to shift future consumption to earlier periods. To achieve this, it implements policies that encourage foreign countries to produce instead of innovate in the early periods, as shown in Figure 2h.

Under $\sigma > 1$, Home government increases export taxes higher than $1/(\theta\pi_{22,t})$, as shown in Figure 2e. This has two key effects in foreign markets: depressing real wages (Figure 2f) while raising foreign real interest rates (Figure 2g). When σ is high, the interest rate effect dominates, triggering an initial decline in foreign innovation labor L_2^r, relative to the exogenous-T-tax case. This shift causes Foreign to produce more, and thus goods become cheaper, which tends to raise Home consumption, C_1, in the early periods.

Domestically, the export policy simultaneously reduces Home real wages (Figure 3e) and elevates Home interest rates (Figure 3f). Unlike the foreign country, Home's interest rate is not directly related to its real wage, as Home also receives revenue from export taxes and import tariffs. In this numerical example, even with $\sigma = 2.5$ for Home, the wage effect dominates—Home innovation (L_1^r) increases despite rising interest rates compared to the exogenous-T-case.

Figure 3: Dynamic Technology Manipulation: Home Prices and Innovation



Note: Each figure plots the outcome differences between the Ramsey policy and outcomes under the reference model, exogenous-T-tax, which applies the tax formula $1/(\theta\pi_{22,t})$. w_1/P_1 is Home real wage rate, R_1 Home real interest rate, L_1^r Home innovation labor, and C_1 Home consumption. The upper panels plot the relative outcome under $\sigma = 0$, and the lower panels plot the relative outcome under $\sigma = 2.5$.

This numerical example illustrates how the Home government uses export taxes to direct foreign technology development. Starting with a technology level below the steady state, the dynamic component of optimal export taxes follows a distinctive pattern: initially higher and subsequently lower than the optimal taxes in the exogenous technology case ($1/(\theta\pi_{22,t})$). As a result, foreign real wages are initially lower and later higher than those in the exogenous technology case, while foreign real interest rates follow the opposite pattern. As all variables eventually reach the steady state, the dynamic component disappears, and all variables are the same as those in the exogenous technology case.

This deviation from the exogenous technology case serves two purposes. Home can either achieve higher lifetime domestic consumption by encouraging greater foreign innovation, or it can shift future consumption to current periods by stimulating higher foreign production early on. Which outcome prevails depends on the competition between wage growth and interest rate effects. When risk aversion is low (small σ), the foreign wage effect dominates—the higher-then-lower export tax pattern promotes foreign innovation, generating higher lifetime consumption for Home. In contrast, when risk aversion is high (large σ), the foreign interest rate effect becomes dominant—the deviation of export taxes from the exogenous case reduces foreign innovation while increasing early-period production, enabling Home to smooth consumption over time.

3.2 Markov policies

In each period, the Markov government optimizes over current export taxes while directly choosing domestic innovation and allocations, respecting the world market equilibrium and future Markov policies. We normalize Home's import tariff to zero, as in the Ramsey case. The following proposition characterizes the optimal Markov policy.

Proposition 6 (**Markov Policy**). *Under the two-country, one-sector model, the optimal Markov policy is characterized by zero tariffs and the export tax $\tau^{x,M}$ and domestic innovation subsidy τ^d on profits as follows:*

$$1+\tau^{x,M} = \frac{1+\theta\pi_{22}}{\theta\pi_{22}+\gamma_2^r(\sigma-1)\rho(1-\delta)\frac{u'_{c_2}/P'_2}{u_{c_2}/P_2}\frac{w'_2}{\alpha_2}\frac{1}{u_{c_1}x_2}}, \tag{24}$$

$$\tau_d = \frac{1}{\frac{1}{\theta}\frac{w_1 L_1^p}{T_1}} \gamma_2^r \frac{\theta}{1+\theta} \frac{1}{u_{c_1}} \frac{\rho(1-\delta)}{u_{c_2}/P_2} \frac{\partial(\frac{u'_{c_2}}{P'_2}\frac{w'_2}{\alpha_2})}{\partial T_1}. \tag{25}$$

The innovation subsidy τ_d implements the Home government's optimal innovation choices that satisfy

$$\frac{w_1}{\alpha_1} = \frac{1}{\theta}\frac{w_1 L_1^p}{T_1} + \rho(1-\delta)\frac{u'_{c_1}/P'_1}{u_{c_1}/P_1}\frac{w'_1}{\alpha_1} + \underbrace{\gamma_2^r \frac{\theta}{1+\theta}\frac{1}{u_{c_1}}\frac{\rho(1-\delta)}{u_{c_2}/P_2}\frac{\partial\left(\frac{u'_{c_2}}{P'_2}\frac{w'_2}{\alpha_2}\right)}{\partial T_1}}_{\text{innovation wedge}}. \tag{26}$$

At the steady state, the multiplier $\gamma_2^r = 0$ and thus $\tau^{x,M} = \frac{1}{\theta\pi_{22}}$ and $\tau_d = 0$.

Proof. See Online Appendix G. What affects Foreign's innovation incentives today is the return to innovation and the relative cost of innovation. As we explain below, export taxes affect contemporaneous prices, while innovation policies are deployed to impact future prices—given the lack of commitment—and the two policy tools in the above equations combine to determine current-period foreign innovation efforts.

Export tax Relative to the exogenous case in Proposition 4, there is an extra term in the denominator of the export tax formula, $\gamma_2^r(\sigma-1)\rho(1-\delta)\frac{u'_{c_2}/P'_2}{u_{c_2}/P_2}\frac{w'_2}{\alpha_2}\frac{1}{u_{c_1}x_2}$, reflecting the dynamic technology consideration. The intuition is similar to the Ramsey case. The export tax imposed by the Home government affects foreign price P_2 and thus foreign real wages and interest rate, which in turn determines the foreign worker-research constraint (20). Hence, the multiplier γ_2^r on this constraint shows up in the export tax formula. Furthermore, such impact depends on the wage versus interest rate effect, and thus $(\sigma-1)$ shows up. When $\sigma = 1$, the wage and interest rate effects cancel out, the export tax has no impact on country 2's innovation incentives, and the export tax formula is the same as the static one.

The optimal Markov export tax formula of (24) looks similar to the one in Ramsey (21). To compare, we plug in the worker-researcher constraint (20) to Markov formula (24), and the Markov export tax becomes

$$1+\tau^{x,M} = \frac{1+\theta\pi_{22}}{\theta\pi_{22} + \left(\gamma_2^r \frac{w_2}{\alpha_2} - \gamma_2^r \frac{w_2}{\theta}\frac{L_2^p}{T_2}\right)(\sigma-1)\frac{1}{u_{c_1}x_2}}. \tag{27}$$

As is clear, the multiplier $\gamma_2^v u_{c_2}/P_2$ in the Ramsey corresponds to the multiplier γ_2^r in the Markov case. However, taxes under Markov and Ramsey differ in an important way. Markov export taxes (27) depend only on the current multiplier γ_2^r associated with the foreign innovation incentive, while Ramsey export taxes $\tau^{x,R}$ depend not only on the current multiplier γ_2^v but also on past cumulative commitments $\Gamma_{2,-1}^v$. Furthermore, the past commitments $\Gamma_{2,-1}^v$ dampen the impact of the current multiplier γ_2^v on the export tax, showing up as the negative term in the denominator of (21). This comparison demonstrates how the commitment feature affects optimal trade policies.

Innovation policy Because Foreign's future prices matter for current-period innovation, and because the Home country cannot commit to a path of trade policies to affect foreign future wages and prices, domestic innovation policies must be deployed. By dictating its own innovation and technology T_1, Home can influence Foreign's innovation efforts today. To see this—in Home 'Euler' equation of innovation choices (26), there is an *innovation wedge* term when compared to the private market equilibrium. We can combine the first and third terms of this Euler equation (26) and rewrite it as

$$\frac{w_1}{\alpha_1} = \frac{1}{\theta}\frac{w_1 L_1^p}{T_1}\left[1 + \underbrace{\frac{1}{\frac{1}{\theta}\frac{w_1 L_1^p}{T_1}}\gamma_2^r \frac{\theta}{1+\theta}\frac{1}{u_{c_1}}\frac{\rho(1-\delta)}{u_{c_2}/P_2}\frac{\partial\left(\frac{u'_{c_2}}{P'_2}\frac{w'_2}{\alpha_2}\right)}{\partial T_1}}_{\text{innovation subsidy } \tau_d}\right] + \rho(1-\delta)\frac{u'_{c_1}/P'_1}{u_{c_1}/P_1}\frac{w'_1}{\alpha_1},$$

where $\frac{1}{\theta}\frac{w_1 L_1^p}{T_1}$ is the before-subsidy profit. Thus, the Home government can implement the innovation wedge with a subsidy τ_d applied to the current innovation profit.

There are two key elements in this wedge term: (1) the multiplier γ_2^r, and (2) the derivative of the foreign marginal utility of innovation to T_1, denoted as $der \equiv \partial\left(\frac{u'_{c_2}}{P'_2}w'_2\right)/\partial T_1$ for the purpose of discussion. Using $C'_2 = w'_2/P'_2$ in the foreign country and the preference $u(C) = C^{1-\sigma}/(1-\sigma)$, we can further write $der = \partial[(w'_2/P'_2)^{1-\sigma}]/\partial T_1$.

A higher T_1 lowers Home's future export prices, pushing down foreign price P'_2 and raising foreign real wage w'_2/P'_2. As a result, the foreign country has a higher real wage in the future but a higher foreign interest rate (due to the lower marginal utility of consumption). When the interest rate effect dominates, $der \leq 0$, and the high interest rate depresses foreign innovation incentives. This affects the tightness of the foreign worker-researcher constraint (20)—the reason why the multiplier of this constraint γ_2^r shows up in the wedge.

The sign of the multiplier γ_2^r once again matters, and captures whether Home would like to reduce or raise Foreign's innovation. For instance, when T_1 is below the steady-state level and $\sigma > 1$, Home would like to have more research and higher consumption. Hence, Home wants Foreign to innovate less and produce more to increase Home's real consumption today. In this case, γ_2^r tends to be negative and, along with a negative *der* term, produces a positive innovation wedge. The higher the innovation wedge, the larger the Home innovation incentive as the right-hand side of equation (26) reflects the benefit as a researcher. The innovation wedge behaves as a subsidy to Home's innovation efforts.

At the steady state, γ_2^r becomes zero, and the optimal export tax is the same as in the exogenous case, and there are no innovation subsidies, $\tau_d = 0$. The intuition is straightforward: when the technology reaches a steady state, the government can no longer use policies to affect foreign wages path and interest rates.

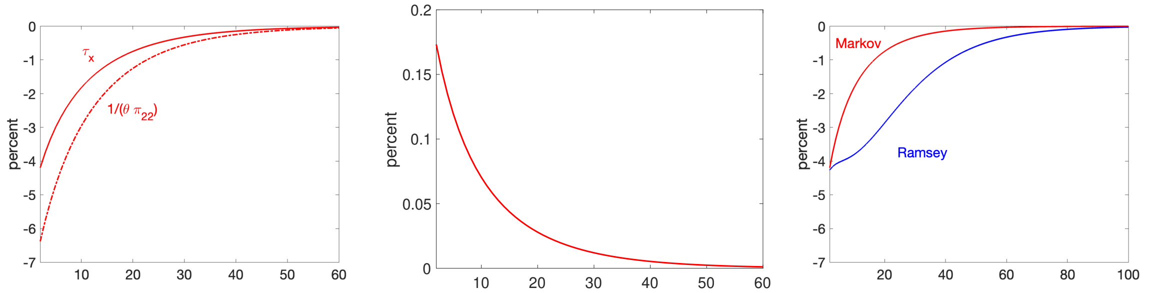
Numerical example Consider the same numerical example in the Ramsey case with $\sigma = 2.5$. Now the Markov government utilizes both export taxes and innovation subsidies, as depicted in Figures 4a and 4b. The export tax has two salient features. First, it increases when T_1 increases over time. Second, it consistently exceeds the level in the static model of $1/(\theta\pi_{22})$. Moreover, the gap between export tax and $1/(\theta\pi_{22})$ shrinks and eventually goes to zero when T_1 increases over time.

These two features reinforce our previous discussions in Proposition 6. When T_1 increases over time, the home country gains monopoly power and is able to impose a higher export tax. This motive is clear from the rising $1/(\theta\pi_{22})$, capturing the static terms of trade effect. A higher export tax than $1/(\theta\pi_{22})$ reflects the home government's motives to lower foreign innovation efforts by raising foreign interest rates.

In addition, Home increases subsidies on domestic research efforts to further deter Foreign's. As technology progresses towards its long run value, the need to manipulate foreign innovation incentives diminishes and eventually disappears. As a result, the export tax equals $1/(\theta\pi_{22})$, and innovation subsidies become zero, in the long run.

Figure 4: Optimal Markov Polices: Two-Country, One-Sector

(a) Export tax (b) Innovation subsidy (c) Export tax: Markov & Ramsey



Note: Panel (a) plots the optimal export tax under Markov problem and the implied $1/(\theta\pi_{22})$ by this optimal policy. Panel (b) plots the innovation subsidy defined in equation (25). Panel (c) compares the optimal export tax in Markov and Ramsey.

Figure 4c plots Markov export taxes against Ramsey export taxes. The path of export taxes tends to be flatter under Ramsey than under Markov. This discrepancy arises from the ability of a Ramsey government to manipulate not only the current foreign price P_2 through the current τ^x, but also future prices P_2' through commitments to future $\tau^{x\prime}$. Consequently, the government is able to avoid excessive increases in the current τ^x. In contrast, the Markov government cannot commit to a sequence of export taxes to influence the dynamic terms of trade, and it is obliged to implement distortionary domestic industry policies such as innovation policies.

In the long run, neither Markov nor Ramsey policies have any additional incentive to alter the dynamic terms of trade. Both end up with the same steady state of technology and export taxes. Note that the steady-state innovation and trade policy becomes the same as in a static model only in the special case with one sector and no externalities. We proceed to discuss this in detail in the following section and explore why the multi-country and multi-sector model provides additional insights.

4 Comparative Advantage: Multiple Sectors

The multiple-sector framework introduces comparative advantage across sectors into our analysis. In this expanded context, the Home government has an extra incentive to manipulate foreign technology to influence foreign prices across sectors. To make these forces transparent, we derive optimal taxes in the long-run equilibrium. This section demonstrates that, in contrast to the uniform tariff applied across all sectors under exogenous technology, optimal policies with endogenous technology consist of *heterogeneous* tariffs and export taxes that vary across sectors.

To better illustrate the underlying mechanism, we first present the optimal policies in a two-country framework, comparing both exogenous technology and endogenous technology cases. We then extend our analysis to include multiple countries, revealing how Home chooses trade policies with more complex general equilibrium interactions across countries.

4.1 Two countries

As a reference, we first present the optimal policies under exogenous technology. We then characterize the optimal policies with endogenous technology accumulation. With only two countries, under endogenous technology accumulation, we demonstrate that relative tariffs across sectors depend on the trade elasticity and Home country's relative import shares of foreign production—essentially, Home's buyer power.

Proposition 7 (**Exogenous Technology, Multiple Sectors, Two Countries**). *When technology is exogenous in a two-country, multi-sector model, Home's optimal trade policies consist of uniform import tariffs τ_2^m and sector-specific export taxes $\{\tau_{2,j}^x\}$, satisfying $(1+\tau_2^m)(1+\tau_{2,j}^x) = 1 + \frac{1}{\theta \pi_{22,j}}$ for each j. Furthermore, according to tax neutrality, Home can optimally implement zero tariffs $\tau_2^m = 0$ and set the sector-specific export tax at $\tau_{2,j}^x = \frac{1}{\theta \pi_{22,j}}$.*

Proof: we apply the case with $N = 2, j > 1$ to the proof established in Online Appendix D. Extending the single sector logic from Proposition 4, here Home imposes export taxes to exploit its sellers' market power across sectors. In each sector j, the optimal export tax increases with Home's market power, which decreases with $\pi_{22,j}$. Higher foreign dependence on Home's export (higher $\pi_{21,j}$) incentivizes Home to impose higher export taxes in that sector.

Unlike sector-specific export taxes, optimal import tariffs are uniform across sectors.

While Home would like to leverage its market power as a buyer through tariffs, this power cannot be effectively targeted at specific sectors. Here is the reason. Foreign supply prices in each sector are proportional to wages divided by sector-specific productivity. Because perfect labor mobility equalizes wages across foreign sectors and productivities are exogenous, Home cannot selectively influence foreign prices in individual sectors through targeted tariffs. When Home imposes higher tariffs on a particular sector j, the result is merely increased domestic prices without affecting foreign supply prices in that sector relative to other sectors. These sector-specific tariffs only distort domestic relative consumption without improving sector-specific terms of trade. Therefore, the optimal policy for Home is to apply a uniform tariff across all sectors, affecting the foreign overall wage level. Under tax neutrality, we can normalize optimal tariffs to zero.

In contrast, when technology is endogenous, Home possesses sector-specific buyer power as it can use sector-specific import tariffs to influence foreign innovation incentives and thus technologies T_{2j} sector by sector. This allows Home to affect foreign prices on a sector-by-sector basis. The following proposition demonstrates that with endogenous technology, optimal policy involves heterogeneous tariffs across sectors, reflecting Home's incentive to exploit its differential buyers' power in each foreign sector.[13]

Proposition 8. *With endogenous technology accumulation, at the steady state,*

1. *Neither the Home Markov nor Ramsey governments use domestic innovation policies. Moreover, they choose the same trade policies.*
2. *Home optimal tariffs are sector-specific and satisfy the following condition for any sectors j, j':*

$$\tau^m_{2,j} - \tau^m_{2,j'} = -\frac{1}{\theta}\left(\frac{\beta_j x_1 - Y_{1j}}{Y_{2j}} - \frac{\beta_{j'} x_1 - Y_{1j'}}{Y_{2j'}}\right), \tag{28}$$

where $Y_{nj} = \frac{1+\theta}{\theta} w_n L^p_{nj}$ represents production in country n and sector j, and $\frac{\beta_j x_1 - Y_{1j}}{Y_{2j}}$ is Home net imports as a share of Foreign production for sector j.

[13] Bai, Lu, and Wang (2024) examines optimal domestic and trade policies across various labor market general equilibrium specifications. Their analysis reveals that, unlike the perfect mobility case, imperfect labor mobility gives Home the ability to exert differential market power across sectors through targeted tariff policies. Specifically, when labor mobility is imperfect across sectors, foreign wages become sector-specific, and foreign relative prices respond to Home demand, which is in turn affected by sector-specific tariffs. This creates an incentive for the Home government to exploit buyer's power to depress foreign prices, particularly in sectors with higher imports.

3. *Home optimal export taxes satisfy* $(1+\tau^m_{2,j})(1+\tau^x_{2,j}) = 1 + \frac{1}{\theta\pi_{22,j}}$.

Proof. See Online Appendix H. At the steady state, technologies across countries do not change. Thus, a Markov government has no incentive to implement domestic policies that manipulate foreign research efforts through wages and interest rates over time. As a result, both the Markov and Ramsey governments opt for the same trade policies, leading to the same allocations in both cases.

Again, the market works efficiently at the micro level, but the unilateral government holds market power as both a monopsony buyer and a monopoly supplier for different sector goods. As a monopoly supplier, Home would like to use different export taxes to set different markups across sectoral goods, depending on its comparative advantage, hence market power in foreign destinations. As a monopsony buyer, Home would like to lower the foreign supply prices of goods it imports. With endogenous technology, Home can use heterogeneous tariffs to effectively influence the relative prices of Foreign sector goods. When a lower tariff is imposed on a specific sector, it stimulates demand and incentivizes firms to innovate and improve their technology. The wage per productivity level decreases in this sector, effectively lowering Home import prices relative to other sectors.

In this two-country model, Home's monopsony power and, thus, the import tariffs are directly linked to the trade elasticity θ and comparative advantages. The optimal tariffs can be expressed in terms of Home's net import as a share of foreign production in each sector, along with the trade elasticity θ, as shown in tariff formula (28). Home's net import in a sector—calculated as the difference between its expenditure $\beta_j x_1$ and income Y_{1j}—reflects its comparative disadvantage in this sector. When comparing two sector j and j', where Home is a net importer in sector j ($\beta_j x_1 - Y_{1j} \geq 0$) and a net exporter in sector j' ($\beta_{j'} x_1 - Y_{1j'} \leq 0$), our proposition shows that $\tau^m_{2,j} < \tau^m_{2,j'}$. This means Home imposes lower tariffs on importing sectors relative to exporting sectors to stimulate innovation and further reduce import prices.

This two-country analysis highlights the crucial distinction between optimal policies in endogenous versus exogenous technology frameworks. When technology is endogenous, the Home government can use heterogeneous import tariffs across sectors to leverage its buyer power and influence foreign technology accumulation. By contrast, when technology is exogenous, Home's buyer power remains uniform across sectors, resulting in uniform tariffs as demonstrated by Costinot et al. (2015). This two-country model has another advantage: we can directly link the relative tariff across sectors to Home's relative buyer power between sectors. This allows us to derive an explicit tax formula that depends solely on the two sectors in question without direct linkages to other sectors.

In the following section, we extend our analysis to multiple countries, demonstrating that the key mechanism is still present in this more complex environment. However, the multi-country setting introduces intricate general equilibrium effects that create cross-country and sector interdependencies. As a result, the tax formula becomes substantially more complex. Even with exogenous technology, tariffs become country-specific, though they remain uniform across sectors.

4.2 Multiple countries

We now turn to the general case involving multiple countries and sectors. First, we demonstrate that import tariffs—whether with or without technology accumulation—are linked to the Lagrangian multiplier on the goods market clearing condition (8). This multiplier captures Home's marginal welfare gain from increased domestic demand for a foreign country's good. We then proceed to analyze how these multipliers are determined under two scenarios: when technology accumulation is exogenous and when it is endogenous.

Proposition 9 (**Multiple Countries**). *In the multi-country, multi-sector model,*

1. *When technology is* ***exogenous****, Home's optimal trade policies consist of country-specific import tariffs and country-sector-specific export taxes:*

$$\tau^m_{n,j} = -\frac{\gamma_n}{u_{c_1}}, \qquad 1 + \tau^x_{n,j} = \frac{1 + \theta(1 - \pi_{n1,j})}{\theta \sum_{i \neq 1}(1 + \bar{\tau}^m_i)\pi_{ni,j}}, \tag{29}$$

   where γ_n are the multipliers on country n's goods market clearing conditions and satisfy the system of equations A.12.

2. *In the* ***endogenous*** *technology steady state, neither the Home Markov nor Ramsey governments use domestic innovation policies, and both choose identical policies characterized by:*

   (i) Optimal policies feature heterogeneous import tariffs and export taxes across countries and

sectors:

$$\tau^m_{n,j} = -\frac{\gamma^L_{nj}}{u_{c_1}}, \qquad 1 + \tau^x_{n,j} = \frac{1 + \theta(1 - \pi_{n1,j})}{\theta \sum_{i \neq 1}(1 + \tau^m_{i,j})\pi_{ni,j}}. \tag{30}$$

where γ^L_{nj} satisfy the system of equations A.76.

(ii) Furthermore, the following relationship holds:

$$\sum_{n \neq 1} (\tau^m_{n,j} + \xi_n) Y_{n,j} = -\frac{1}{\theta}(\beta_j x_1 - Y_{1,j}). \tag{31}$$

Proof: See Online Appendix D and H.3.

Exogenous technology In a multi-country framework, optimal tariffs become country-specific while remaining uniform across sectors. As previously established, Home would like to leverage its buyer power through tariff implementation. When T is exogenous, optimal tariffs are uniform across sectors because the fully mobile labor market within each foreign country prevents Home from altering relative prices across sectors, which are determined by the ratio of aggregate wage to exogenous sectoral technology. However, Home can influence wages and relative import prices across different countries by imposing country-specific tariffs. This results in tariffs that vary by country but remain uniform across sectors within each foreign country.

Whether or not to implement a lower tariff to specific foreign countries depends on Home's marginal welfare gain from inducing additional domestic demand for those countries' goods. This gain is captured by the Lagrangian multipliers $\gamma^L_{n,j}$ on the goods market clearing condition (8). Under exogenous technology and free labor mobility across sectors, these multipliers become identical across sectors for each country and can be simplified to γ_n. Equation (29) shows that $\tau^m_{n,j} = -\frac{\gamma_n}{u_{c_1}}$, the import tariffs directly link to γ_n. Thus, when additional domestic demand for country n's goods increases Home welfare ($\gamma_n > 0$), Home should reduce tariffs on that country.

Intuitively, import tariffs create consumption wedges across goods from different countries. While this distorts consumption, it allows the Home government to affect foreign wages and relative import prices. In equilibrium, the marginal cost of these distortionary wedges must equal the marginal welfare gains from the tariffs—a relationship precisely captured in the first-order conditions. As demonstrated in Online Appendix D, these γ_n multipliers are simultaneously determined by the system of first-order conditions on wages across N countries (equations A.12). Importantly, optimal tariffs cannot be set independently for individual countries. When Home chooses tariffs on one foreign country, it must account for how wage changes in that country will affect all other countries' exports to Home. Meanwhile, the tariff on one foreign country changes equilibrium wages for all other countries, and, in turn, the demand and supply of other countries. Thus, optimal tariffs across countries are jointly determined through the system of first-order conditions on wages.

Second, given Home import tariffs affect foreign wages and foreign demands, the import tariffs show up in the export tax formula. Nonetheless, 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 tariff to zero, and the symmetrical equilibrium implies that all tariffs become zero. Under these conditions, the export tax formula (29) simplifies to $1 + \tau^x_{n,j} = \frac{1+\theta(1-\pi_{n1,j})}{\theta(1-\pi_{n1,j})}$. This formula shows that export taxes increase with $\pi_{n1,j}$, meaning that the export tax for a specific country-sector pair rises with the Home country's market power (and exports) in that market. In general, when dealing with multiple asymmetric countries, Home employs country-specific tariffs to manipulate relative wages and buyer's power, alongside country-specific export taxes to exploit its sellers' power. All trade policies are jointly determined, satisfying our formulas.

Endogenous technology Proposition 9 shows that tariffs are now sector-specific rather than uniform across sectors as in the exogenous technology case. With multiple countries, Home's tariffs are, on average, higher for sectors with relatively higher net exports ($Y_{1j} - \beta_j x_1$): Equation (31) shows that for that sector, the weighted average of Home's tariff across countries is higher. This demonstrates the Home government's incentive to reduce foreign innovation efforts in sectors where the Home holds a comparative advantage, which we explained in the two-country case.

For the country-sector specific tariffs, they are jointly determined, again because tariffs on one foreign sector affect *all other* countries' sectoral profits and incentives to do innovation, hence technology. Furthermore, the Home government strategically influences foreign innovation incentives to maximize its welfare gains from sectoral consumption demand. We can formally demonstrate that $\gamma^L_{n,j}$ is connected to $\gamma^r_{n,j}$ (the multiplier on the foreign worker-researchers constraint Eq.20) through the following relationship:

$$\gamma^L_{n,j} = \gamma^r_{n,j} \frac{1}{(1+\theta)T_{n,j}} + \sum_j^J \gamma^L_{n,j} \frac{\frac{1+\theta}{\theta} w_n L^p_{n,j}}{x_n}. \tag{32}$$

The second term in this equation sums across all sectors within country n, making it sector-independent but country-specific. According to this relationship, when the Home country benefits from increasing domestic demand in sector j (reflected by a higher $\gamma^L_{n,j}$), the multiplier $\gamma^r_{n,j}$ is correspondingly higher relative to the sector's technology level. This higher multiplier $\gamma^r_{n,j}$ captures Home's marginal gain from foreign innovation in that sector.

By combining equations (30) and (32), we conclude that the Home government optimally lowers tariffs in sectors where it wishes to stimulate foreign innovation. These tariff reductions enhance foreign technology and increase Home welfare gains from further reductions in import prices. In equilibrium, optimal policies, multipliers, and allocations are jointly determined. For the complete system of equations that determines $\gamma^L_{n,j}$, see A.76 in Online Appendix H.3

Discussions Here we present two discussions: (1) the distinction between the two-country and multi-country frameworks, and (2) the robustness of our main mechanism.

In a multi-country world, a tariff imposed on one foreign country's goods affects equilibrium wages across all countries, thereby affecting both the demand and supply of all countries. When formulating optimal policy for a particular sector, the Home government must therefore consider its impact across all other sectors and countries. As a result, optimal policies across sectors and countries have significant interdependency. Such an interdependency across countries is absent in a two-country model.

Another distinction between two-country and multi-country cases is that in a two-country context, one country's net exports in a sector must be the other country's net imports. However, in multi-country cases, both Home and Foreign can simultaneously be net exporters to third countries within the same sector. This 'third-country effect' generates distinct implications for optimal policies when comparing different countries' unilateral policies.

In the two-country case, only one country has an incentive to levy a tariff in a given sector. In contrast, in multi-country scenarios, both Home and Foreign may be net exporters of certain goods, and both countries would favor high tariffs in those sectors under unilateral policies. Numerical examples in Online Appendix J demonstrate this third-country effect.

It's worth emphasizing that the main mechanism—whereby optimal trade and innovation policies are employed to influence a foreign nation's innovation efforts—is robust to a range of extensions, including those with varying returns to scale in innovation. In Online Appendix L, we explore a case with decreasing return to scale in innovation. The gap between the private and social return for innovation justifies industrial policies that subsidize or tax innovation when there are externalities. However, there are also nontrivial interactions between industrial policies and heterogeneous trade policies. For example, if all sectors and countries have the same decreasing returns to scale in innovation, and both Home and Foreign use innovation tax to correct these externalities at the steady state, Markov policy will still employ additional innovation policies. Ramsey policy can simply use a constant innovation tax to target domestic externality and use a path of trade policies for terms of trade. But without commitment, Home resorts to additional innovation policies to change future marginal innovation costs across sectors in Foreign.

Thus, our Markov results contrast with optimal policy in the static models[14] where industrial policies are employed exclusively to address domestic inefficiencies or wedges. For our dynamic optimal policies, even at the steady state, there are future periods, and whether Home can commit to future policy matters. Furthermore, we find that a Markov government also uses innovation policies for terms of trade consideration, even when the economiy has reached steady state.

[14] Bartelme, Costinot, Donaldson, and Rodriguez-Clare (2025) characterize optimal policy for a small open economy in a multi-sector Ricardian model with Marshallian externalities. Lashkaripour and Lugovskyy (2023) study optimal industry and trade policy with scale economies.

5 Conclusion

Our intention in this paper has been to examine optimal policies for countries when technologies are endogenous through innovation. The question can be fully answered only by examining a dynamic model that incorporates multiple goods in a multi-region world economy. Two important motives for governments—a dynamic manipulation of foreign technology and an intra-period terms of trade effect–underlie optimal policies. Markov optimal policies of a country invoke innovation and trade policies, even when private innovation allocations are efficient. Innovation policies can be used to manipulate the benefits and costs of foreign innovation investment in the absence of commitment. In contrast to the Markov government, Ramsey optimal policies are able to avoid deploying innovation policies that distort their own innovation investment by using committed trade policies (heterogeneous export taxes and tariffs across sectors and over time).

Our model yields explicit expressions for optimal policies and more general results, which make the mechanisms transparent. These results stand in sharp contrast to the standard models with exogenous technology, where optimal policies call for uniform tariffs across sectors. Future work can take up an analysis of a more quantitative nature, engage with other models of technology competition, or explore various state-of-the-art developments in trade theory.

Data Availability

Code replicating the figures in this article can be found in Bai, Jin, and Lu (2025) in the Harvard Dataverse, https://doi.org/10.7910/DVN/RKQLX6.

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