



# 1 Introduction

The effect of competition from foreign firms on domestic firms and industries has been a recurring theme surrounding industrial policy. Why should countries respond to increasing foreign competition? What is the scope for domestic innovation policy? To shed light on these questions, we present and quantitatively analyze a new open-economy endogenous growth model that centers on the relationship between foreign competition and firms' innovation incentives. We analyze the impact of globalization, both in the form of foreign technological catch-up and an increase in trade openness, on the scope for domestic innovation policy, unveiling new links between globalization and the key market distortions motivating policy intervention. We apply this framework to evaluate a historical example—namely, the Research and Experimentation Tax Credit introduced in 1981 in the United States. Drawing on counterfactual experiments, we also compare trade and innovation policies as alternative responses to stronger foreign competition. Our analysis highlights an important takeaway: damping competitive pressures on domestic firms through heightened trade barriers instead of supporting their productive investments in the face of increased foreign competition distorts firms' innovation incentives and harms aggregate productivity growth and welfare.

Recent anecdotes underline the prominence of the main subject of analysis. Concerned with the United States losing its security and competitiveness to other major economic players in the world, the previous U.S. Administration raised barriers to international trade imposing tariffs on certain imports, against which Chinese authorities retaliated quickly. Similar concerns were also prevalent four decades ago following the exposure of the United States to a remarkable convergence by advanced countries such as Japan, Germany, and France, in terms of technology and productivity (Figure 1). Causing utmost concern in U.S. policy circles, this development led the Ronald Reagan Administration to adopt wide-ranging policies, which, as opposed to the recent focus on protectionist policies, introduced a research and development (R&D) tax credit scheme in 1981 for the first time in U.S. history.<sup>1</sup> Part

---

<sup>1</sup>In his first term, Ronald Reagan passed some protectionist measures but, at the same time, implemented policies to open borders. In his second term, his trade policy agenda had shifted drastically away from protectionism (Irwin, 2017).

of a broader set of industrial policies aimed at improving the competitiveness and innovativeness of U.S. firms, these subsidies lasted for the full length of Reagan's administration and beyond (Mowery and Rosenberg, 1993).<sup>2</sup>

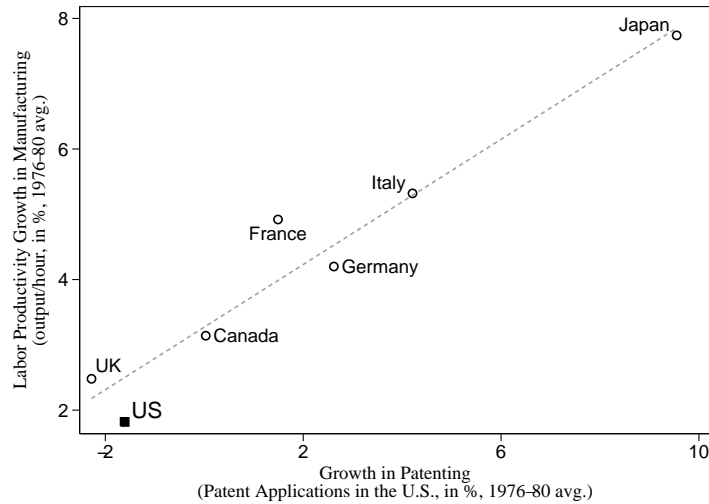


Figure 1: Convergence between the United States and its peers

Notes: The figure shows the relationship between growth of average labor productivity in the manufacturing sector and growth in the number of patent applications for the United States and its major trading partners between 1976 and 1980. We obtain data on patent applications in the United States from the USPTO and on international productivity comparisons from Capdevielle and Alvarez (1981).

Influenced by this recurring policy debate, we examine the nexus of foreign competition, economic growth, and the role of policy. A new set of empirical facts motivates our analysis and guides the model construction. As illustrated in Figure 1, the United States performed poorly relative to its main competitors in terms of labor productivity and innovation in the second half of the 1970s, with the labor productivity growth in manufacturing lagging behind peers (Capdevielle and Alvarez, 1981). Moreover, foreign innovation, proxied by new patent applications registered in the United States by the residents of these foreign countries, expanded substantially except for the United Kingdom. The United States held 70 percent of the patent applications registered in the U.S. in 1975, 10 years later this share declined

<sup>2</sup>Similar measures included the reinforcement of the protection of intellectual property rights, the promotion of the transfer of military technologies to commercial applications, and the extension of procurement contracts by agencies from NASA to the Department of Defense, aimed at creating markets of an appropriate size to encourage firms to make risky innovation investments.

to around 55 percent (see Online Appendix A.1 for additional details).<sup>3</sup>

Concerns over U.S. competitiveness back then led to the introduction of a set of demand- and supply-side policies explicitly targeting incentives for innovation. One of those incentives was the federal R&D tax credits enacted in 1981. Starting in 1982 with Minnesota, several states followed suit by introducing state-level R&D tax credits (Figure 2a). Subsequently, aggregate R&D intensity of U.S. public firms increased dramatically (the blue line in Figure 2a).<sup>4</sup> With an expected delay, the annual share of patents registered by U.S. residents in total patent applications increased as well, as denoted by the orange line in the same figure. By contrast, there was no significant action in R&D policies for the other major countries (Figure 2b).

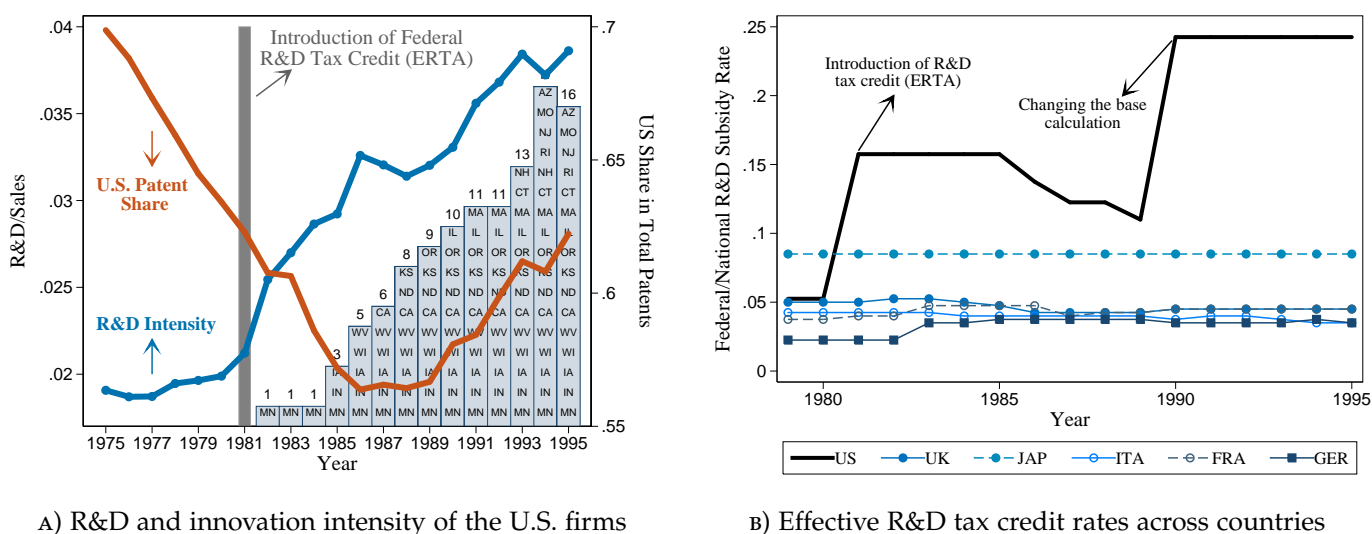


Figure 2: Tax Credits in the U.S. and Other Major Economies

Notes: Panel A shows the evolution of aggregate R&D intensity (the ratio of total R&D spending over total sales) of public U.S. firms in the Compustat database and the share of patents registered by U.S. residents in total patents registered in the USPTO database from 1975 to 1995. The ratios are calculated annually. The bars show the total number of U.S. states with a provision of R&D tax credits and their names for every year since the first adoption of such a measure in 1982. Panel B depicts effective R&D subsidy rates in the United States and its major trading partners from 1979 to 1995 (unavailable for Canada). R&D subsidies are calculated using corporate tax data from Bloom et al. (2002), who take into account different tax and credit systems. The subsidies reflect key features of the tax system aimed at reducing the cost of R&D, particularly depreciation allowances and tax credits for R&D expenditures—the reason why the subsidy measure has a positive value initially.

To analyze the economic processes presented above, we build a two-country

<sup>3</sup>Similar trends are found in countries' share of global R&D at the sectoral level (see Impullitti, 2010). For a historical account of the dynamics of the U.S. technological leadership and the Japanese and European convergence, see Nelson (1990).

<sup>4</sup>Sales and R&D expenditures of U.S. public firms are obtained from the Compustat database.

framework featuring innovation-driven growth and technological convergence. Our framework builds on the step-by-step innovation models of Schumpeterian creative destruction, which allow for strategic interaction among firms competing globally. The key driver of innovation in the closed-economy step-by-step framework is the *escape-competition effect*, which refers to the incentive of the leading firms to move away from the followers in order to escape competition. One novel implication of our open-economy model is that two such effects arise in a similar spirit. In each product line, domestic and foreign firms compete in quality for market leadership investing in innovation. Consequently, innovation generates a ranking of the product lines based on the quality difference between the home firm and the foreign firm. Trade costs generate quality cutoffs that partition the product space into exporting and non-exporting firms, and export status is regulated by firms' productivity relative to their foreign competitors. In addition, as in the standard Ricardian model, the presence of variable trade costs (iceberg and tariffs) regulates the set of non-traded goods between the two cutoffs. But different from the standard framework, comparative advantage is endogenous and influenced by quality-improving innovation.

The key feature of the two cutoffs is that innovation efforts intensify around them due to increased competition. Just below the import cutoff, firms exert additional effort to gain their leadership and begin to sell in the domestic market; hence, we name it the *defensive R&D* effort. Likewise, when a firm just below the export cutoff exerts additional effort to improve its lead and conquer the foreign market, we call this effort the *expansionary R&D* effort. These two new effects generate a double-peaked R&D effort distribution over the relative quality space that, remarkably, is also supported in the USPTO patent data. The distinction between defensive and expansionary R&D is crucial in shaping the effects of alternative industrial policies.

Countries differ in their policy choices in addition to R&D efficiencies. Moreover, for historical reasons, there is an initial technology gap that skews the distribution of technology and market leadership in favor of a country. Decreasing returns to R&D drives cross-country convergence in leadership along the transition to the steady state. Countries' incentives to subsidize or tax R&D depend on various key externalities. The presence of *intertemporal knowledge spillovers* implies that current innovators do not internalize the benefit of their success for future innovators, causing an

underinvestment in innovation, and providing a motive for subsidies. By contrast, the *business-stealing effect* typically motivates a tax on innovation as successful innovation by national entrants steal the business and profits of national incumbents, weighing on their innovation incentives. Different than the typical step-by-step innovation framework in closed economies, an incumbent's innovation does not steal the business of the other domestic incumbent, as the rival is from another country in our open-economy setting. But domestic incumbents can steal markets from foreign rivals, which expands their market size as well as that of the prospective domestic entrants, adding to innovation externalities not internalized by incumbent firms.

We parameterize the model to match key trade, innovation, and growth facts in the late 1970s. The implied transitional dynamics reproduces the convergence in technological leadership observed in the patent data during the 1970s and early 1980s, with the United States initially representing the frontier in most sectors, while a set of European countries plus Japan lag behind. After validating main mechanisms with multiple out-of-sample tests, we simulate the model beyond the calibration period and show that, in the absence of policy interventions, the significant deterioration in the positions of U.S. firms in international technological competition would have sustained, with profits of U.S. firms shifting to foreign rivals.

In regard to policy evaluation, we first feed into the model the increase in R&D subsidies observed in the U.S. in the early 1980s and assess its welfare implications over the period of intensifying foreign competition. The average effective U.S. R&D subsidy increases from about 5 percent in the 1970s to approximately 19 percent in the post-1981 period. This increase generates small losses in the short to medium run and substantial gains in the long run. The losses are due essentially to the cost of the subsidy. The gains stem from stimulating U.S. innovation and accelerating productivity growth. In addition, the resulting acceleration of U.S. firms' product quality improvements boosts their competitiveness, helping firms recoup global leadership, thereby shifting profits back home. Over the three decades following the subsidy increase, there is 0.36 percent consumption equivalent welfare gain per year, driven by profit shifting and especially by innovation-induced productivity growth.

Next, we consider a counterfactual scenario where, in the period of growing foreign competition, the U.S. raises import tariffs instead of introducing the sub-

sidy to R&D. This has the benefit of taming the profit shifting caused by foreign technological catch-up, but this benefit is overturned by mainly two counteracting forces. First, the replacement of better-quality imported goods with inferior domestic counterparts affects aggregate domestic productivity adversely. Second, protective measures—helping domestic firms retain their market more easily—reduce domestic firms’ innovation rates in import-competing sectors and, as such, weigh on productivity growth. As time goes by, this force becomes more dominant and leads to substantial drops in welfare.

The optimal policy analysis reveals that the optimal R&D subsidy is increasing with the horizon of the policy maker, as subsidies’ benefits in terms of higher product quality levels materialize over time. A key reason to subsidize R&D is intertemporal knowledge spillovers, which play a stronger role the longer the policy horizon under consideration becomes. Indeed, we find that the optimal subsidy rate is substantially higher than the observed change if the horizon in consideration is about three decades.

A novel insight from the quantitative analysis is that the optimal R&D subsidy is decreasing in trade openness (lower bilateral import tariffs). Foreign competition induces firms to increase their innovation effort to either protect their turf (defensive) or expand into export markets (expansionary). Around the two cutoffs the private incentive to innovate is stronger. Away from these cutoffs, conquering a market is harder, or keeping it is easier; therefore, firms are less motivated to innovate and the need for public support is stronger. In a more integrated global economy, the distance between these cutoffs decreases, exposing a larger set of firms to stiffer foreign competition, and these firms are stimulated to innovate more intensely. If the mass of these firms around the new cutoffs is large enough, a more liberal trade regime has a strong effect on aggregate innovation, thereby improving the alignment between private and public incentives to R&D and reducing the need for aggressive subsidies.<sup>5</sup> Considering the growing tendencies toward protectionism around the

---

<sup>5</sup>While the effect of trade liberalization on aggregate innovation and growth is positive in our benchmark calibration, our framework does not necessarily predict a positive relationship between trade liberalization and growth. The effect at the firm level is heterogeneous depending on the firm’s position in market competition relative to its rival. Therefore, the aggregate effect depends on the exact distribution of firms across technology gaps, which determine the degree of competition, as we showcase in Online Appendix G. With the help of this feature, the model also provides a suitable

world accompanied by generous national industrial policies, this result on the interdependence between R&D policy and trade openness becomes even more relevant. Higher trade barriers create dynamic losses through reduced competition and innovation incentives and thereby aggravate the burden to correct for those losses in the optimal way.

Finally, the optimal unilateral tariff is positive in the short horizon but quickly tapers as the policy horizon lengthens. Zero tariff is optimal for horizons longer than a decade.<sup>6</sup> As discussed above, trade protection slows productivity growth by weakening the incentives to innovate. The dynamic welfare losses from lower growth accumulate fast and more than offset the potential gains via terms of trade manipulation, relocation, and profit-shifting present in the model, which motivate unilateral tariff protection in static trade models. As such, our finding highlights the variation in optimal unilateral trade policy over different policy horizons depending on the evolution of dynamic gains. We also show that the joint optimal U.S. trade and innovation policy requires positive R&D subsidies, increasing in the policy horizon, and zero tariff at almost any horizon.

**Literature Review.** The endogenous technical change framework that we use as the backbone of our economy is a model of growth through step-by-step innovation (e.g., [Aghion et al., 2001, 2005](#); [Acemoglu and Akcigit, 2012](#); [Akcigit and Ates, 2023](#)). The strategic interaction among firms renders this framework particularly useful to study the nexus of competition and innovation. The existing applications are in closed economy and, except for [Akcigit and Ates \(2023\)](#), focus on the steady state and abstract from free entry. We propose the first open-economy version, add free entry, solve for the transition path, and perform policy analysis.

The paper is closely related to the literature on innovation policy and R&D subsidies in particular. A recent survey by [Bloom et al. \(2019\)](#) suggests large positive gaps between social and private returns to R&D, justifying government intervention. Recent work in quantitative growth theory provides an evaluation of the impact of innovation policy on growth and welfare (e.g., [Acemoglu et al., 2018](#); [Akcigit et al.,](#)

---

setting to analyze the impact of import penetration on domestic innovation and can reconcile some divergent empirical observations documented in recent prominent studies (see [Autor et al., 2016](#) and [Bloom et al., 2016](#), among others).

<sup>6</sup>If the policy set includes negative rates, an import subsidy becomes optimal for longer horizons.

2021; Atkeson and Burstein, 2019). We contribute to this work by analyzing the impact of globalization on the effectiveness and optimality of innovation subsidies.

On the rich links between trade, innovation and productivity growth, the pioneering contributions of Grossman and Helpman (1990) and Rivera-Batiz and Romer (1991) inspired a large body of literature (e.g., Eaton and Kortum, 1999, 2001; Impullitti and Licandro, 2018; Somale, 2021; Santacreu, 2021; Cai et al., 2022; Sampson, 2023).<sup>7</sup> The specific contribution of our open-economy step-by-step model is that, different from existing models, the effect of trade on innovation and growth can be non-monotonic. As such, our framework provides a more flexible ground for the quantitative analysis of changes in foreign competition, with both the sign and the size of the effect of trade on growth potentially disciplined by the data.

Finally, our analysis of import tariffs contributes to the optimal trade policy literature. To the best of our knowledge, this is the first paper studying optimal trade policy in an endogenous growth framework. Our model encompasses all distortions justifying a positive optimal tariff in standard trade models—terms of trade manipulation (e.g., Gross, 1987), relocation effects (e.g., Ossa, 2011), and profit shifting (e.g., Ossa, 2012)—but another dynamic distortion proves dominant. Tariff protection produces large welfare losses via its discouraging effects on innovation and productivity growth. This growth channel dominates and justifies a zero optimal unilateral tariff.

In the remainder of the paper, Section 2 introduces the theoretical framework. Section 3 outlines the calibration procedure and provides out-of-sample tests. Section 4 discusses policy implications and optimal policies. Section 5 concludes.

## 2 Model

We present a two-country growth model where each country, indexed by  $c \in \{A, B\}$ , has access to the same final-good production technology. There is a continuum of intermediate goods indexed by  $j \in [0, 1]$  used in final-good production. There is no

---

<sup>7</sup>In a related study featuring a multi-country framework of innovation and adoption, Sampson (2023) analyzes the role of heterogeneous R&D efficiencies and knowledge spillovers across countries and industries in shaping global technological gaps and wage inequality. See also Buera and Oberfield (2020), Perla et al. (2021), and Sampson (2016). Melitz and Redding (2021) and Akcigit and Melitz (2021) provide extensive recent surveys.

trade in assets, which rules out international borrowing and lending and enables the two countries to grow at different rates during the transition.

In each intermediate-good sector there are two active firms—one from each country—competing in quality to obtain market leadership. Firms innovate by investing resources to improve the quality of their product. If the quality difference between the products of two firms is large enough, the firm with the leading technology can cover the trade cost and export to the foreign country. Trade is costly due to a combination of iceberg costs and tariffs. Firms' export status is also determined by the labor cost, which, in our asymmetric country setting, differs across countries. Hence, trade is shaped by both Schumpeterian and Ricardian forces. In addition to incumbents, there is an outside pool of entrant firms engaging in research activity to replace the domestic incumbent in a particular product line.

## 2.1 Fundamentals

**Preferences.** Both countries admit a representative household with CRRA utility:

$$U_t = \int_t^\infty \exp(-\rho(s-t)) \frac{C_{cs}^{1-\psi} - 1}{1-\psi} ds. \quad (1)$$

$C_{ct}$  is consumption at time  $t$  in country  $c$ ,  $\psi$  is the curvature parameter, and  $\rho > 0$  is the discount rate. The budget constraint of a representative household is

$$r_{ct}A_{ct} + L_c w_{ct} + F_c f_{ct} = P_{ct}C_{ct} + \dot{A}_{ct} + G_{ct}, \quad (2)$$

where  $L_c$  is labor that is supplied inelastically for intermediate-good production,  $F_c$  is the fixed factor (e.g., land) in country  $c$ , and  $G_{ct}$  is the lump-sum taxes/transfers that stem from revenues/losses associated with government policy on innovation and trade.<sup>8</sup> The associated prices are  $r_{ct}$ , the return to asset holdings of the household,  $w_{ct}$ , the wage level,  $f_{ct}$ , the fixed factor income, and  $P_{ct}$ , the price of the consumption good in country  $c$ . Households in country  $c$  own all the firms in the country; therefore, the asset market clearing condition requires that the asset holdings have to be equal to the sum of firm values  $A_{ct} = \int_0^1 (\tilde{V}_{cjt} + V_{cjt}) dj$ , where tilde “~” denotes

---

<sup>8</sup> $F_c$  pins down the economy's scale ensuring constant returns to scale in final-good production.

values pertaining to entrant firms. We assume full home bias in asset holding, which is robustly supported by the empirical evidence in the 1980s and 1990s.<sup>9</sup>

**Technology and Market Structure.** The final good, used for consumption and as R&D input, is produced in perfectly competitive markets in both countries:

$$Y_{ct} = \frac{F_c^\beta}{1-\beta} \int_0^1 \left( q_{Ajt}^{\frac{\beta}{1-\beta}} k_{Ajt} + q_{Bjt}^{\frac{\beta}{1-\beta}} k_{Bjt} \right)^{1-\beta} dj. \quad (3)$$

Here,  $k_j$  refers to the intermediate good  $j \in [0, 1]$ ,  $q_j$  is the quality of  $k_j$ , and  $\beta$  is the share of fixed factor in total output. Intermediate goods can be obtained from any country, whereas the fixed factor  $F_c$  is assumed to be immobile across countries. We normalize the supply of the fixed factor  $F_c = 1$  in both countries.

Firms in both countries may produce each variety  $j$ . In the absence of trade frictions, varieties are perfect substitutes in the final-good production, once adjusted for their qualities. As a result, final-good producers will choose to buy their inputs from the firm that offers a higher quality (after adjusting for relative prices). When trade costs exist, final-goods producers buy the intermediate good of higher quality, once the prices are adjusted to reflect the trade costs.<sup>10</sup> Both countries produce the same identical final good, which under the assumption of frictionless trade in final goods, implies that the price of the final output in both countries is the same.<sup>11</sup> We normalize that price to be the numeraire without any loss of generality.

Each intermediate good  $j$  can be produced by two incumbent firms—one from each country—competing for the market leadership à la Bertrand. Operating under a linear production technology, these firms produce differentiated varieties employing domestic labor:

---

<sup>9</sup>In 1989, 92 percent of the U.S. stock market was held by U.S. residents. Japan, the U.K., France, and Germany show similar patterns, at 96 percent, 92 percent 89 percent, and 79 percent, respectively. A similar picture can be observed until the early 2000s, when the home bias started to decline (see, for example, [Coerdacier and Rey, 2013](#)).

<sup>10</sup>The intermediate-goods prices from the two countries may differ also due to relative labor costs.

<sup>11</sup>An alternative is to assume no trade in final good with the additional equilibrium condition that aggregate trade in intermediate goods is balanced, which would determine the relative prices of final goods. But that would bring additional computational burden without much further insight for the core of our analysis, which focuses on the link between economic growth and trade openness.

$$k_{cjt} = \frac{\bar{q}_{ct}}{\eta} l_{cjt}, \quad (4)$$

where  $\eta$  is a constant and  $\bar{q}_{ct}$  is the country-specific labor productivity, which depends on the domestic technology frontier, whose endogenous dynamics will be introduced later. As such, an important difference between these firms is their marginal costs of production stemming from differences in productivity and aggregate wages. Firms can sell their goods both domestically and abroad. Exports are subject to iceberg trade cost  $\kappa \geq 0$  and foreign import tariffs  $\tau^c$ .

The second major difference between competing firms is the quality of their output, denoted by  $q_{cjt}$ . A firm in country  $A$  is *the technological leader* in industry  $j$  if  $q_{Ajt} > q_{Bjt}$  and *the technological follower* if  $q_{Ajt} < q_{Bjt}$ . Firms are in a *neck-and-neck* position when  $q_{Ajt} = q_{Bjt}$ . Quality  $q_{Ajt}$  improves chiefly through successive innovations in  $A$  (or through limited spillovers from  $B$ ), which we detail later. Upon an improvement in country  $c$  specific to product line  $j$  during an interval of time  $\Delta t$ , the quality increases proportionally such that  $q_{cj(t+\Delta t)} = \lambda^{n_t} q_{cjt}$ , where  $\lambda > 1$  and  $n_t \in \mathbb{N}$  is a random variable, which will be specified below. We initialize  $q_{cj0} = 1$ ,  $\forall j \in [0, 1]$ .

Let us denote by  $N_t = \int_0^t n_s ds$  the number of quality jumps up to time  $t$ . Hence, the quality of a firm at time  $t$  is  $q_{cjt} = \lambda^{N_{cjt}}$ . The relative state of a firm with respect to its foreign competitor is called the technology gap between two countries (in the particular product line) and can be summarized by the integer  $m_{Ajt} \in \mathbb{N}$  such that

$$\frac{q_{Ajt}}{q_{Bjt}} = \frac{\lambda^{N_{Ajt}}}{\lambda^{N_{Bjt}}} = \lambda^{N_{Ajt} - N_{Bjt}} \equiv \lambda^{m_{Ajt}}.$$

As we shall see,  $m_{cjt}$  conveys all the line-specific information relevant to the firm values, and we will therefore drop the subscript  $j$  when a line-specific value is denoted by  $m$ . We assume that at a sufficiently large but exogenously determined technology gap,  $\bar{m}$ , whenever the leader innovates, the follower learns about the frontier technology partially by the same magnitude. This limited occurrence of international spillovers ensures that the gap between two firms is bounded and never exceeds  $\bar{m}$ , making the state space finite. Thus, the gap that can separate two firms is such that

$$m_{ct} \in \{-\bar{m}, \dots, 0, \dots, \bar{m}\}.$$

Firms invest in R&D in order to obtain market leadership through improving the quality of their products. Let  $R_{cj}^d$  and  $x_{cj}$  denote the amount of R&D investment in terms of final output and the resulting Poisson arrival rate of innovation by country  $c$  in  $j$ , respectively. The production function of innovations takes the following form:  $x_{cjt} = \left( \gamma_c R_{cjt}^d / (\alpha_c q_{cjt}) \right)^{1/\gamma_c}$ . Note that  $q_{cjt}$  in the denominator captures the fact that a quality is more costly to improve if it is more advanced. The implied convex cost of generating  $x_{cjt}$  takes the form  $R^d(x_{cjt}, q_{cjt}) = q_{cjt} \frac{\alpha_c}{\gamma_c} x_{cjt}^{\gamma_c}$ .

Every period, a new entrepreneur in each product line and from each country invests in innovation to enter the market. If an entrepreneur succeeds in her attempt, the entrant firm replaces the domestic incumbent; otherwise, the firm disappears. The innovation technology for entrants is  $\tilde{x}_{cjt} = \left( \tilde{\gamma}_c \tilde{R}_{cjt}^d / (\tilde{\alpha}_c q_{cjt}) \right)^{1/\tilde{\gamma}_c}$ , which implies the following convex cost function:  $\tilde{R}^d(\tilde{x}_{cjt}, q_{cjt}) = q_{cjt} \frac{\tilde{\alpha}_c}{\tilde{\gamma}_c} \tilde{x}_{cjt}^{\tilde{\gamma}_c}$ .

Each innovation improves the relative position of the firm in the technological competition. Conditional on innovation, the new position at which the firm will end up is determined randomly by a certain probability mass distribution  $\mathbb{F}_m(\cdot)$ .<sup>12</sup> Because the maximum number of gaps is capped by  $\bar{m}$ , there is a different number of potential gaps that each firm may reach depending on its current position in the technological competition. For instance, if a firm is leading by 10 gaps, with a single innovation it can potentially open up the advantage to  $\{11, \dots, \bar{m}\}$ , whereas for a neck-and-neck firm, an innovation can help it reach  $\{1, \dots, \bar{m}\}$ . Hence, the probability mass function that determines the new position,  $\mathbb{F}_m(\cdot)$ , is a function of  $m$ .

In order to maintain the model's parsimony, we assume there exists a fixed given distribution  $\mathbb{F}(\cdot)$ , and we derive  $\mathbb{F}_m(\cdot)$  from this distribution in the following way. First, we define the benchmark distribution over positions larger than  $-\bar{m}$ , the most laggard position (Figure 3a). We assume that it has the following functional form:  $\mathbb{F}(n) \equiv c_0 (n + \bar{m})^{-\phi} \quad \forall n \in \{-\bar{m} + 1, \dots, \bar{m}\}$ . This parametric structure is defined by only two parameters: a curvature parameter  $\phi > 0$ , and a shifter  $c_0$  that ensures  $\sum_n \mathbb{F}(n) = 1$ . It implies a decaying probability in the new position  $n$ . As such, the probability that an innovation generates larger technological jumps is lower.

---

<sup>12</sup>Conversely, innovations come with a random size drawn from some probability mass function.

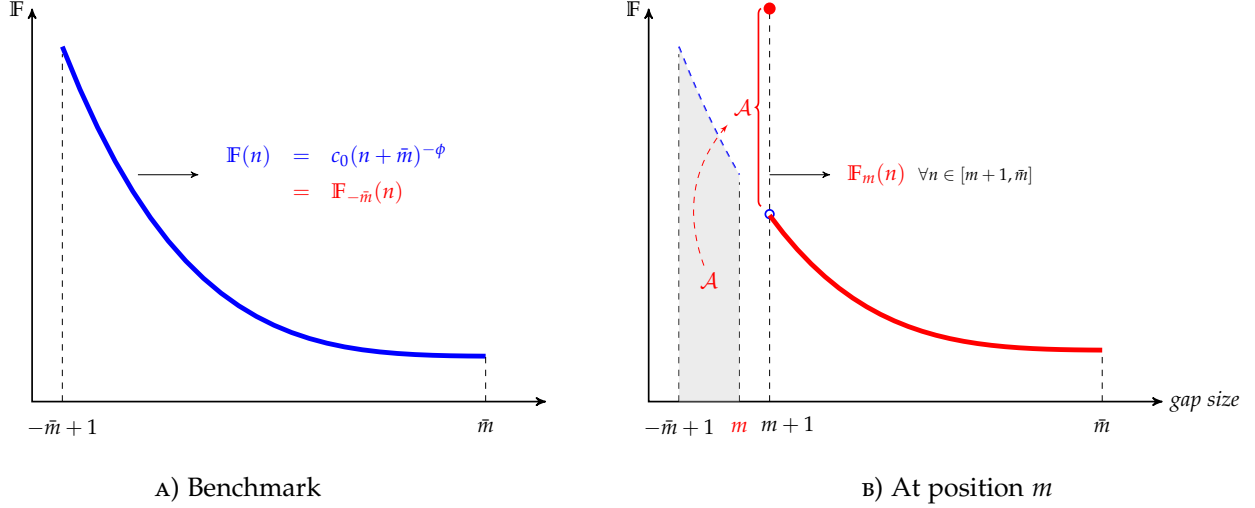


Figure 3: Probability mass function for new position

Notes: Panel A illustrates the function  $\mathbb{F}(\cdot)$ , which we use to generate the position-dependent distributions of innovation size. Thus, it describes also the probability distribution over potential positions, where an innovation can take the most laggard incumbent, denoted by  $\mathbb{F}_{\bar{m}}(\cdot)$ . Similarly, Panel B illustrates  $\mathbb{F}_m(\cdot)$  for a generic position  $m$ .

The highest gap size a firm can reach is  $\bar{m}$ . The step size distribution specific to the firm's position,  $\mathbb{F}_m(\cdot)$ , is defined over positions  $n \in \{m+1, \dots, \bar{m}\}$  as follows:

$$\mathbb{F}_m(n) = \begin{cases} \mathbb{F}(m+1) + \mathcal{A}(m) & \text{for } n = m+1 \\ \mathbb{F}(s) & \text{for } n \in \{m+2, \dots, \bar{m}\} \end{cases} . \quad (5)$$

As Figure 3b shows,  $\mathcal{A}(m) \equiv \sum_{s=-\bar{m}+1}^m \mathbb{F}(s)$  is an additional probability of improving the current quality only one more step, on top of what  $\mathbb{F}(\cdot)$  would imply for that event, which is given by  $\mathbb{F}(m+1)$ . This specification for position-specific distributions implies that, as firms become technologically more advanced relative to their competitors, it is relatively harder to open up the gap more than one step at a time. Moreover, their derivation comes at no additional cost in terms of parameters thanks to the additive nature of  $\mathcal{A}$ . Finally, notice that  $\mathbb{F}_{-\bar{m}}(n) = \mathbb{F}(n)$ .

This particular modeling of innovation step sizes is quantitatively oriented. As examined in Section 3.1, the empirical distribution of leadership shares is dominated by the United States in the early years of our sample, with this U.S. lead diminishing at a certain pace in subsequent years, highlighting the observed technological convergence by foreign firms. Ideally, we would like our calibrated economy to mimic

this pace of technological convergence between U.S. and foreign firms. In standard step-by-step models in a closed economy, each innovation improves the existing quality of the follower either by a single step or by a full jump that makes the follower exactly catch up with the leader independent of the initial gap. The former is dubbed “slow catch-up regime,” while the latter is dubbed “quick catch-up regime” in [Acemoglu and Akcigit \(2012\)](#). A slow catch-up regime would imply a more protracted convergence in leadership shares than that observed in the data, while the quick catch-up regime would result in too quick of a convergence. By incorporating  $\mathbb{F}(n)$ , we generalize the modeling of firms’ catch up dynamics and equip the model with enough flexibility to replicate the convergence process observed in the data. Note that this specification converges to the standard step-by-step model as  $\phi \rightarrow \infty$ .

The treatment of  $\mathcal{A}(m)$  in the derivation of position-specific distributions serves the same purpose while maintaining the parsimony and tractability of the model. For instance, we could alternatively assume equal distribution of the truncated probability mass  $\mathcal{A}(m)$  across potential positions  $\{m + 1, \dots, \bar{m}\}$ . This alternative would imply a relatively fatter right tail in  $\mathbb{F}_m(n)$  and, thus, a higher chance of climbing up the position ladder. However, this structure would favor the United States, most of whose firms are technological leaders in their products, as opposed to the foreign countries, whose firms are lagging in most product lines. Even though a laggard firm can close the gap by multiple steps, a leading firm in this alternative setup could easily open up the gap again.<sup>13</sup> Then, the model, once initiated at the empirical distribution with an initial U.S. lead, on average, would have a strong force working against producing a fast enough convergence as observed in the data. By contrast, our current structure with innovations of heterogeneous step sizes helps the model generate the correct speed of convergence as in the data, while the distributional assumptions capture the idea of “advantage of backwardness” as in [Gerschenkron \(1962\)](#), with relatively more laggard firms being in a more advantageous position to receive multiple-step innovations.

---

<sup>13</sup>Another alternative we entertained is  $\mathbb{F}_m(n) = c_0 m n^{-\phi} \forall n \in \{m + 1, \dots, \bar{m}\}$  for any  $m < \bar{m}$ . Such alternatives produce a counterfactually large mass for leading U.S. firms over time, because firms with large leads still draw a multi-step innovation with a considerably high chance. By contrast, the current structure implies that the probability of one-step improvements becomes disproportionately higher at larger leads, as implied by the accumulation of  $\mathcal{A}(m)$ .

During a small time interval  $\Delta t \rightarrow 0$ , the resulting law of motion for the quality level of an incumbent from  $A$  that operates in product line  $j$  can be summarized as follows. For  $m > -\bar{m}$  the law of motion becomes

$$q_{Aj(t+\Delta t)} = \begin{cases} \lambda^n q_{Ajt} \text{ w.p. } (x_{Ajt} + \tilde{x}_{Ajt}) \mathbb{F}_m(n) \Delta t + o(\Delta t) & \text{for } n \in \{m+1, \dots, \bar{m}\} \\ q_{Ajt} \text{ w.p. } 1 - (x_{Ajt} + \tilde{x}_{Ajt}) \mathbb{F}_m(n) \Delta t + o(\Delta t) & \end{cases},$$

and for  $m = -\bar{m}$  the law of motion follows

$$q_{Aj(t+\Delta t)} = \begin{cases} \lambda^n q_{Ajt} \text{ w.p. } (x_{Ajt} + \tilde{x}_{Ajt}) \mathbb{F}_{-\bar{m}}(n) \Delta t + o(\Delta t) & \text{for } n \in \{-\bar{m}+1, \dots, 2\bar{m}\} \\ q_{Ajt} \text{ w.p. } 1 - (x_{Ajt} + \tilde{x}_{Ajt}) \mathbb{F}_{-\bar{m}}(n) \Delta t + o(\Delta t) & \\ \lambda q_{Ajt} \text{ w.p. } (x_{Bjt} + \tilde{x}_{Bjt}) \mathbb{F}_m(n) \Delta t + o(\Delta t) & \end{cases},$$

where  $o(\Delta t)$  denotes the second-order terms. In a product line where the incumbent from  $A$  is in position  $m$ , the quality improves when either the domestic incumbent or entrant innovates. Moreover, the quality in a product line where the firm from  $A$  is at the highest possible lag  $-\bar{m}$  improves not only with innovations by the domestic incumbent and entrant, but also with those by the foreign incumbent or entrant. When the leader at gap  $\bar{m}$  innovates, the technology at  $-\bar{m}+1$  becomes freely available to the follower in this product line.

## 2.2 Equilibrium

In this section, we solve for the Markov Perfect Equilibrium of the model where the strategies are functions of the payoff relevant state variable  $m$ . We start with the static equilibrium. Then we build up the value functions for the intermediate producers and entrants and derive their closed form solutions along with the R&D decisions. These variables help us characterize the evolution of the world economy over time. Henceforth, we will drop the time index  $t$  unless it causes confusion and denote export-related variables by an asterisk.

**Static Equilibrium and Trade Flows.** The production function (3) implies standard demand schedules of the final-good producers for intermediate good  $j \in [0, 1]$  and the fixed factor  $F_c$  as

$$p_{cjt} = F_c^\beta q_{cjt}^{\frac{\beta}{1-\beta}} \left( q_{Ajt}^{\frac{\beta}{1-\beta}} k_{Ajt} + q_{Bjt}^{\frac{\beta}{1-\beta}} k_{Bjt} \right)^{-\beta} \quad \text{and} \quad f_{ct} = \beta(1-\beta)^{-1} F_c^{\beta-1} \left( q_{Ajt}^{\frac{\beta}{1-\beta}} k_{Ajt} + q_{Bjt}^{\frac{\beta}{1-\beta}} k_{Bjt} \right)^{1-\beta}. \quad (6)$$

In every product line, intermediate firms engage in Bertrand competition in both domestic and foreign markets given the demand by the respective final-good producers. In this Bertrand competition setting, the existence of a competitor with inferior quality—by definition, located in the foreign country—could potentially push the leader to limit pricing. The following assumption simplifies the analysis.

**Assumption 1** *In every product line, incumbents enter a two-stage game where each pays an arbitrarily small fee  $\varepsilon > 0$  in the first stage in order to bid prices in the second stage.*

Assumption 1 ensures that only the incumbent with the highest cost-adjusted quality finds it profitable to pay the fee. Therefore, this incumbent becomes the sole producer in the specific market, being able to set its price freely to the monopoly price in the second stage.<sup>14</sup>

A domestic firm that can secure the monopolist position in the home market based on its cost-adjusted technological advantage under Assumption 1 maximizes its profits according to<sup>15</sup>

$$\pi(q_{jt}) = \max_{k_{jt} \geq 0} \left\{ F_c^\beta q_{jt}^\beta k_{jt}^{1-\beta} - \frac{\eta}{\bar{q}_{ct}} w_{ct} k_{jt} \right\} \quad \forall j \in [0, 1].$$

We denote the wage rate relative to the productivity level as  $\bar{w}_{ct} = \frac{w_{ct}}{\bar{q}_{ct}}$ , which is an important object in determining prices, quantities, and terms of trade. The optimal quantity and price for variety  $j$  are derived as

---

<sup>14</sup>Our framework could accommodate a domestic follower affecting the price of the good sold domestically. Assumption 1 ensures that only the domestic firm with the best quality would pay the fee and become the sole producer domestically. Our analysis of a version with a non-innovative domestic copy-cat fringe that limits the price of the domestic leader indicates that policies replacing imports by monopolist foreign exporters to domestic firms would also alleviate monopoly distortions, providing an additional motive for policies such as tariffs. [Choi and Shim \(2024\)](#) extend this framework to include a domestic follower in their recent study of industrial policies in South Korea.

<sup>15</sup>The conditions that determine the exact technology gap advantage needed to secure the monopoly position are derived later.

$$k_{jt} = \left[ \frac{1-\beta}{\eta} \bar{w}_{ct}^{-1} \right]^{\frac{1}{\beta}} q_{jt} \quad \text{and} \quad p_j = \frac{\eta}{1-\beta} \bar{w}_{ct}, \quad (7)$$

with  $F_c$  set to 1. The price is a constant markup over the marginal cost and is independent of the individual product quality. Thus, the profit earned by selling an intermediate good domestically is  $\pi_{ct}(q_{jt}) = \pi \bar{w}_{ct}^{\frac{\beta-1}{\beta}} q_{jt}$ , where  $\pi \equiv \eta^{\frac{\beta-1}{\beta}} (1-\beta)^{\frac{1-\beta}{\beta}} \beta$ .

When exporting a good, firms need to consider the iceberg trade cost  $\kappa$  and the foreign tariff rate  $\tau^{c'}$ , which we model as a cost-shifter à la [Costinot and Rodríguez-Clare \(2014\)](#). The marginal cost of producing export goods is then equal to the cost of producing domestically sold goods scaled by  $(1+\kappa)(1+\tau^{c'})$ . The final-good producers' demand under [Assumption 1](#) implies that in a given product line, only the firm with high enough cost-adjusted quality to cover the trade costs will be able to penetrate the market in the other country. Similar derivations as in the case of domestic sales lead to the following optimal quantity, price and profits for exports:

$$k_{cjt}^* = \left[ \frac{1-\beta}{(1+\kappa)(1+\tau^{c'})\eta} \bar{w}_{ct}^{-1} \right]^{\frac{1}{\beta}} F_{c'} q_{cjt}; \quad p_{cj}^* = \frac{(1+\kappa)(1+\tau^{c'})\eta}{1-\beta} \bar{w}_{ct}; \quad \pi_{ct}^*(q_{jt}) = \pi_c^* \bar{w}_{ct}^{\frac{\beta-1}{\beta}} F_{c'} q_{cjt}; \quad (8)$$

with  $c \in \{A, B\}$ ,  $c \neq c'$ , and  $\pi_c^* = \left[ (1+\kappa)(1+\tau^{c'})\eta \right]^{\frac{\beta-1}{\beta}} (1-\beta)^{\frac{1-\beta}{\beta}} \beta$ .

Due to trade costs and differences in production costs, it is possible that an intermediate-goods firm that produces a higher-quality product compared to its foreign competitor cannot export, because the quality of its goods becomes lower than the foreign counterpart in cost-adjusted terms. As such, technological leadership and market leadership do not necessarily overlap; technological advantage alone is not enough to have a foothold in the foreign market. A firm from country  $A$  exports good  $j$  to country  $B$  if and only if

$$\frac{q_{Ajt}}{q_{Bjt}} \geq \left[ (1+\kappa)(1+\tau^B) \omega_{At} \right]^{\frac{1-\beta}{\beta}},$$

where  $\omega_{At} = \frac{\bar{w}_{At}}{\bar{w}_{Bt}}$  is the ratio of productivity-adjusted wages in both countries. This condition implies that the iceberg cost, foreign import tariff, and the productivity-adjusted relative wage all contribute to shape a country's comparative advantage. As

such, the Schumpeterian structure endogenizes Ricardian comparative advantage.

We denote by  $m_c^X$  the smallest technology gap by which a leader from country  $c \in \{A, B\}$  needs to lead its follower in order to be able to export its good. Then, to secure a quality advantage when selling abroad even after other costs are accounted for, the technology gap between a leader and its follower has to reach the threshold

$$m_{ct}^X \equiv \arg \min_m \left\{ m \in [0, \bar{m}] : \lambda^m \geq \left[ (1 + \kappa) (1 + \tau^{c'}) \omega_{ct} \right]^{\frac{1-\beta}{\beta}} \right\}. \quad (9)$$

Reciprocally, the cutoff for imports—conversely, the export cutoff for the foreign firms—is defined as

$$m_{ct}^M \equiv \arg \max_m \left\{ m \in [-\bar{m}, 0] : \lambda^m < \left[ (1 + \kappa) (1 + \tau^c) \omega_{ct}^{-1} \right]^{\frac{1-\beta}{\beta}} \right\}. \quad (10)$$

The cutoffs for exports and imports are almost always asymmetric—i.e.,  $m_{ct}^X \neq |m_{ct}^M|$  almost always holds.

Now we define the quality index of sectors where firms from country  $c$  are in state  $m$ . Denote the measure of product lines where firms from  $c$  are  $m$ -steps ahead by  $\mu_{cm}$ . Then, the aggregate quality across these product lines is given by  $Q_{cmt} \equiv \int q_{cjt} \mathbb{1}_{\{j \in \mu_{cm}\}} dj$ , with the domestic technology frontier—i.e., the average quality of goods that can be produced domestically—being defined as

$$Q_{ct} \equiv \int_0^1 q_{cjt} dj = \sum_{-\bar{m}}^{\bar{m}} Q_{cmt}. \quad (11)$$

Substituting equilibrium quantities as defined in equations (7) and (8) in equation (3), total output is given as

$$Y_{ct} = \sum_{m=m_{ct}^M+1}^{\bar{m}} \left[ \frac{1-\beta}{\eta} \bar{w}_{ct}^{-1} \right]^{\frac{1-\beta}{\beta}} \frac{Q_{cmt}}{1-\beta} + \sum_{m=-\bar{m}}^{m_{ct}^M} \left[ \frac{1-\beta}{(1+\kappa)(1+\tau^c)\eta} \bar{w}_{c't}^{-1} \right]^{\frac{1-\beta}{\beta}} \frac{Q_{c'mt}}{1-\beta}. \quad (12)$$

The first sum is the contribution of domestic intermediate goods. The second sum, which is across product lines where foreign exporters have a lead of at least  $|m_{ct}^M|$  gaps, denotes the contribution of imported goods. While trade in intermediate goods

may be in surplus or deficit, aggregate trade, accounting for the flows of both intermediate and final goods, is in balance at all times, sustained by adjustments in the relative prices  $w_{At}/w_{Bt}$  and  $f_{At}/f_{Bt}$ .

The wage rate follows from the labor market condition after recovering firms' optimal labor demand from equation (4):

$$1 = \frac{\eta}{\bar{q}_{ct}} \left[ \int \mathbb{I} \{ m > m_{ct}^M \} k_{cjt} dj + \int \mathbb{I} \{ m > m_{ct}^X \} (1 + \kappa) k_{cjt}^* dj \right] \Rightarrow$$

$$\bar{w}_{ct}^{\frac{1}{\beta}} = \frac{\eta}{\bar{q}_{ct}} \left[ \frac{1 - \beta}{\eta} \right]^{\frac{1}{\beta}} \underbrace{\left[ \sum_{m_{ct}^M}^{\bar{m}} Q_{cmt} + \Lambda \sum_{m_{ct}^X}^{\bar{m}} Q_{cmt} \right]}_{\equiv \Omega_{ct}} \Rightarrow \bar{w}_{ct} = \frac{1 - \beta}{\eta^{1 - \beta}} \left[ \frac{\Omega_{ct}}{Q_{ct}} \right]^{\beta}, \quad (13)$$

with  $\Lambda \equiv \left[ (1 + \kappa)^{1 - \beta} (1 + \tau^{c'}) \right]^{-\frac{1}{\beta}}$ . We assume that the domestic technology frontier determines the aggregate labor productivity in intermediate-goods production, such that  $\bar{q}_{ct} = Q_{ct}$ . The (inverse) ratio of this variable to  $\Omega_{ct}$ , which reflects the quality frontier of domestic firms that actually produce via a (trade) cost-weighted average, determines the wage rate. As a result, the wage rate pressure is lower in a technologically laggard country, which in turn helps the competitiveness of the firms in that country through lower unit costs.<sup>16</sup> Lastly, the final factor price to be determined is that of the fixed factor, which follows as  $f_{ct} = \beta Y_{ct}$ .

**Firm Values and Innovation.** We can write the value function for country  $A$ 's incumbents in the following way:

$$r_{At} V_{Amt}(q) - \dot{V}_{Amt}(q) = \max_{x_{Amt}} \left\{ \Pi_t(m; \tau^A, \tau^B) \bar{w}_{ct}^{\frac{\beta-1}{\beta}} q - (1 - s^A) \alpha_A \frac{(x_{Amt})^{\gamma_A}}{\gamma_A} q \right. \quad (14)$$

$$+ x_{Amt} \sum_{n_t=m+1}^{\bar{m}} \mathbb{F}_m(n_t) \left[ V_{Ant}(\lambda^{(n_t-m)} q) - V_{Amt}(q) \right] + \tilde{x}_{Amt} [0 - V_{Amt}(q)]$$

$$\left. + \left( x_{B(-m)t} + \tilde{x}_{B(-m)t} \right) \sum_{n_t=-m+1}^{\bar{m}} \mathbb{F}_{-m}(n_t) \left[ V_{A(-nt)}(q) - V_{Amt}(q) \right] \right\},$$

<sup>16</sup>The reason is that the more technologically laggard a country is, the less it produces, reducing  $\Omega_{ct}$  relative to  $Q_{ct}$ .

where the profit function  $\Pi(m; \tau^A, \tau^B)$  is defined as

$$\Pi_t(m; \tau^A, \tau^B) = \begin{cases} \pi F_A + \pi^* F_B & \text{if } m \geq m_{At}^X \\ \pi F_A & \text{if } m_{At}^X > m > m_{At}^M \\ 0 & \text{if } m \leq m_{At}^M \end{cases} .$$

and depends on both home and foreign import tariffs.<sup>17</sup> The flow value of the firm is discounted at the country-specific interest rate  $r_{ct} = g_{ct}\psi + \rho$ , which satisfies the Euler equation of the household problem, with  $g_{ct}$  denoting the aggregate growth rate in the country.

The first line on the right-hand side of equation (14) denotes the operating profits net of R&D costs, where  $s^A$  is the R&D subsidy. Profits are linear in product quality, creating an incentive for innovation even for firms at the largest lead. As is evident from the definition of  $\Pi_t(m; \tau^A, \tau^B)$ , capturing the domestic market or expanding into foreign markets adds to profits, reflecting a market-size effect, and thereby intensifies the incentives to innovate. The second line denotes the expected gains from innovation. This expectation is over potential new positions. The exact position is determined probabilistically by the step size of innovation. The remaining components capture the creative destruction by domestic and foreign competitors. The second part of the second line reveals that entry by domestic firms forces the incumbent to exit, as by construction every product line is forced to have one firm from each country. This domestic business-stealing effect reduces the value of an incumbent firm and therefore its incentive to innovate. Moreover, in an open economy, there is an additional channel through business stealing. The last line explains the changes as a result of innovation in the foreign country. Any innovation there, regardless of the source being an entrant or an incumbent, deteriorates the position and the value of the domestic incumbent, creating an international business-stealing effect.<sup>18</sup> The size of the deterioration is again determined probabilistically by  $\mathbb{F}_{-m}(\cdot)$ .<sup>19</sup>

---

<sup>17</sup>In equilibrium,  $m$  sums up all product line-specific information relevant to a firm's value. Lemma 1 at the end of this subsection verifies this result. Accordingly, we replace subscript  $j$  with  $m$  unless otherwise necessary. The problem for incumbent firms from country  $B$  is defined reciprocally.

<sup>18</sup>Note that there is no threat of exit posed by the foreign entrant, as that entrant replaces the incumbent of its own country.

<sup>19</sup>The distribution function is labeled with the subscript  $-m$  because it is associated with the competitor's position. We define the value functions for the two boundary cases where the incumbent

The firms' problems involve an infinite-dimensional space of intermediate-good qualities. The following lemma renders the firm environment independent of the current quality of their products, reducing the state space to finite dimensions.

**Lemma 1** *The value functions are linear in quality such that  $V_{cm}(q) = qv_{cm}$  for  $m \in \{-\bar{m}, \dots, \bar{m}\}$ . This ensures that the innovation decision of the firm is independent of  $j$  once controlled for  $m$ .*

**Proof.** See Appendix B for the derivation and the definition of  $v_{cm}$ . ■

The first-order conditions of the problems defined above yield the following equilibrium R&D decisions for an incumbent in state  $m$ :

$$x_{cmt} = \begin{cases} \max \left\{ \left[ \frac{1}{\alpha_c(1-s^c)} \sum_{n=m+1}^{\bar{m}} \mathbb{F}_m(n) \left\{ \lambda^{(n_t-m)} v_{cnt} - v_{cmt} \right\} \right]^{\frac{1}{\gamma_c-1}}, 0 \right\} & \text{if } m < \bar{m} \\ \max \left\{ \left[ \frac{1}{\alpha_c(1-s^c)} (\lambda - 1) v_{c\bar{m}t} \right]^{\frac{1}{\gamma_c-1}}, 0 \right\} & \text{if } m = \bar{m} \end{cases} . \quad (15)$$

Similarly, the equilibrium innovation rates for entrants become<sup>20</sup>

$$\tilde{x}_{cmt} = \begin{cases} \max \left\{ \left[ \lambda v_{c\bar{m}t} \cdot \tilde{\alpha}_c^{-1} \right]^{\frac{1}{\gamma_c-1}}, 0 \right\} & \text{if } m = \bar{m} \\ \max \left\{ \left[ \tilde{\alpha}_c^{-1} \sum_{n=m+1}^{\bar{m}} \mathbb{F}_m(n) \lambda^{(n_t-m)} v_{cnt} \right]^{\frac{1}{\gamma_c-1}}, 0 \right\} & \text{if } m < \bar{m} \end{cases} . \quad (16)$$

The relationship between competition and innovation incentives lies at the heart of the model dynamics. The following lemma formalizes this relationship in a bare-bones version of this model.

**Proposition 1** *In a stripped-down version of the model with two symmetric countries that abstracts from firm entry and trade barriers and features quick catch-up by followers and an infinitesimal innovation step size, the following results hold:<sup>21</sup>*

1. *the innovation intensity becomes highest at the neck-and-neck position;*

---

is  $\bar{m}$ -steps ahead (behind) in Appendix B.5.

<sup>20</sup>See Appendix B.5 for the derivation of entrant firm values.

<sup>21</sup>The last condition is to ensure that innovation incentives are driven purely by competitive forces rather than market-size effect—firms' motive to expand rents via quality improvements.

2. the followers innovate at the same rate and strictly less than the neck-and-neck firms;
3. the leaders do not innovate.

Formally,  $x_0 > x_{-m} = x_{-\bar{m}} > x_m = x_{\bar{m}} = 0$  for  $m > 0$ .

**Proof.** See Appendix B.4 for the analytic discussion. ■

Proposition 1 defines the escape-competition effect that is typical of step-by-step innovation models. For firms that are close to their rivals and feel an intense competitive pressure because their market size can expand or shrink with only a small change in qualities, the innovation effort peaks, reflecting a dominant incentive to eclipse the competitor. A distinguishing feature of our model, however, is that this force emerges at two distinct positions in the technology gap space instead of a single one as is typical of closed-economy versions. Figure 4 demonstrates this point, showing the innovation effort of a firm as a function of the technology gap in the calibrated model. The first case is when a domestic producer is one step short of gaining access to export markets—i.e., just below cutoff  $m^X$  as defined in equation (9). The firm just below the cutoff intensifies its innovation activity just to improve its quality slightly more to make its cost-adjusted quality advantage large enough to



Figure 4: Innovation effort over technology gaps

*Notes:* The figure exhibits the innovation effort of U.S. firms as a function of their technological position relative to their rivals in the balanced growth path of the calibrated model (positive gaps indicate U.S. firm's superiority). Dashed vertical lines indicate import and export cutoffs.

export, resulting in the peak effort on the right, which we label as *expansionary R&D*. Second, a similar intensification happens when a laggard firm is one-step short of beating the foreign exporter and gaining access to domestic production—i.e., just below cutoff  $m^M$  as defined in equation (10). In this case, the *defensive R&D* motive emerges leading to the peak effort on the left. We further discuss this extension of the *escape-competition* effect across different stages of competition—over domestic and foreign markets—in Section 3.2 by confronting the model with the data.

Closing the model, aggregate consumption is derived from the budget constraint in equation (2). Aggregate R&D spending  $R_{ct}$  (in units of final output) follows from R&D cost functions and firms' optimal innovation rate decisions specified in equations (15) and (16):

$$R_{ct} = \sum_{m=-\bar{m}}^{\bar{m}} \left( \alpha_c x_{cmt}^{\gamma_c} + \tilde{\alpha}_c \tilde{x}_{cmt}^{\tilde{\gamma}_c} \right) Q_{cmt}. \quad (17)$$

The net government spending reads as

$$G_{ct} = s^c \sum_{m=-\bar{m}}^{\bar{m}} \alpha_c x_{cmt}^{\gamma_c} Q_{cmt} - \tau^c \sum_{m=-\bar{m}}^{m_{ct}^M} \left[ \frac{1 - \beta}{(1 + \kappa)(1 + \tau^c)\eta} \bar{w}_{c't}^{-1} \right]^{\frac{1-\beta}{\beta}} \frac{Q_{c't}}{1 - \beta'} \quad (18)$$

where the first part accounts for the bill of R&D subsidies and the second part accounts for the revenue from tariffs. Any government expenditure on (income from) subsidies (taxes and tariffs) is levied as a lump-sum tax on (rebated as lump-sum transfer to) households.

Finally, we present the laws of motions that summarize the endogenous evolution of the gap distribution. The change in  $\mu_{Amt}$ , the share of product lines where the firm from country  $A$  is at position  $m$ , is given by

$$\begin{aligned} \dot{\mu}_{Amt} = \dot{\mu}_{B(-m)t} = & \sum_{s=m+1}^{\bar{m}} \mathbb{F}_{-s}(-m) \left( x_{B(-s)t} + \tilde{x}_{B(-s)t} \right) \mu_{Ast} \\ & + \sum_{s=-\bar{m}}^{m-1} \mathbb{F}_s(m) \left( x_{Ast} + \tilde{x}_{Ast} \right) \mu_{Ast} \\ & - \left[ x_{Amt} + x_{B(-m)t} + \tilde{x}_{Amt} + \tilde{x}_{B(-m)t} \right] \mu_{Amt} \end{aligned} \quad (19)$$

The change in  $\mu_{Amt}$  defines reciprocally the change in  $\mu_{B(-m)t}$ . The measure  $\mu_{Amt}$

grows when the gap difference in some product lines reach  $m$ , and it shrinks when existing lines with difference  $m$  reach another position. The first line on the right-hand side refers to the increase in  $\mu_{Amt}$  due to innovations by foreign firms in lines where the gap difference is larger than  $m$ , which bring the gap difference in those lines to  $m$ . The second line refers to the increase in  $\mu_{Amt}$  due to domestic innovations in lines where the gap difference is smaller than  $m$ . The last line refers to the decrease in  $\mu_{Amt}$  due to any innovation in those lines with gap difference in  $m$ . We leave further details and the discussion of the evolution of  $Q_{cmt}$  to Appendix B.

**Definition 1 (Equilibrium)** *A Markov Perfect Equilibrium in this world economy with two countries  $c \in \{A, B\}$  is an allocation*

$$\{r_{ct}, w_{ct}, f_{ct}, p_j, k_{jt}, k_{jt}^*, x_{cjt}, l_{jt}, l_{jt}^*, \tilde{x}_{cjt}, Y_{ct}, C_{ct}, R_{ct}, G_{ct}, F_c, L_c, \{\mu_{cmt}, Q_{cmt}\}_{m \in \{-\bar{m}, \dots, \bar{m}\}}\}_{c \in \{A, B\}, j \in [0, 1]}^{t \in [0, \infty)}$$

such that (i) the sequence of prices and quantities  $p_j, k_{jt}, k_{jt}^*, l_{jt}, l_{jt}^*$  satisfy equations (4)-(8) and maximize the operating profits of the incumbent firm in the intermediate-good product line  $j$ ; (ii) the R&D decisions  $\{x_{cjt}, \tilde{x}_{cjt}\}$  are defined in equations (15) and (16), and  $R_{ct}$  is given in equation (17); (iii) supply of fixed factor  $F_c$  is equal to the profit-maximizing demand by the final-good producers, which is defined by the inverse demand function in equation (6); (iv)  $Y_{ct}$  is given in equation (12) and is spent on  $C_{ct}$  and  $R_{ct}$ ; (v)  $C_{ct}$  is consistent with the budget constraint specified in equation (2); (vi) fixed factor compensation  $f_{ct}$  clears the markets for the fixed factor at every  $t$ ; (vii) wages  $w_{ct}$ , as defined in equation (13) clear the labor markets at every  $t$  given the fixed supply  $L_c$  and the profit-maximizing demand by the intermediate-good producers; (viii) interest rates  $r_{ct}$  satisfies the households' Euler equation; (ix) government has a balanced budget at all times in line with equation (18); (x) and  $\{\mu_{cmt}, Q_{cmt}\}_{m \in \{-\bar{m}, \dots, \bar{m}\}}$  are consistent with optimal R&D decisions.

**Welfare.** Aggregate welfare in economy  $c$  over horizon  $T$  calculated at time  $t_0$  is given by  $W_{t_0}^c = \int_{t_0}^{t_0+T} \exp(-\rho(s-t)) \frac{C_{cs}^{1-\psi} - 1}{1-\psi} ds$ . Accordingly, the quantitative section reports the welfare differences between a counterfactual and the baseline economy in consumption equivalent terms using the following relationship:

$$\int_{t_0}^{t_0+T} \exp(-\rho(s-t_0)) \frac{(C_{cs}^{new})^{1-\psi} - 1}{1-\psi} ds = \int_{t_0}^{t_0+T} \exp(-\rho(s-t_0)) \frac{((1+\zeta)C_{cs}^{base})^{1-\psi} - 1}{1-\psi} ds.$$

If a policy change at time  $t_0$  yields a new income sequence  $C_{ct}^{new}$  between  $t_0$  and  $t_0 + T$  satisfying the above relationship, we say that the policy change results in  $\zeta\%$  variation in consumption-equivalent welfare over horizon  $T$ . This means that the representative consumer in the baseline economy would need to receive  $\zeta\%$  additional income at each point in time between  $t_0$  and  $t_0 + T$  in order to obtain the level of welfare it would have in the counterfactual scenario.

### 3 Quantitative Analysis

In this section, we study the quantitative implications of our theoretical framework. After calibrating the model, we first discuss its performance in terms of out-of-sample predictions. Then, we focus on the implications of R&D subsidies evaluating alternative scenarios including the simultaneous use of both policy measures and tariff retaliation by trade partners in terms of their welfare consequences.

#### 3.1 Calibration

When mapping our two-country model to the data, we envision a world that consists of the United States and a foreign country, which is a weighted combination of the six countries employed in the empirical section: Canada, France, Germany, Italy, Japan, and the U.K.<sup>22</sup> The weights associated with each country, listed in Table 1, reflect the count of patents registered in the United States by the residents of a specific country in the initial year of the sample (1975) as a fraction of all foreign patents registered in the United States in that year. In the remainder, country  $A$  represents the United States and country  $B$  the foreign country.

Table 1: Patent weights of countries

Canada	France	Germany	Italy	Japan	U.K.
6.2%	11.7%	30.0%	3.8%	33.1%	14.6%

*Notes:* Weights may not sum to 1 because of rounding.

<sup>22</sup>These are the most innovation-intensive countries competing with the United States, measured by their share of patent applications in the USPTO patent data.

There is a strong convergence in the relative shares of domestic and foreign patents registered in the United States prior to 1981 (see also Figure A.1a). A key objective of our calibration strategy is to reproduce this convergence in order to conduct our policy evaluation exercises in an environment that mimics the intensification of the foreign technological competition faced by U.S. firms in those years. Therefore, we match the model to a set of moments that we obtain from the data that span 1975 to 1981. Then, we impose the changes in R&D policy observed in the data (Figure 2b) to the calibrated model and analyze their implications for the post-1981 period (1981 to 2016).

In the calibrated model, we try to keep the least amount of heterogeneity across countries, other than subsidy levels, in order to focus solely on the effect of policy differences. The two large open economies share symmetric technologies except the scale parameters of R&D cost functions and the imposed R&D subsidies. These assumptions leave us with the following 16 structural parameters to be determined:  $\theta \equiv \{ \alpha_A, \alpha_B, \tilde{\alpha}_A, \tilde{\alpha}_B, \gamma, \tilde{\gamma}, \rho, \psi, \beta, \kappa, \eta, \lambda, \phi, \tau_{75-81}, s_{75-81}^A, s_{75-81}^B \}$ . Some of these parameters are calibrated externally and the remaining are calibrated internally.

**External Calibration.** We set the CRRA parameter  $\psi = 2$  and the time discount parameter  $\rho = 1\%$ , which imply a 3.11 percent interest rate in the balanced growth path and an average rate of 2.46 percent between 1975 and 1981 for the United States. We take  $\beta = 0.5$ , which leads to a roughly 75 percent share of fixed factor and wage income in U.S. GDP in the balanced growth path, with  $\eta$  set equal to  $1 - \beta$ .<sup>23</sup> R&D cost functions have a quadratic shape with  $\gamma = \tilde{\gamma} = 2$ , consistent with well-known empirical estimates of the elasticity of patents to R&D expenditure (Blundell et al., 2002; Hall and Ziedonis, 2001).<sup>24</sup> The tariff rate, which we take to be common for both countries, is 5.5 percent, a value that is consistent with U.S. International Trade Commission (2009). The left panel of Table 2 lists these values.

A crucial set of parameters is the R&D subsidy rates. We obtain them from

---

<sup>23</sup>By income approach, GDP is equal to the sum of profits, wages, and fixed factor income earned.

<sup>24</sup>Applying dynamic count data models to U.S. data on patents and R&D, Blundell et al. (2002) obtain a similar value, which Hall and Ziedonis (2001) corroborate by examining the semiconductor industry. Acemoglu et al. (2016) and Acemoglu et al. (2018) also provide empirical estimates for the elasticity of innovative output to R&D spending from the U.S. Census data, obtaining similar values.

Table 2: List of parameter values

Panel A: Externally calibrated			Panel B: Internally calibrated		
Parameter	Value	Description	Parameter	Value	Description
$\psi$	2	Elasticity of substitution	$\alpha_A$	1.97	R&D scale, incumbents US
$\gamma, \tilde{\gamma}$	2	R&D cost curvature	$\alpha_B$	3.16	R&D scale, incumbents FN
$\rho$	1%	Rate of time preference	$\tilde{\alpha}_A$	56.8	R&D scale, entrants US
$\beta$	0.5	Factor income share	$\tilde{\alpha}_B$	18.4	R&D scale, entrants FN
$s_{75-81}^A$	5.3%	R&D subsidy US, 75-81	$\phi$	1.21	Curvature of $\mathbb{F}(n)$
$s_{75-81}^B$	3.8%	R&D subsidy FN, 75-81	$\lambda$	1.58%	Innovation step size
$\tau_{75-81}$	5.50%	Tariff rate	$\kappa$	6.08%	Iceberg trade cost

[Impullitti \(2010\)](#), which lack only Canada.<sup>25</sup> These data go back to 1979. Given that the rates in the sample countries do not fluctuate markedly before the mid-1980s, we take the values before 1979 to be the same as in 1979. For the calibration, the subsidy rates for both countries are 1975-1981 averages (again weighted for the foreign countries). When we simulate the model for the post-1981 period, we will recalculate the subsidy rates to match the averages across 1982 to 1995.<sup>26</sup> We also recalculate the weights of foreign countries the same way but use 1981 patent counts.

**Internal Calibration and Identification.** We have seven remaining parameters:  $\{\alpha_A, \alpha_B, \tilde{\alpha}_A, \tilde{\alpha}_B, \lambda, \phi, \kappa\}$ . One of these,  $\phi$ , determines the shape of the generic step-size distribution. In order to calibrate them, we use six data points and the distribution of firms across technology gaps that we derive using USPTO patent data. We start with the discussion of the six moments, summarized in Table 3, that are not directly related to the gap distribution.

The first two moments are the average growth rates of total factor productivity (TFP) in both countries, calculated using TFP series in [Coe et al. \(2009\)](#). The next two moments are aggregate non-defense R&D expenditure as a percentage of GDP,

<sup>25</sup>We address this issue by recalculating the patent weights after dropping Canada.

<sup>26</sup>We focus our calibration on the period before 1995 for several reasons. First, we want to avoid the run-up to the U.S. dot-com bubble and the crisis that followed in the early 2000s. Second, we isolate our period from heightened competition exerted by China. Although valuable in itself, this would introduce a second period of exogenous variation to our analysis, making it more complicated for no apparent benefit. Finally, our theoretical assumption of home bias is better suited for this relatively earlier period of financial globalization.

which we obtain from the Main Science and Technology Indicators (MSTI) database of the OECD.<sup>27</sup> As a fifth target, we include the birth rate of new establishments for the United States, computed using the BDS database.<sup>28</sup> The sixth moment is the ratio of U.S. manufacturing exports to GDP, which we derive using World Bank data. These moments allow us to determine six parameters as follows. Aggregate R&D shares discipline the scale parameters of the incumbent R&D cost functions  $\{\alpha_A, \alpha_B\}$ . The scale parameter of the entrant R&D cost function for country  $A$  ( $\tilde{\alpha}_A$ ) is determined by the U.S. establishment birth rate. Then, TFP growth rates pin down the basic step size  $\lambda$  and the entrant R&D cost for country  $B$  ( $\tilde{\alpha}_B$ ). The U.S. export-to-GDP ratio determines the iceberg cost  $\kappa$ , as  $\kappa$  drives  $m^X$ , the minimum gap a firm needs to open up in order to export, given  $\tau$  and  $\lambda$ .

The last parameter to be internally calibrated is  $\phi$ , which controls the curvature of the generic probability function over technology gaps,  $\mathbb{F}(n)$ . As manifested by equations (A.2), this function, by forming the basis of position-specific  $\mathbb{F}_m(n)$ , becomes an integral determinant of the model dynamics that govern the evolution of firms' measure across technology gaps ( $\mu_{cm}$ 's). We make use of this relationship to discipline the shape of  $\mathbb{F}(n)$ . To this end, we first derive the empirical distribution of sectors across technology gaps using the information on patents in the USPTO data. This procedure, illustrated in Figure 5, provides us with the data counterpart of firms' measure across technology gaps (gap distribution) in the model.

We start with sorting sectors in a given year according to the fraction of patents in each sector that are registered by U.S.-based entities in that year. Then, we divide this unit interval into 33 equally spaced bins, each of which corresponds to a range of approximately 3 percent. For instance, sectors with a fraction of U.S. patents between 0 and 3 percent would fall into  $m = -16$ , sectors with a fraction between 4 and 6 percent would fall into  $m = -15$ , and so on. Sectors in the data correspond to product lines in our model, and thus, the measure of sectors across bins (normalized to sum to 1) corresponds in our model to  $\mu_m$ 's for country  $A$  across 33 gap levels

---

<sup>27</sup>Non-defense R&D spending data do not include Japan. However, Science and Engineering Indicators reports from the National Science Foundation, based on MSTI data, provide estimates for Japan, which we use to amend our calculations with the OECD data. Also, MSTI data start in 1981, which is why we use the initial values of this variable.

<sup>28</sup>We prefer entry by establishments instead of firms because while in the data firms enter at different sizes, in our model every firm operates in one product line.

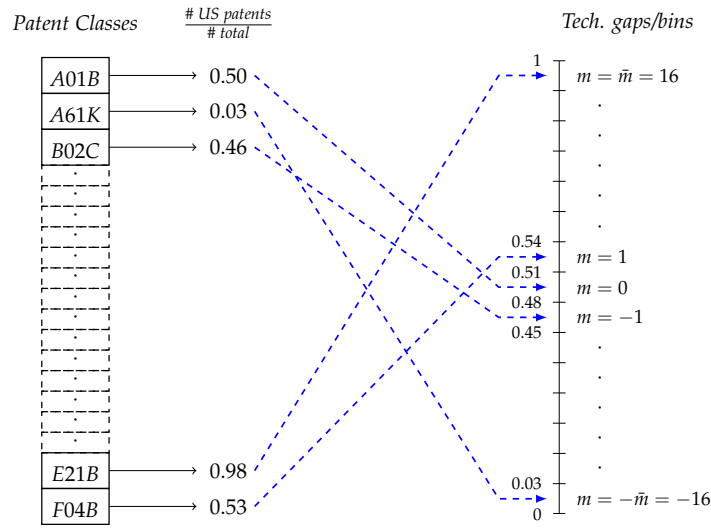


Figure 5: Mapping USPTO patent data to the model

Notes: The figure illustrates how patent classes in the USPTO data are assigned to equally sized bins on a unit measure according to the share of patents owned by U.S. residents, obtaining an empirical distribution of technology gaps.

from  $-\bar{m} = -16$  to  $\bar{m} = 16$ .

This method to build an empirical measure of technology gaps offers a natural correspondence to the theory. It builds on the idea that, in the model, the technology gap in a product line reflects the difference between the number of past innovative improvements the firms in each country have developed. Accordingly, the empirical procedure aims at measuring the empirical gap in each technology class using patents registered by the U.S. firms and their foreign competitors. The maximum gap in favor of U.S. firms emerges when the fraction of the U.S. patents among all patents registered in a sector approaches one. The worst technological position for the U.S. occurs when that fraction is zero.<sup>29</sup> The procedure divides this unit interval into a reasonably large number of bins that corresponds to a non-binding level of  $\bar{m}$ . It then generates the distribution of sectors across these bins, which informs the model directly on the distribution of technology gaps.

<sup>29</sup>We use the ratio instead of absolute differences in the number of patents, because the total number of patents could vastly differ across sectors for various reasons, and the same absolute difference would possibly mean varying degrees of technology gaps. As such, using the ratio serves as a normalization that corrects for the differences across sectors in the propensity to generate patents.

The construction of the empirical gap distribution certainly relies on a number of assumptions. For instance, we set the maximum gap to allow for a realistic catch-up process for laggard firms while having enough observations in each bin of the empirical distribution, but alternative values could be entertained. In addition, sectoral patent shares are calculated on an annual basis, while it is also possible to compute those shares based on patents registered over a number of previous years. It would also be viable to weight patents by the number of citations they received to capture the importance of the technology content as is standard in the literature. This method would also echo the heterogeneity across innovations present in the model, as they differ in the number of step sizes with which they improve product qualities. We reassess the main quantitative results under these alternative specifications in robustness exercises presented in Appendix F.4.

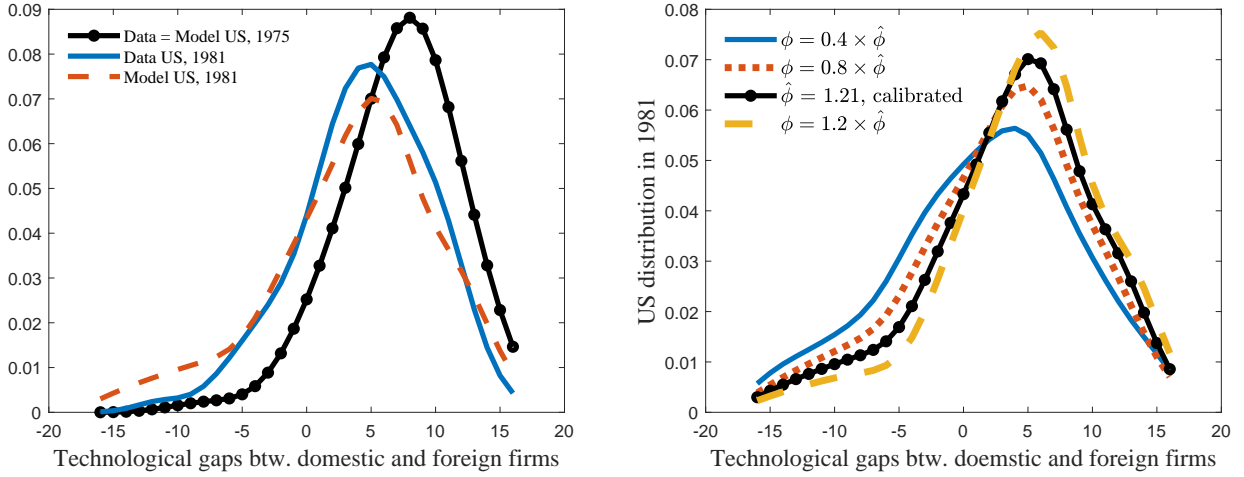
Figure 6a shows the distribution in the data for years 1975 (circled black line) and 1981 (solid blue line).<sup>30</sup> It reveals that, initially, a substantial mass of U.S. firms are technological leaders, with a mean gap close to seven; however, subsequently, their distribution has shifted leftward, with the mean gap falling to around four in 1981. This shift translates into a larger mass of U.S. firms in relatively smaller gap sizes and, therefore, signifies a strong foreign technological catch-up. The calibration of  $\phi$  aims at matching the dynamics of this catch-up process that occurred between 1975 and 1981, as described later.

In order to obtain the model counterparts of our data targets, we simulate the two economies between 1975 and 1981, initializing the model at the empirical gap distribution in 1975. Initially, we normalize the quality of U.S. intermediate goods to one—i.e.,  $q_{Aj1975} = 1 \forall j$ .<sup>31</sup> We solve the transition path of the model over 1975 to 1981 as described below. We derive the model counterparts of the seven moments presented in Table 3 by taking averages of the simulated series over the relevant period. We also compute the evolution of the gap distribution in the model using equations (A.2) defined in Appendix B and try to hit the empirical gap distribution in 1981 as the terminal point of the economy in transition.

---

<sup>30</sup>Distributions are smoothed using a kernel density function with a bandwidth of 1.8.

<sup>31</sup>The quality levels of firms from  $B$  are initialized accordingly with respect to their position in technological competition. Mathematically, this normalization implies that if in product line  $j$  the firm from  $A$  is at position  $m$ , then  $q_{Bj1975} = \lambda^{-m}$ ,  $m \in \{-\bar{m}, \dots, \bar{m}\}$ .



A) Technological gap distribution: data and calibration

B) Identification of  $\phi$

Figure 6: Dynamics of the gap distribution and the identification of  $\phi$

*Notes:* Panel A depicts three technology gap distributions and demonstrates the model's performance. Positive values on the horizontal axis denote U.S. technological leadership. The dotted solid line is the empirical distribution in 1975, which defines the initial distribution for the model simulation in the calibration. The solid blue line is the empirical distribution in 1981—the target distribution of the simulation. The dashed red line is the model-generated distribution in 1981, simulated at the calibrated parameters. Panel B illustrates the effect of  $\phi$  (the curvature parameter of the step-size distribution function) on the simulated gap distribution, the variation in which enables the identification of  $\phi$ . It exhibits various model-generated distributions in 1981 that result from simulations with varying levels of  $\phi$  with other parameters kept at their calibrated values. All distributions are smoothed using a kernel density function with a bandwidth of 1.8.

**Solution Algorithm and Model Fit.** To solve the model, we first discretize it. The algorithm assumes that the economy starts in 1975 and transitions to the balanced growth path in  $T$  periods, and each period is divided into  $(\Delta t)^{-1} = 2^5$  sub-periods. The algorithm is an iterative backward solution method. The main procedure consists of solving for the balanced growth path and then deriving the values over the transition period going backward from the balanced growth path.<sup>32</sup> Akcigit et al. (2018) provide a detailed account of the solution method.

The targeted moments and the model's fit are summarized in Table 3 and Figure 6a, with the resulting calibrated parameters listed in the right panel of Table 2. Along

<sup>32</sup>To ensure numerical stability, a small extension is introduced to the relationship between the gap structure and the trade of goods in the computations. We assume that the quality of the foreign good is observed imperfectly subject to an iid error. Appendix B.2 provides a detailed account. Effectively, the additional structure comes into play only around the cutoffs, and thus it is inconsequential for the aggregates while still ensuring a smooth numerical solution.

the transition, the catching-up country exhibits higher R&D-to-GDP ratios growing faster than the leading country. The model captures these differences between the two economies observed in the data quite successfully. The entry rate and the export shares are also well fitted. Finally, the position of the dashed red line relative to the solid blue one in Figure 6a indicates the strong performance of the model in matching the 1981 distribution of technology gaps.

Table 3: Model fit

Moment	Estimate	Target	Source
TFP Growth U.S.	0.74%	0.55%	Coe et al. (2009) 1975-81
TFP Growth FN	1.69%	1.73%	Coe et al. (2009) 1975-81
R&D/GDP U.S.	1.61%	1.75%	OECD 1981
R&D/GDP FN	2.00%	1.96%	OECD 1981
Entry Rate U.S.	9.97%	10.0%	BDS 1977-81
Export Share U.S.	7.00%	7.00%	WB 1975-81

In the model, the forces of cross-country convergence that enable the reproduction of the catch-up observed in the data are chiefly governed by the curvature of the step-size distribution  $\phi$ . Figure 6b illustrates how different values of  $\phi$  lead to various shapes of technology gap distribution. Each line in the figure represents a distribution that emerges in 1981 once the model is simulated between 1975 and 1981 at the calibrated parameter values except  $\phi$ , which takes a different value in each iteration. Lower values of  $\phi$  mean a flatter probability distribution  $\mathbb{F}(n)$  over step sizes (or, equivalently, positions ahead), allowing technologically laggard firms to catch up more quickly. Therefore, a low value of  $\phi$  would imply a larger leftward shift in the initial gap distribution of U.S. firms. The position of the solid blue line in Figure 6b relative to the circled black line, which represents the calibration result, illustrates this case. The converse happens for larger values of  $\phi$ , as demonstrated by the relative position of the yellow dashed line, which is generated by a value that is 20 percent higher than the calibrated one. As such, the pace of technological convergence observed in the data provides distinct information to discipline  $\phi$ . Ultimately, the calibrated level of  $\phi$  generates a considerable chance of improving multiple steps with a single innovation for laggard firms: The probability that an innovation by the

most laggard firm brings a multi-step improvement is 67 percent.<sup>33</sup>

The distribution across new positions,  $\mathbb{F}(n)$ , facilitates technological convergence owing to the implied property of advantage of backwardness.<sup>34</sup> Importantly, an innovation can generate an improvement of multiple steps for laggard firms, whereas the number of potential steps to improve becomes smaller as a firm opens up the technological gap with its follower. In the words of [Gerschenkron \(1962\)](#), this structure creates an “advantage of backwardness” for followers—i.e., laggard firms have an advantage in the number of steps they can improve with each innovation, while far-ahead leaders cannot open further their lead quickly. Thus, foreign firms catch up with domestic firms along the transition, generating a cross-country technological convergence. This convergence in our economy echoes that in the canonical Solow model with a key difference. In the Solow model, convergence is driven by decreasing returns in capital accumulation; in our economy, endogenous innovation together with an “advantage of backwardness” is the driver.

Another salient feature of the equilibrium relates to the goods trade. The calibrated parameters are such that in the BGP,  $m_A^X = 8$  and  $|m_A^M| = 6$ —i.e., a firm from  $A$  ( $B$ ) needs to lead by at least 8 (6) technological gaps to export.<sup>35</sup> In addition, the model generates a trade elasticity of about 7 for the U.S. in the BGP.<sup>36</sup> This value falls in the range of estimates reported by seminal papers such as [Anderson and van Wincoop \(2004\)](#) and [Eaton and Kortum \(2002\)](#), while it is somewhat higher than the range estimated by [Simonovska and Waugh \(2014\)](#) more recently and the

---

<sup>33</sup>Conversely, the probability that the most laggard firm receives a single-step innovation is 33 (= 100 – 67) percent.

<sup>34</sup>While not driving the convergence per se, the limited cross-border flow of technology occurring at gap  $\bar{m}$  upon an innovation by the leader keeps laggard firms from the foreign country in the global innovation race, preventing them from falling too far behind technologically. Similarly, Ricardian forces ensure that when the firms of a country become too laggard, they benefit from a cost advantage through reduced wages, allowing them to retain some edge in their markets.

<sup>35</sup>Notice that the introduction of imperfect observability of the foreign good quality in the numerical solution implies that some firms at these cutoffs may fail to export with a certain probability.

<sup>36</sup>We measure trade elasticity in the spirit of [Hsieh et al. \(2023\)](#) as the change in the log of the import share in a year starting from the BGP in response to a 1 percent reduction in the U.S. tariff rate. Formally, this elasticity is defined as  $-\log(IMD_{t_0+\Delta t^{-1}}^{US}(\tau^{US} - 0.01)/IMD_{t_0}^{US}(\tau^{US}))/\log((1 + \tau^{US} - 0.01)/(1 + \tau^{US}))$ , where  $IMD$  refers to the ratio of imports to domestic sales (computed as in [Alessandria et al., 2021](#)),  $\tau^{US}$  is the calibrated tariff level,  $t_0$  denotes the last period in the BGP, and  $t_0 + \Delta t^{-1}$  denotes one year after the tariff change.

conventional value of 5 preferred by [Head and Mayer \(2014\)](#), which serves as the target value in [Costinot and Rodríguez-Clare \(2014\)](#) and [Hsieh et al. \(2023\)](#). Moreover, trade elasticity in our model is time-varying, echoing the dynamics in the recent studies of [Alessandria et al. \(2021\)](#) and [Hsieh et al. \(2023\)](#). This result, illustrated in [Figure 7](#), stems from the endogenous motion of firms' distribution across technology gaps and, therefore, of the level of imports and other aggregate variables, which are triggered by variations in firms' innovation decisions in response to parameter changes.

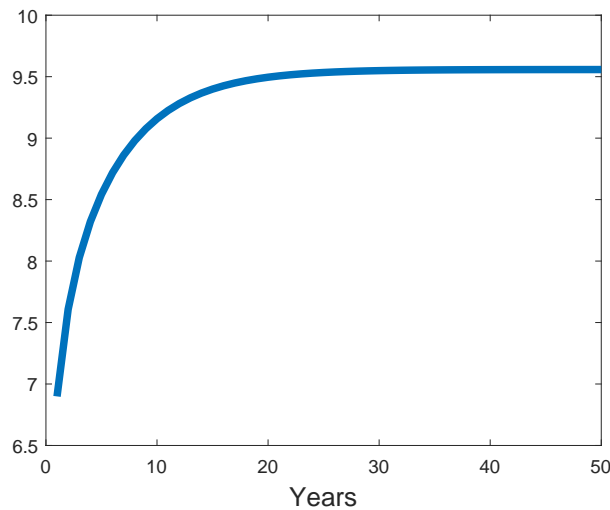


Figure 7: Trade elasticity over time

*Notes:* The figure exhibits the path of U.S. trade elasticity following a 1 percent unilateral decline in U.S. import tariffs.

### 3.2 Validation of the Model

[Figure 8](#) compares the relationship between innovation efforts of incumbent firms and their technological position relative to their competitors in the model and in the data. [Figure 8a](#) displays incumbents' innovation intensity as a function of the technology gap. [Figure 8b](#) shows average patenting intensity of U.S. firms in the USPTO data, measured by patent applications per firm, across sectors ranked according to their share of patents registered by U.S. residents, as described in the calibration.<sup>37</sup>

<sup>37</sup>We create the empirical measure of average innovation intensity across technology gaps as follows. First, we calculate the total number of domestic patent applications and unique domestic owners of those patents for each pair of technology class and year. Next, we rank these class-year

In Figure 8a, we observe two spikes at  $-m^M = -6$  and  $m^X = 8$ , which correspond to the two cutoffs defined in equations (9) and (10).<sup>38</sup> The left one emerges because of the *defensive R&D* effort, as the firm increases its innovation to improve its position and capture domestic production. Similarly, the right peak emerges because of the *expansory R&D* effort of firms that sell domestically. They increase their innovation efforts when closer to the export cutoff, as an innovation right before that threshold enables the domestic firm to expand into the export market. Interestingly, we observe a similar shape with two peaks also in the data, as illustrated in Figure 8b. Again, the peaks emerge in sectors where U.S. firms hold a strong technological advantage, or disadvantage, as measured by the sectoral share of total patents registered by U.S. residents. The notable performance in capturing the innovation intensity observed in the data provides further evidence for our model’s ability to mimic firms’ innovation behavior.<sup>39</sup>

The jump in innovation in the proximity of the export cutoff is consistent with a large body of evidence showing that firms innovate in order to enter the export

---

pairs according to the share of domestic applications in total applications and assign them to technology bins as in Figure 5. Then, in each bin, we sum the total domestic patents and unique domestic assignees across class-year pairs. The ratio of those is the average patenting intensity per assignee in a given bin, which proxies for innovation intensity in our model. The exercise considers applications between 1975 and 1995, a long span of time, as the comparison is to the balance growth path in the model. To generate the figure, we also drop patents assigned to the assignee id “0”, as most of the other assignee values have more than six digits. Figure A.6 in Appendix D shows that including those patents leads to sharper spikes in the data.

<sup>38</sup>Owing to the random term associated with the observed foreign good quality, some domestic firms retain profits from the domestic market, even though the true comparison of cost-adjusted qualities would not allow it. Therefore, while the peak innovation effort happens at the aforementioned cutoffs, the innovation rate is also noticeably high at the adjacent gap.

<sup>39</sup>In a multi-country model in which countries differed drastically along the determinants of trade cutoffs such as tariffs and relative wages, one could expect more than two cutoffs to influence trade flows and, thereby, innovation incentives. But to the extent that the determinants do not vary drastically across trade partners of the U.S., a multi-country model could also admit an approximate double-peak innovation effort. Indeed, the largest trade partners we consider are all developed economies and members of the GATT in the period of the analysis, suggesting a certain degree of homogeneity in the likely cutoffs one could expect vis-à-vis each trading partner. In fact, if distinct, apparent cutoffs arose vis-à-vis different major trading partners that we consider, those cutoffs would be visible in the empirical relationship of the patenting intensity over the leadership shares. Finally, the data constructed by matching patent data to 4-digit SITC (rev2) (see validation exercise II in Online Appendix C) display a notable positive correlation between the technology gaps and the average U.S. export share (of total bilateral exports between the U.S. and the trade partners) across bins, which corroborates the model’s prediction that better relative technology facilitates exports.

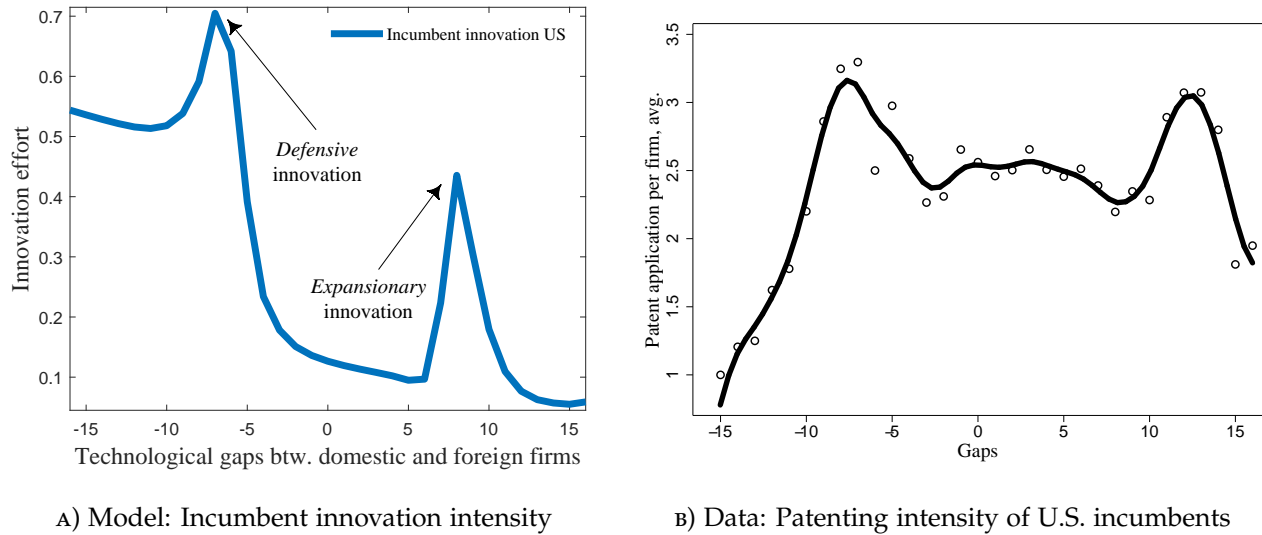


Figure 8: Incumbent innovation effort and leadership

Notes: Panel A shows the innovation intensity of U.S. incumbent firms in the calibrated BGP. Panel B shows the average number of patents applied for by the U.S. firms in the USPTO data across technology gaps (the creation of the technology gaps is illustrated in Figure 5). The hollow markers designate actual data points, and the line is fit by smoothing splines.

market. Using Chilean data, López (2009) finds that productivity and investment increase before plants begin to export. Estimating a dynamic structural model with Taiwanese plant-level data, Aw et al. (2011) show that the decisions of firms to innovate and enter the export market are highly correlated—i.e., firms entering the export market are more likely to speed up their investment in R&D. Lileeva and Trefler (2010) find that Canadian plants that were induced by the U.S. tariff cuts to start exporting (i) increased their labor productivity, (ii) engaged in more product innovation, and (ii) had higher adoption rates of advanced technologies.

Appendix C discusses three more exercises, which explore the link between trade barriers and firms' innovation, entrants' innovation intensity and the elasticity of firm innovation to R&D subsidies. All exercises provide empirical support for the model's key implications.

## 4 Policy Evaluation

We first demonstrate the foreign catch-up process that the United States would experience in the absence of policy changes. Then we perform a quantitative investigation

of various policy alternatives, their welfare implications, and the design of optimal policies considering different horizons for policy and the transition periods.

**Foreign Catch-up in the Baseline Economy.** Foreign technological catch-up is a key implication of the model. Improvements in a country's trade partners' technology is a mode of globalization that has received less attention in the literature than the reduction of trade and offshoring barriers. To explore this relationship in our model, we focus on how foreign technological catch-up manifests itself in the technological advantage of the leading country, which again represents the United States. In particular, Figure 9 shows the evolution of the average technological lead that U.S. firms would have over their foreign competitors in the absence of any policy intervention (i.e., policy parameters remaining at their calibrated levels). In line with the leftward shift of the gap distribution displayed in Figure 6, Figure 9 suggests that the average technological lead that U.S. firms would have would continue to decline drastically.

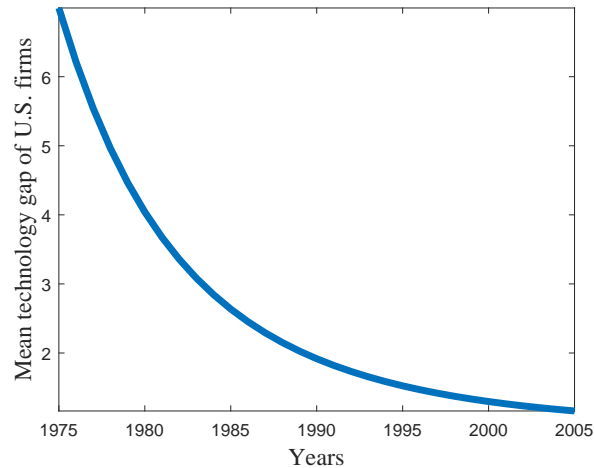


Figure 9: Average technology lead of the U.S. firms absent policy change

*Notes:* The figure exhibits the evolution of the average technology lead that the U.S. firms have over their foreign competitors across years along the transition of the calibrated economy.

This dramatic decline implies a strong international business-stealing effect, whereby foreign firms progressively capture leadership in more and more markets, and profits collected previously by the U.S. firms are now going into the pockets

of foreign firms. Notice that, while losing a domestic market to foreign exporters brings about a productivity gain from better-quality imports, the same is not true when the U.S. exporters lose their technological leadership and thus, profits from abroad but continue to serve the domestic market—the case for a large set of U.S. firms. As such, international business stealing suggests that foreign technological convergence indeed hurt the U.S. economy. In addition, our model implies that this convergence has dynamic effects. With the technological advantage of the U.S. firms shrinking as a result of the foreign catch-up, as time passes, they find themselves further away from the export cutoff and decrease their innovation effort in response (as would be implied by Figure 8a).<sup>40</sup> As we discuss below, this dynamic change in innovation incentives and its effect through intertemporal spillovers are key margins shaping the policy implications of our analysis. Now we turn to the industrial policies that could potentially help the economy tackle foreign technological catch-up.

**Research and Experimentation Tax Credit.** Policy intervention in the 1980s to improve U.S. competitiveness pushed up the R&D subsidies from an average of 5.1 percent in the pre-1981 period to an average of 19.2 percent in the subsequent period. The subsidy in the foreign country remained fairly constant, with 3.8 percent and 4.1 percent in the respective periods.

Figure 10 shows the effect of the subsidy to incumbents' R&D spending on the post-1981 distribution of technology gaps. As discussed previously, the transition path after 1981 in the benchmark economy with no policy intervention entails a large leftward shift in the distribution of technology gaps, which, by 1995, reaches the position demonstrated by the solid blue line. In the alternative economy, where subsidies were introduced in 1981, the resulting distribution in 1995 becomes the dashed red line. The effect of higher subsidies is a small shift to the right relative to the no-intervention case in the dashed lines. This positive shift would have been drastic had the optimal level of R&D subsidy been introduced in 1981 (circled solid line). We discuss optimal subsidies in Section 4.1.

---

<sup>40</sup>In theory, foreign technological convergence can potentially support domestic innovation temporarily if, as a consequence, a large set of domestic exporters who were comfortably above the export cutoff are now closer to that cutoff and are induced to increase their innovation effort in the face stiffer competition. However, in the baseline model, the dominant effect stems from domestic firms falling further below the cutoff, a force that strengthens over time.

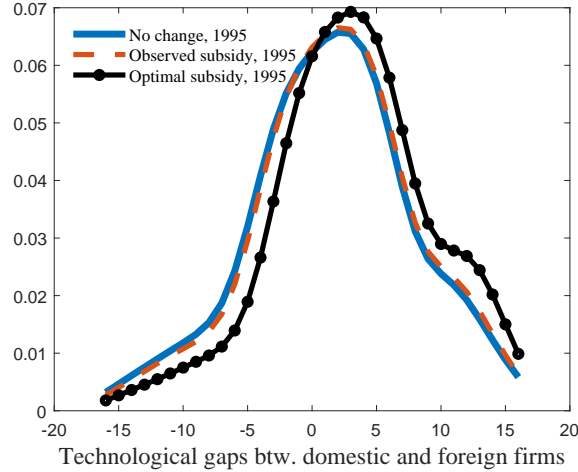


Figure 10: Gap distribution in 1995, baseline vs. counterfactual subsidies

*Notes:* The figure exhibits the resulting simulated gap distributions in 1995 under three different scenarios: under no policy change (solid blue line), under the actual R&D policies after 1981 (dashed red line), and under the model-implied optimal U.S. subsidy rate for the horizon between 1981 and 2006. Positive x-axis values indicate U.S. firms' advantage.

In our framework, a rich set of externalities typical of Schumpeterian growth models, albeit with some novel twists, justify subsidy policies. To start, future innovations build on the stock of current innovations, but current innovators do not take into account that their activity will benefit future innovators. This *intertemporal spillover effect* leads to underinvestment in R&D and provides a motive for subsidies. Second, entrant innovation destroys domestic incumbents' business, exerting a negative externality on domestic incumbent innovation. This *business-stealing effect* leads to overinvestment in R&D and rationalizes a tax on R&D. Furthermore, foreign competition interacts with these forces via its effect on firms' innovation incentives and the resulting evolution of the distribution of relative technology gaps, which ultimately determines the magnitude of the spillover and business-stealing effects in the aggregate economy. In addition, the international aspect of the model generates a third externality that misses in standard closed-economy models. Through catching up or leapfrogging, a laggard domestic firm can steal the foreign leader's business (or part of it). This dynamic—dubbed as the *international business-stealing*—can encourage overall innovation, as access to a larger market also raises prospective rents future domestic entrants can reap and yet is not internalized by the incumbents (or, conversely, it can discourage innovation if the foreign firms steal markets from

the domestic ones). In Section 4.1, we discuss in detail how the trade openness of an economy affects the need for policy intervention through R&D subsidies.

Table 4: Observed R&D Subsidy: 1981-2016

	Subsidy rate	Welfare gains (1981-2016)
Observed R&D Subsidy	19.2%	0.36%
Optimal R&D Subsidy	54%	1.11%

Now we examine the welfare properties of the subsidy intervention. We compute the welfare difference for a 35-year horizon from 1981 until 2016 relative to the path the calibrated economy would generate with no policy change. The result is reported in the first row of Table 4. We find that the U.S. subsidy increase generates a 0.36 percent consumption gain every year over a span of 35 years. Decomposing the overall welfare change into variations in individual sources of income (not shown), we find that these gains are driven by an increase in innovation by U.S. firms leading to faster growth in both U.S. productivity and profit income. As illustrated in Figure 11a, the underlying economic mechanism is straightforward: By reducing the

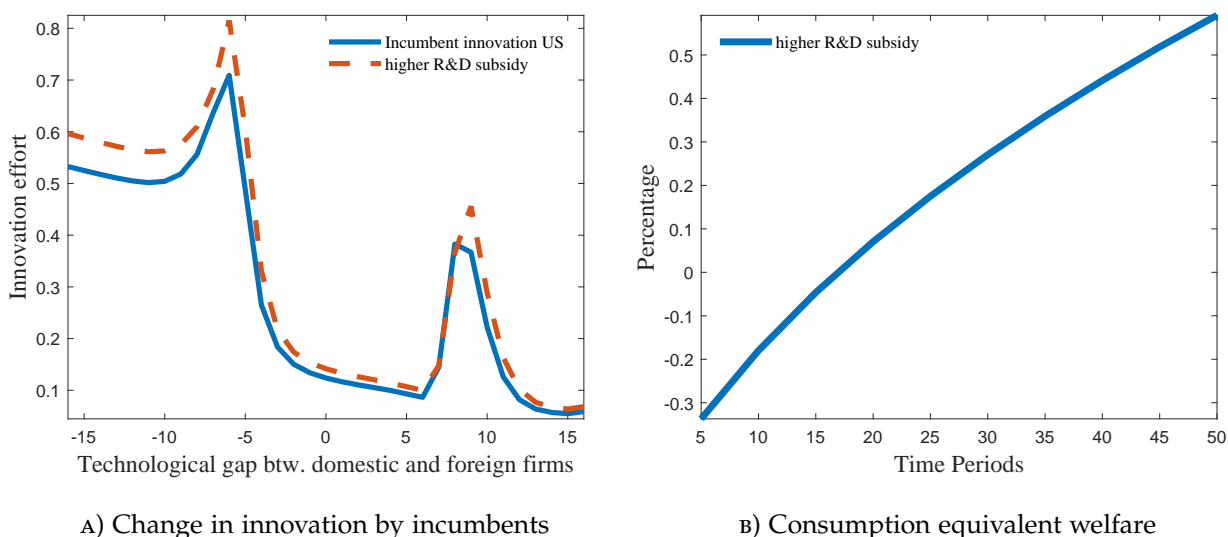


Figure 11: The effect of the change in R&D subsidies

Notes: The figure illustrates the effects of a unilateral subsidy increase in the U.S. (replicating actual policy changes). Panel A shows the shift in the innovation-effort profile of U.S. incumbent firms over technology gaps (averages over the first 15 years after the policy change). Panel B shows the welfare change in consumption equivalent terms over different policy horizons.

cost of R&D, subsidies stimulate innovation in U.S. incumbents, thereby accelerating productivity growth and allowing U.S. firms to obtain market leadership, and the related profits, in a large share of sectors in the economy. These gains more than offset the resources devoted to the higher aggregate R&D spending.<sup>41</sup>

In Figure 11b, we show the evolution of welfare gains over time generated by the increase in U.S. subsidies. The figure shows that in the shorter run—when a horizon of up to approximately 17 years is considered—the subsidy change leads to a welfare loss, which turns to gains as years go by. This early loss means that the consumption path in the economy with higher subsidies is below the baseline path for some time following the policy change. This loss reflects two factors. First, an increase in subsidies shifts resources from consumption to innovation. Second, a relatively faster growth as a result of higher innovation effort pushes up the U.S. relative wage, hurting its competitiveness and dampening the profit-shifting channel. Over time, the profit shifting and, even more importantly, the increase in labor productivity generated by higher domestic innovation, offset the losses, leading to sizable gains.

**A Unilateral Increase in Import Tariffs.** We now explore the implications of a unilateral increase in tariffs as an alternative policy response. Figure 12a shows the welfare gains/losses for the representative household generated by a 100 percent rise in tariffs  $\tau^{US}$  in 1981 (equivalent to a 5.5-percentage-point change). Compared to the calibrated economy's path under no policy change, protectionism hurts consumers in both the short and the long run, despite gains from an increase in profits. The loss in welfare grows over time.

Higher U.S. trade barriers initially generate a small increase in profit income by protecting some sectors from import penetration and shifting profits toward home firms. Recall, though, that the measure of relatively most laggard firms that can benefit from trade protection is relatively small for the United States, as indicated by the left tail of the technology gap distribution, shown by the gray area in Figure 12b. Therefore, the initial gain from laggard firms recapturing production in the domestic market is limited. Moreover, the replacement of foreign exporters by the

---

<sup>41</sup>Figure A.7b demonstrates the positive effect of higher subsidies on the time path of average technology lead of the U.S. firms, resulting in a significantly higher path than the one in the “no-intervention” case in Figure 9.

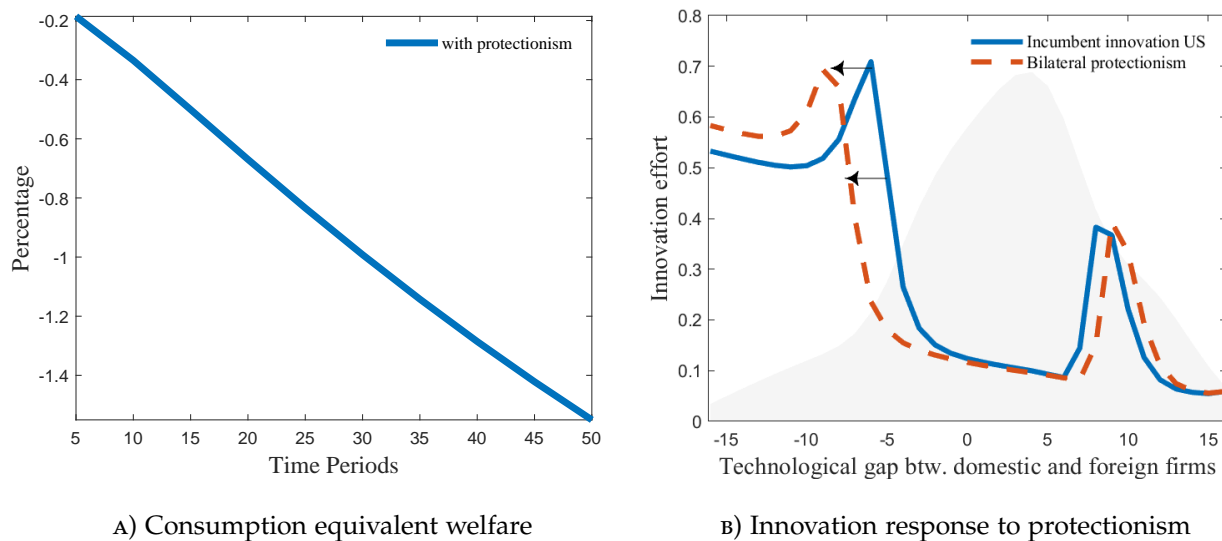


Figure 12: Welfare effects of protectionism: unilateral 100 percent (5.5 ppt) increase in tariffs

*Notes:* The figure illustrates the effects of a unilateral 100 percent increase in U.S. tariffs (without retaliatory response). Panel A shows the welfare change in consumption equivalent terms over different time horizons. Panel B shows the shift in the innovation-effort profile of U.S. incumbent firms over technology gaps (averages over the first 15 years after the policy change). The shaded area shows the resulting gap distribution (scaled up to a scalar to fit in the range of the y-axis).

laggard home firms means that the high-quality foreign products are foregone and replaced by inferior domestic alternatives. This foregone intermediate-good quality leads to substantial welfare losses. The combined effect is negative regardless of the horizon over which the welfare is computed and growing as the horizon lengthens.<sup>42</sup>

As time goes by, the factor that governs variations in welfare is the decline in competitive pressures on domestic firms, which leads to a drop in their innovative activity. Figure 12b shows that innovation efforts by most of the laggard U.S. firms decrease substantially. Since protectionism shifts the U.S. import cutoff further to the left, more firms move further from such an immediate threat. This weakens the defensive innovation motive and leads to lower innovation efforts, making it harder to compensate for the loss of imported frontier technology. Moreover, most U.S. firms, being either exporters or solid domestic producers that are technologically close to or ahead of their competitors, do not benefit from higher domestic tariffs.<sup>43</sup>

<sup>42</sup>As the horizon approaches infinity the consumption-equivalent welfare loss converges to about 3.4 percent (the total loss as the economy approaches the new BGP, accounting for the transition period). For comparison, in a version with logarithmic utility as discussed in Online Appendix F.7, the loss becomes double that figure.

<sup>43</sup>In fact, the unilateral tariff increase has a small negative effect on these firms, as the export

As shown in Figure 12b, innovation decisions of this large group of firms barely change, implying that they do not contribute any additional boost to profit income or factor productivity in response to the policy move.<sup>44</sup> As such, the short-run gains from profit shifting are subdued by the loss of foreign technology, which grows over time as weaker defensive innovation incentives stifle domestic innovation, and thus, growth in productivity and profit income.

The emphasis on dynamic gains from trade—conversely, dynamic losses induced by higher barriers to trade—which is vital for the policy and welfare implications of our model, is a common characteristic across a number of recent contributions in the literature. A notable feature of these models is that international knowledge spillovers drive dynamic gains. For instance, technology diffusion drives productivity dynamics in Perla et al. (2021) as firms draw ideas from the existing distribution of producers in the domestic market, including the foreign exporters. Similarly, in Hsieh et al. (2023), innovation by a firm builds on the blueprint of the seller in the firm’s local market, which, in case the product is currently imported, amounts to international spillovers. In Buera and Oberfield (2020), ideas that improve firm productivity comprise of an original idea (innovation) and insights from other firms (spillovers). In Sampson (2023), efficiency of both innovation and adoption investments benefits from the global knowledge stock. All these studies find sizable dynamic gains from trade.

From a theoretical standpoint, international spillovers are rather limited in our framework when compared with the aforementioned studies, as we posit that it is genuinely occurring only when a foreign firm that is  $\bar{m}$  steps ahead innovates, translating into an automatic quality improvement for the follower via learning part of the leader’s technology. That said, in the spirit of these papers, another view could be that, in our model, any quality improvement by the followers constitutes learn-

---

cutoff shifts slightly to the right, as depicted in Figure 12b. This shift reflects the effect on wages of protecting import-competing firms. Protected domestic firms start production and increase their labor demand, and the ensuing increase in wages reduces the competitiveness of U.S. exporters, which requires them to have a slightly larger technological lead over their competitors before being able to export.

<sup>44</sup>Evidently, the time path of the average technology lead of the U.S. firms is lower than the one in the “no-intervention” case in Figure 9, implying a faster loss in average U.S. leadership (see Figure A.7a in Appendix D).

ing from the foreign leader and thus international knowledge spillovers. Based on this interpretation, we can demonstrate how reduced international spillovers affect dynamic gains from trade. Consider a setting where the step-size distribution for innovations is different for followers ( $m < 0$ ) and the rest of the firms ( $m \geq 0$ ). In particular, we assume both share the same functional form as before but with  $\theta_f > \theta$  for  $m < 0$ , implying a distribution that is more skewed to innovations of smaller size for followers, so that the scope for spillovers is reduced.<sup>45</sup>

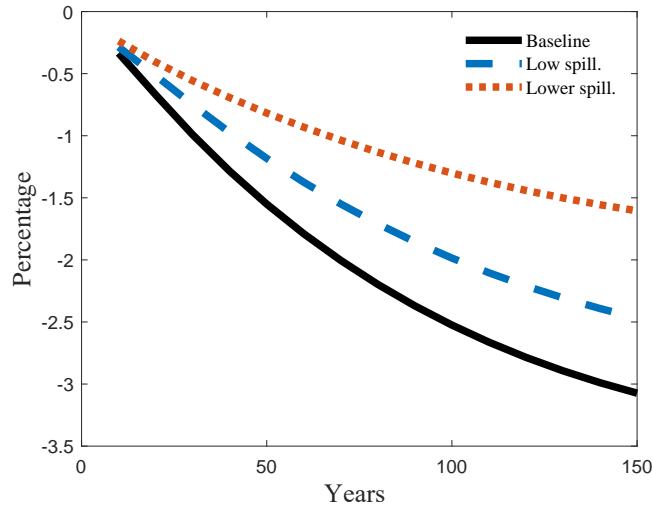


Figure 13: Welfare effects of protectionism under different spillover specifications

*Notes:* The figure exhibits welfare changes resulting from a unilateral doubling of U.S. import tariffs under different specifications for spillovers.

Figure 13 shows the welfare implications of the U.S. doubling import tariffs unilaterally under different scenarios. The dynamic losses diminish with reduced scope for spillovers, concurring with the aforementioned work. That said, the mechanism is different here. In most of these studies, knowledge spillovers are facilitated by goods trade, and lower dependence of spillovers on trade implies smaller dynamic gains from trade, as, for instance, shown by Hsieh et al. (2023) recently. By contrast, in our model, limited spillovers to laggards imply slower catch-up in the baseline and a smaller share of U.S. firms falling behind their rivals. As a result, reduced competition due to trade higher barriers, which is the main factor driving dynamic

<sup>45</sup>The  $m$ -specific distributions,  $F_m(\cdot)$ , are derived in the same fashion as before, and the rest of the parameters are unchanged.

losses, impinge upon a smaller fraction of U.S. firms, limiting its deleterious effect on aggregate innovation and the associated dynamic effects.

## 4.1 Optimal Policies

Next we discuss the implications for optimal policy starting with R&D subsidies.

**Optimal R&D Subsidies.** We compute the optimal subsidies for the home country and compare them with the U.S. subsidy observed in the data in the post-1981 period (reported in Table 4). Precisely, we compute the subsidy rate that maximizes the present discounted value of welfare in a 35-year horizon from 1981 to 2016 and calculate the welfare gains from the optimal subsidy with respect to the benchmark scenario, where the U.S. subsidy does not change in 1981. We also compare these welfare gains under optimal subsidy with those obtained under the observed post-1981 subsidy. The second row in Table 4 reports the results for the optimal policy.

The comparison of the two rows in Table 4 indicates that, although U.S. policymakers went in the right direction by increasing the subsidy rate in response to accelerating foreign catching-up in the 1980s, they did not go far enough. According to our model, the subsidy rate should have increased to 54 percent, about three times the observed one. This high subsidy would have pushed up welfare by a notable 1.11 percent every year in the 35-year period considered. In fact, the observed post-1981 subsidy is only optimal for a time horizon of about 15 years.

Figure 14a shows optimal subsidy levels for different horizons. The optimal subsidy increases with the length of the policy horizon, because a longer horizon allows larger gains from policy-induced innovation and growth to materialize. The intertemporal knowledge spillovers motive plays a key role here, as it springs from the failure of current innovators to internalize the benefit of their success for future innovators. A long-sighted policymaker subsidizes innovation more as this market failure is stronger when future innovation and growth is taken into account.

Figure 14b shows another intriguing result, plotting the level of optimal subsidy for a fixed 35-year horizon in economies with varying degrees of openness, measured by the level of import tariff. In a more open world with smaller bilateral trade

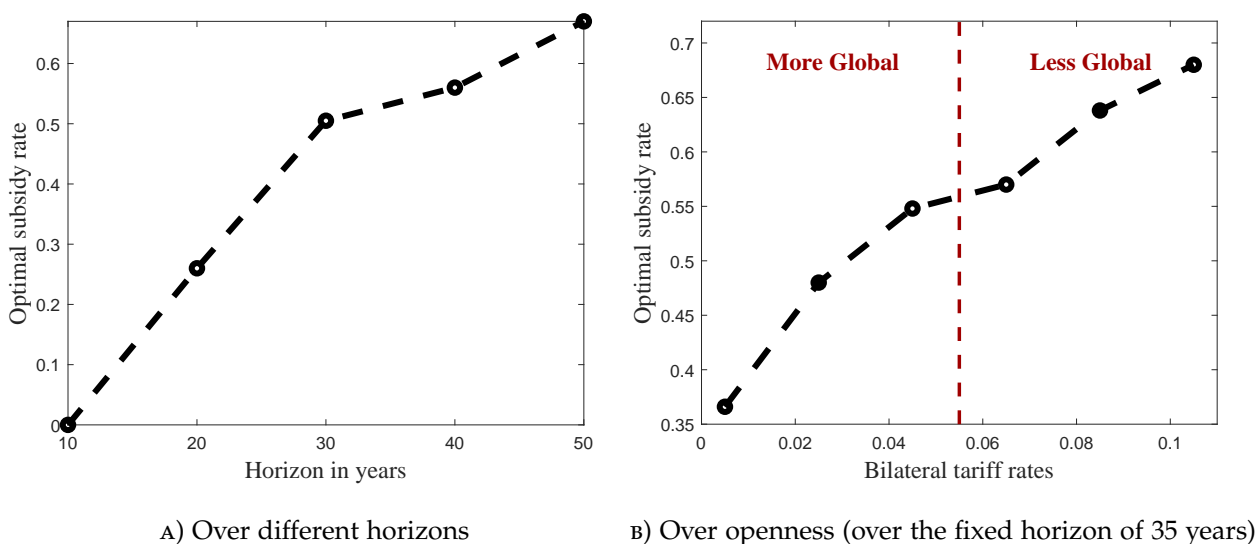


Figure 14: Optimal U.S. R&D subsidy, over different horizons and levels of openness

Notes: Panel A exhibits the profile of the optimal R&D policy for the United States over various policy horizons. Panel B exhibits optimal R&D policy rate for the United States over a fixed horizon of 35 years subject to varying degrees of globalization. The vertical dashed line indicates the calibrated tariff rate.

costs, the level of optimal subsidy is lower and less aggressive policy is appropriate. In other words, the underinvestment in R&D in the home country is lower in a more open world, and policy needs to make a smaller correction.

This result is again driven by the innovation-boosting effect of foreign competition. As discussed above, around the import and export cutoffs, the private incentive to innovate is stronger, because competition is stiffer. In between these cutoffs lies a region where competition is weak and innovation is scarce. Each domestic firm produces comfortably only for its domestic market, and being far from the cutoffs, it has neither a big risk of losing its market nor a big drive to gain new ones. As a result, the incentives to innovate are low. Trade liberalization decreases the distance between these cutoffs, shrinking the set of non-traded goods (goods sold only domestically), where competition and innovation are at their lowest (Figure 15a). If the mass of firms that are exposed to higher competition as a result of the inward shift in cutoffs is large enough, trade liberalization has a strong positive effect on aggregate innovation, incentivizing those firms to increase their effort. This is indeed the case in our benchmark economy: A substantial mass of U.S. firms face more fierce competition upon bilateral reduction in tariffs (Figure 15a); consequently, ag-

gregate U.S. innovation increases (Figure 15b). As such, trade liberalization helps align private and public incentives for R&D, allowing the policy maker to pursue a less aggressive R&D policy in a more globalized world with lower bilateral tariffs. This complementarity is a novel implication of our analysis, underscoring the relevance of investigating R&D policy in an open-economy setting that captures the essence of foreign competition.<sup>46</sup>

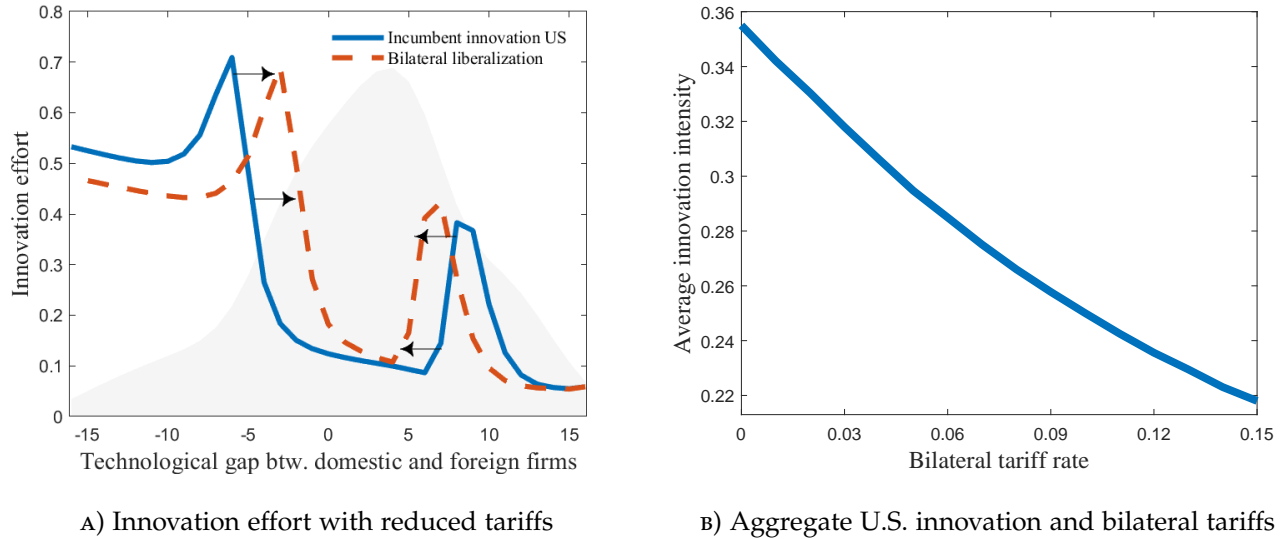


Figure 15: Innovation effects of bilateral tariff changes

Notes: Panel A exhibits the shift in the innovation effort profile of the U.S. incumbents upon a bilateral reduction in the tariff rates to 1 percent (averages over the first 15 years after the policy change). The shaded area shows the resulting gap distribution (scaled up to a scalar to fit in the range of the y-axis). Panel B shows the negative relationship between bilateral tariff rates and aggregate U.S. innovation.

**Optimal Unilateral Tariffs.** The negative relationship between the aggregate innovation effort and protection also plays an important role for the design of optimal tariff policy. On the one hand, reduced tariffs expose more domestic firms to foreign competition (recall that more U.S. firms lie to the right of the import cutoff, as shown in Figure 12b), increasing the rate of domestic innovation and productivity growth. On the other hand, reduced barriers to imports shift profits from domestic firms to

<sup>46</sup>This finding speaks closely to a recent policy event. After the Brexit vote, which will likely raise trade barriers between the U.K. and the European partners, the U.K. government introduced a new “industrial strategy” to boost productivity via investment in innovation and skilled workforce [UK-Government \(2017\)](#). Our finding on the interaction between optimal R&D subsidies and the level of trade openness provides an economic rationale for this policy decision—that is, to compensate for the increased trade barriers with industrial policy that supports innovation.

higher-quality foreign exporters. The interplay between these static and dynamic forces shape the unilateral tariff policy.

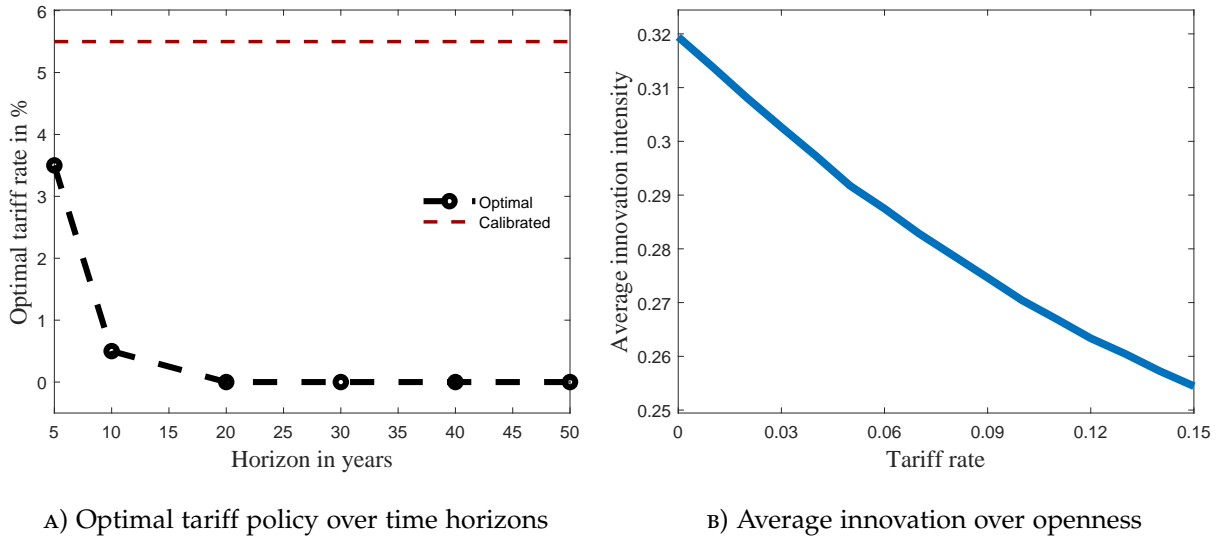


Figure 16: Optimal tariff policy and innovation over openness

Notes: Panel A shows the optimal unilateral tariff policy for the United States over various policy horizons. Horizontal dashed line denotes the calibrated tariff level. Panel B shows the negative effect of unilaterally higher U.S. tariff rates on average innovation intensity of U.S. firms.

Figure 16a demonstrates that the optimal policy, where the U.S. unilaterally sets its non-negative import tariff, is to have zero tariffs for any horizon beyond a decade, over which the policy maker computes welfare. By contrast, the optimal rate is positive in shorter horizons, albeit still lower than the calibrated level. This optimal tariff schedule reflects exactly the shift in the strength of static and the dynamic forces. In the shortest horizons, static gains from tariffs including profit-shifting, which are typically found in standard static models, dominate, and the optimal policy is to increase the tariff rate slightly or maintain the calibrated level. As the policy horizon extends, the negative dynamic losses from high tariff levels, which stem from reduced aggregate innovation (Figure 16b), become more forceful, because the forgone quality improvements emanating from the damping effects of tariffs on the innovation incentives of protected firms accumulate over time. Conversely, over longer policy horizons, there is a larger scope for dynamic gains by lowering tariff barriers and incentivizing domestic firms to innovate. As a result, the optimal tariff

level declines as the horizon extends, though full elimination is not optimal when the horizon is shorter than a decade, because dynamic gains do not fully offset the losses from forgone domestic production and tariff revenue.

The fact that, for horizons longer than a decade, the optimal tariff rate becomes zero, again highlights the dynamic gains from intensified foreign competition. Indeed, when negative tariffs—i.e., import subsidies—are allowed, the optimal rate becomes negative (Figure A.8a in the Online Appendix): ultimately, the import cutoff declines to the minimum, making foreign competition intensify when firms are around the neck-and-neck position technologically. The mechanism behind this result is again that, as the import cutoff decreases, foreign competition incentivizes a large set of domestic firms to increase their innovation effort from low levels, thereby helping reduce the magnitude of underinvestment in aggregate R&D—echoing the dynamics we discussed in regard to Figure 15.

To be sure, several motives for positive tariffs typical of standard static trade models are at play in our framework. As is typical in intra-industry trade models (e.g., Ossa, 2011), countries can use tariffs to increase the mass of goods produced at home, as shown in Figure 12b. This shift benefits home consumers as the related saving in trade costs lowers the average price. If these benefits are larger than the losses produced by the effect of tariffs on the price of imported goods, countries have incentives to set positive import tariffs. The incentives are even stronger in frameworks with positive equilibrium profits, like ours, as the above “relocation” effect also carries a profit-shifting effect, which adds to the motivation for tariffs (e.g., Ossa, 2012). Finally, there is the terms-of-trade motive, typical of neoclassical trade models. An import tariff increases the profits of domestic firms, which in turn, raises the labor demand, domestic wages, and therefore, domestic prices. As a result, the country’s terms of trade, defined as the ratio of ex-factory prices of export and import, improves. In fact, when only static forces are accounted for—i.e., R&D decisions are fixed at their baseline path, not allowed to respond to policy changes—the optimal tariff rate remains positive over all horizons (see Figure A.8b in the Online Appendix). The fact that, in our model, the optimal (non-negative) tariff level is zero despite these motives for positive levels underscores the significance of accounting for the dynamic implications of tariffs through their effect on endogenous

innovation efforts (Figure 16b). This new channel plays the key role in shaping the welfare effect of a tariff, driving the policy maker to optimally choose free trade at policy horizon longer than a decade.<sup>47</sup>

**Joint Policy Analysis: Optimal Innovation and Trade Policy.** Having analyzed the implications of individual policy options, we now focus on the optimal joint policy in which the U.S. could use both the R&D subsidy and the one-sided tariff policy in tandem. Figure 17 plots the optimal R&D subsidy and the optimal U.S. tariff under this scenario over different horizons. The optimal tariff level is again zero across all horizons as in the single policy experiment. The optimal R&D-policy profile is also rising with the length of the horizon, mimicking earlier results. However, an important difference is that the level of the optimal R&D subsidies is lower than the path obtained in the single policy experiment. The reason is that the concurrent large reduction in tariffs changes the incentives of a significant share of U.S. firms, with the related intensification of foreign competition inducing these firms to innovate more. This increase in overall innovation, in turn, reduces the need for aggressive R&D subsidies, underlining again the complementarity between the two policy tools. Yet, it is worth noting that when considering optimal policies, we assumed away any reaction from the foreign country and focused only on one-sided tariff policies. Appendix E discusses the implications of such foreign response.

**Sensitivity and Robustness.** Various robustness checks for our main results are presented in Appendix F.<sup>48</sup> In each experiment, we re-calibrate the model to ac-

---

<sup>47</sup>In a version of this model that abstracts from Ricardian comparative advantage, the optimal policy is to increase the tariff rate for horizons even up to two decades, and the optimal tariff rate remains positive up to three decades (Akcigit et al., 2018). There, the gains from profit-shifting are large enough to more than offset other losses, importantly the dynamic ones, generated by protectionist policies for a quite extended period. By contrast, a key margin in this model is the adjustment of the relative wage. As higher protection improves the home country's terms of trade, the induced increase in domestic production pushes up labor demand. This higher demand raises the cost of production in the home country relative to the foreign, generating a counteracting force to the competitiveness of domestic firms (see Figure A.9). This, in turn, limits the outward shift of the import cutoff in response to higher tariffs, and thus, the mass of firms that are protected. Consequently, the gains in aggregate profit income from higher tariffs are attenuated, falling short of offsetting the negative productivity effects of higher tariffs as discussed above, even in the shorter horizons.

<sup>48</sup>We consider the following seven alternative specifications: (i) targeting the distribution of quality-adjusted patents, (ii) targeting the distribution of cumulative patent counts, (iii) exclusion

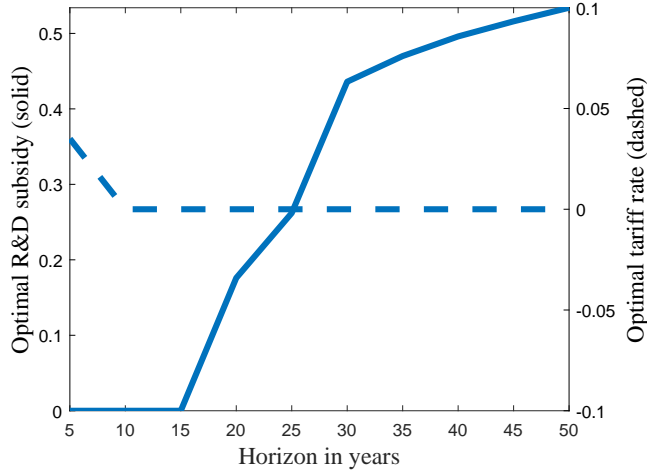


Figure 17: Optimal joint policy with unilateral tariff changes

*Notes:* The figure compares horizon-dependent optimal joint policy under the assumption of no foreign retaliation. The optimal subsidy is the solid line and the optimal tariff the dashed line.

commodate a different assumption and re-evaluate optimal policies along with their welfare implications. A common finding is that, for reasons discussed in Section 4, the optimal unilateral trade policy is the same as in the baseline calibration: zero tariff for most horizons except in the short run. The optimal R&D subsidy rate is again increasing across longer policy horizons as in the baseline result, but with some quantitative differences depending on the experiment. All told, our main results remain robust to the alternative assumptions considered in this analysis.

## 5 Conclusion

Motivated by a set of novel facts on foreign technological catch-up, we build a general equilibrium framework of endogenous growth and trade to evaluate the effectiveness of innovation and trade policies in an open economy, accounting explicitly for transitional dynamics. First, we find that R&D subsidies introduced in the U.S. in the early 1980s was an effective response to restore the technological competitiveness of U.S. firms, with a notable welfare contribution in the medium term. Moreover, the

---

of the U.K. from the target sample, (iv) a lower maximum technology gap ( $\bar{m}$ ), (v) a higher discount rate ( $\rho$ ), (vi) a lower price elasticity ( $\beta$ ), and logarithmic utility ( $\psi$ ).

optimal subsidy is increasing over time horizons and decreasing in openness. The latter is an intriguing result that stems from the dynamic innovation-stimulating effect of foreign competition on domestic firms.

A counterfactual protectionist response to foreign catching-up is always detrimental for welfare. Despite helping less competitive national firms retain their market shares and profits in the short run, protectionism purges their incentives to innovate, thereby making consumers worse off over any horizon in consideration, and increasingly so over longer term. While positive tariff rates are found to be optimal in relatively short horizons, they still imply a reduction from the baseline rate, and the optimal unilateral tariff rate becomes zero for horizons longer than a decade.

With its rich competition structure, our dynamic model provides a useful framework for future work on the nexus of trade openness, competition and firm dynamics. Intriguing topics range from the impact of foreign direct investment on growth to the design of optimal corporate tax policies in open economies, accounting for their broader dynamic implications on firms' innovation decisions.

## References

- ACEMOGLU, D. AND U. AKCIGIT (2012): "Intellectual Property Rights Policy, Competition and Innovation," *Journal of the European Economic Association*, 10, 1–42.
- ACEMOGLU, D., U. AKCIGIT, H. ALP, N. BLOOM, AND W. KERR (2018): "Innovation, Reallocation, and Growth," *American Economic Review*, 108, 3450–91.
- ACEMOGLU, D., U. AKCIGIT, D. HANLEY, AND W. R. KERR (2016): "Transition to Clean Technology," *Journal of Political Economy*, 124, 52–104.
- AGHION, P., A. BERGEAUD, M. LEQUIEN, AND M. MELITZ (2017): "The Impact of Exports on Innovation: Theory and Evidence," Manuscript.
- AGHION, P., N. BLOOM, R. BLUNDELL, R. GRIFFITH, AND P. HOWITT (2005): "Competition and Innovation: An Inverted-U Relationship," *Quarterly Journal of Economics*, 120, 701–728.
- AGHION, P., C. HARRIS, P. HOWITT, AND J. VICKERS (2001): "Competition, Imitation and Growth with Step-by-step Innovation," *Review of Economic Studies*, 68, 467–492.

- AKCIGIT, U. AND S. T. ATEŞ (2023): “What Happened to US Business Dynamism?” *Journal of Political Economy*, 131, 2059–2124.
- AKCIGIT, U., S. T. ATEŞ, AND G. IMPULLITTI (2018): “Innovation and Trade Policy in a Globalized World,” National Bureau of Economic Research Working Paper 24543.
- AKCIGIT, U., D. HANLEY, AND N. SERRANO-VELARDE (2021): “Back to Basics: Basic Research Spillovers, Innovation Policy, and Growth,” *Review of Economic Studies*, 88, 1–43.
- AKCIGIT, U. AND M. MELITZ (2021): “International Trade and Innovation,” National Bureau of Economic Research Working Paper 29611.
- ALESSANDRIA, G., H. CHOI, AND K. J. RUHL (2021): “Trade Adjustment Dynamics and the Welfare Gains from Trade,” *Journal of International Economics*, 131, 103458.
- ANDERSON, J. E. AND E. VAN WINCOOP (2004): “Trade Costs,” *Journal of Economic Literature*, 42, 691–751.
- ATKESON, A. AND A. BURSTEIN (2019): “Aggregate Implications of Innovation Policy,” *Journal of Political Economy*, 127, 2625–2683.
- AUTOR, D., D. DORN, G. H. HANSON, G. PISANO, AND P. SHU (2016): “Foreign Competition and Domestic Innovation: Evidence from U.S. Patents,” National Bureau of Economic Research 22879.
- (2020): “Foreign Competition and Domestic Innovation: Evidence from US Patents,” *American Economic Review: Insights*, 2, 357–74.
- AW, B. Y., M. J. ROBERTS, AND D. YI XU (2011): “R&D Investment, Exporting, and Productivity Dynamics,” *American Economic Review*, 101, 1312–1344.
- BLOOM, N., M. DRACA, AND J. VAN REENEN (2016): “Trade Induced Technical Change? The Impact of Chinese Imports on Innovation, IT and Productivity,” *Review of Economic Studies*, 83, 87–117.
- BLOOM, N., R. GRIFFITH, AND J. VAN REENEN (2002): “Do R&D Tax Credits Work? Evidence from A Panel of Countries 1979–1997,” *Journal of Public Economics*, 85, 1–31.
- BLOOM, N., J. VAN REENEN, AND H. WILLIAMS (2019): “A Toolkit of Policies to Promote Innovation,” *Journal of Economic Perspectives*, 33, 163–184.
- BLUNDELL, R., R. GRIFFITH, AND F. WINDMEIJER (2002): “Individual Effects and Dynamics in Count Data Models,” *Journal of Econometrics*, 108, 113–131.

- BUERA, F. AND E. OBERFIELD (2020): “The Global Diffusion of Ideas,” *Econometrica*, 88, 84–114.
- CAI, J., N. LI, AND A. M. SANTACREU (2022): “Knowledge Diffusion, Trade, and Innovation across Countries and Sectors,” *American Economic Journal: Macroeconomics*, 14, 104–45.
- CAPDEVIELLE, P. AND D. ALVAREZ (1981): “International Comparisons of Trends in Productivity and Labor Costs,” *Monthly Lab. Rev.*, 104, 14–20.
- CHOI, J. AND Y. SHIM (2024): “From Adoption to Innovation: State-Dependent Technology Policy in Developing Countries,” Structural Transformation and Economic Growth Working Paper 091.
- COE, D. T., E. HELPMAN, AND A. W. HOFFMAISTER (2009): “International R&D Spillovers and Institutions,” *European Economic Review*, 53, 723–741.
- COELLI, F., A. MOXNES, AND K. H. ULLTVEIT-MOE (2016): “Better, Faster, Stronger: Global Innovation and Trade Liberalization,” National Bureau of Economic Research 22647.
- COEURDACIER, N. AND H. REY (2013): “Home Bias in Open Economy Financial Macroeconomics,” *Journal of Economic Literature*, 51, 63–115.
- COSTINOT, A. AND A. RODRÍGUEZ-CLARE (2014): *Trade Theory with Numbers: Quantifying the Consequences of Globalization*, Elsevier, vol. 4 of *Handbook of International Economics*, chap. 4, 197–261.
- EATON, J. AND S. KORTUM (1999): “International Technology Diffusion: Theory and Measurement,” *International Economic Review*, 5, 537–570.
- (2001): “Technology, Trade, & Growth: A Unified Framework,” *European Economic Review: Papers and Proceedings*, 45, 742–755.
- (2002): “Technology, Geography, and Trade,” *Econometrica*, 70, 1741–1779.
- GERSCHENKRON, A. (1962): *Economic Backwards in Historical Perspective: A Book of Essays*, Belknap Press of Harvard University Press.
- GORODNICHENKO, Y., J. SVEJNAR, AND K. TERRELL (2010): “Globalization and Innovation in Emerging Markets,” *American Economic Journal: Macroeconomics*, 2, 194–226.
- GROSS, D. (1987): “A Note on the Optimal Tariff, Retaliation and the Welfare Loss from Tariff Wars in a Framework with Intra-industry Trade,” *Journal of International Economics*, 23, 357–367.

- GROSSMAN, G. M. AND E. HELPMAN (1990): "Comparative Advantage and Long-run Growth," *American Economic Review*, 80, 796–815.
- HALL, B. H., A. B. JAFFE, AND M. TRAJTENBERG (2001): "The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools," National Bureau of Economic Research 8498.
- HALL, B. H. AND R. H. ZIEDONIS (2001): "The Patent Paradox Revisited: An Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979-1995," *The RAND Journal of Economics*, 32, 101–128.
- HASHMI, A. R. (2013): "Competition and Innovation: The Inverted-U Relationship Revisited," *Review of Economics and Statistics*, 95, 1653–1668.
- HEAD, K. AND T. MAYER (2014): *Gravity Equations: Workhorse, Toolkit, and Cookbook*, Elsevier, vol. 4 of *Handbook of International Economics*, chap. 3, 131–195.
- HOMBERT, J. AND A. MATRAY (2015): "Can Innovation Help US Manufacturing Firms Escape Import Competition from China?" CEPR Discussion Papers 10666.
- HSIEH, C.-T., P. J. KLENOW, AND I. NATH (2023): "A Global View of Creative Destruction," *Journal of Political Economy Macroeconomics*, 1, 243–275.
- HUMMELS, D. AND V. LUGOVSKYY (2006): "Are Matched Partner Trade Statistics a Usable Measure of Transportation Costs?" *Review of International Economics*, 14, 69–86.
- IACOVONE, L. (2012): "The Better You Are the Stronger It Makes You: Evidence on the Asymmetric Impact of Liberalization," *Journal of Development Economics*, 99, 474–485.
- IMPULLITTI, G. (2010): "International Competition and US R&D Subsidies: A Quantitative Welfare Analysis," *International Economic Review*, 51, 1127–1158.
- IMPULLITTI, G. AND O. LICANDRO (2018): "Trade, Firm Selection, and Innovation: The Competition Channel," *Economic Journal*, 189–229.
- IRWIN, D. (2017): *Clashing over Commerce: A History of U.S. Trade Policy*, Chicago University Press.
- LILEEVA, A. AND D. TREFLER (2010): "Improved Access to Foreign Markets Raises Plant-level Productivity for Some Plants," *Quarterly Journal of Economics*, 125, 1051–1099.
- LÓPEZ, R. A. (2009): "Do Firms Increase Productivity in Order to Become Exporters?" *Oxford Bulletin of Economics and Statistics*, 71, 621–642.

- LYBBERT, T. AND N. ZOLAS (2014): "Getting Patents and Economic Data to Speak to Each Other: An "Algorithmic Links with Probabilities" Approach for Joint Analyses of Patenting and Economic Activity," *Research Policy*, 43, 530–542.
- MELITZ, M. J. AND S. J. REDDING (2021): "Trade and Innovation," National Bureau of Economic Research Working Paper 28945.
- MOWERY, D. AND N. ROSENBERG (1993): "The U.S. National Innovation System," in *National Innovation Systems: a Comparative Analysis*, ed. by R. Nelson, Oxford University Press, 29–75.
- NELSON, R. (1990): "U.S. Industrial Competitiveness: Where Did It Come From and Where Did It Go?" *Research Policy*, 19, 117–132.
- OSSA, R. (2011): "A "New Trade" Theory of GATT/WTO Negotiations," *Journal of Political Economy*, 119, 122–152.
- (2012): "Profits in the "New Trade" Approach to Trade Negotiations," *American Economic Review: Papers and Proceedings*, 102, 466–469.
- PERLA, J., C. TONETTI, AND M. E. WAUGH (2021): "Equilibrium Technology Diffusion, Trade, and Growth," *American Economic Review*, 111, 73–128.
- RIVERA-BATIZ, L. A. AND P. M. ROMER (1991): "Economic Integration and Endogenous Growth," *Quarterly Journal of Economics*, 106, 531–555.
- SAMPSON, T. (2016): "Dynamic Selection: An Idea Flows Theory of Entry, Trade, and Growth," *Quarterly Journal of Economics*, 131, 315–380.
- (2023): "Technology Gaps, Trade, and Income," *American Economic Review*, 113, 472–513.
- SANTACREU, A. M. (2021): "Dynamic Gains from Trade Agreements with Intellectual Property Provisions," Federal Reserve Bank of St. Louis Working Paper 2021-010.
- SIMONOVSKA, I. AND M. WAUGH (2014): "The Elasticity of Trade: Estimates and Evidence," *Journal of International Economics*, 92, 34–50.
- SOMALE, M. (2021): "Comparative Advantage in Innovation and Production," *American Economic Journal: Macroeconomics*, 13, 357–96.
- UK-GOVERNMENT (2017): "Industrial Strategy: Building a Britain Fit for the Future," *Industrial Strategy White Paper*.
- U.S. INTERNATIONAL TRADE COMMISSION (2009): *The Economic Effects of Significant U.S. Import Restraints: Sixth Update 2009*, USITC Publication 4094.

WILSON, D. J. (2009): "Beggar Thy Neighbor? The In-state, Out-of-state, and Aggregate Effects of R&D Tax Credits," *Review of Economics and Statistics*, 91, 431–436.

# Appendices

## A Additional Empirical Material

### A.1 Empirical Facts

This section presents empirical regularities in global technological competition and describes the technological convergence between the United States and other major economies. An account of federal- and state-level R&D tax credit policies follows. The section concludes with suggestive evidence on the positive effect of R&D tax credits on firm-level performance.

#### Fact 1: Technological Convergence

There is a striking change in the relative position of foreign countries relative to the United States in the worldwide technological competition over the course of 1970s until the mid-1980s. At both aggregate and sectoral levels, we observe a clear pattern of catch-up, which we measure using patent and citation counts.

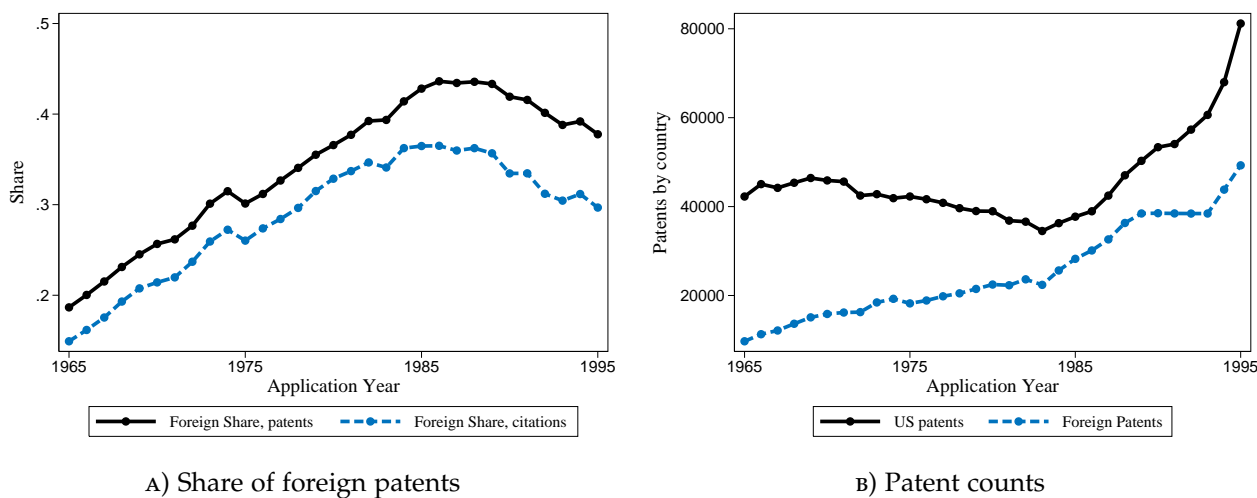


Figure A.1: Share of foreign patents and patent counts: 1965-95

Using USPTO data on patent counts, Figure A.1 shows the yearly change in the

proportion of patents registered in the United States by foreign entities (solid line).<sup>49</sup> It also depicts the same ratio for the citations received by those patents (dashed line). Both lines display an obvious, increasing trend, which means that the growth in the number of foreign-based patents is higher than the growth in U.S.-based ones. Interestingly, the convergence process comes to a halt around the mid-1980s, and we observe a reversal of the trend.

## **Fact 2: R&D Tax Incentives**

Concerns about the strength of the U.S. industries and their ability to compete in a fast-moving global economy increased dramatically in the late 1970s. The key discussions focused on whether the new technologies arising from federally funded R&D were being fully and effectively exploited for the benefit of the national economy, whether there were barriers slowing down private firms in creating and commercializing innovations and new technologies, and whether public-private collaboration in research and innovation could help the U.S. economy in facing these new challenges. Several new policy measures were introduced in those years, with particular attention to avoiding unduly substitution of government for private firms in activities that the latter can naturally perform better. These actions included several programs to facilitate the transfer of the outcome of the federal R&D to private businesses (e.g., the National Cooperative Research Act of 1984 and the Technology Transfer Act of 1986), policies to strengthen intellectual property rights such as the Bayh-Dole Act (1980), and, in particular, tax incentives to innovation that started with the Research and Experimentation Tax Credit (R&E) in 1981.

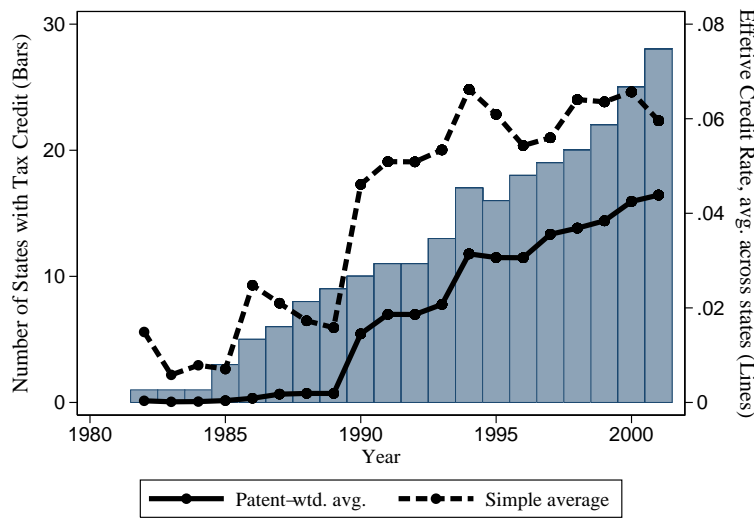
The R&E Tax Credit introduced a 25 percent tax deduction on the increase in R&D spending over the average of the past three years. In 1985, the statutory rate was reduced to 20 percent, and in 1990 the base for eligibility was defined as the average of the 1984–88 R&D to sales ratio (with a maximum of 16 percent) times current sales. The U.S. competitors in high-tech industries—Japan and the large European economies—introduced, or already had in place, tax incentives for innovation. Using corporate tax data, [Bloom et al. \(2002\)](#) estimate the R&D subsidy produced by

---

<sup>49</sup>The distinction between domestic and foreign patents is by geographic location of registry. For more detail, see [Hall et al. \(2001\)](#).

tax policies in the United States, Japan, and key European countries. The data take into account the different tax and tax credit systems used in each country and measure the reduction in the cost of \$1 of R&D investment produced by the tax system. Figure 2b of the main text shows the R&D tax subsidy for the set of countries we are interested in.

The variations across countries are mainly due to the presence and effectiveness of a specific tax credit for R&D. The sudden increase in U.S. subsidies, for instance, takes place with the introduction of the R&E Tax Credit in 1981 and with the revision of the base defining incremental R&D in 1990. We can see that, in 1980, the reduction in innovation cost attributable to the tax system was about 5 percent; it jumps to about 15 percent in 1981, and further increases to more than 25 percent in 1990. In Japan, there is a fixed tax credit of limited effectiveness for the period considered. In the rest of the countries there are no special tax provisions or credits given on R&D expenditures, and the positive and fairly constant subsidy rates are produced by tax credits common to all assets.



Source: Authors' calculations, USPTO, Wilson (2009)

Figure A.2: U.S. state-level R&D tax credit

In 1982, starting with Minnesota, U.S. states also introduced tax subsidies for R&D. In Figure A.2 we report the evolution of the average rate of U.S. state tax credits together with the number of states offering a tax credit each year, using tax

credit data of [Wilson \(2009\)](#). The simple average of effective tax credits across states offering a credit was about 6 percent in 1995, nearly one-fourth of the federal rate, and the number of states following such a policy rose to 32. [Figure A.2](#) also shows the average R&D credit level weighted by the state-level patent production, whose evolution over time is parallel to the simple average.<sup>50</sup>

## B Model Details and Derivations

### B.1 Innovation and Firm Dynamics

[Figure A.3](#) demonstrates the evolution of leadership in intermediate product lines as a result of incumbent innovation, entry, and exit. In the left panel, five product lines with heterogeneous technology gaps are shown. In the first two lines, firms from country *B* (designated by a square) lead, and in the next two lines, firms from country *A* (designated by a circle) lead. In the last line, firms are in neck-and-neck

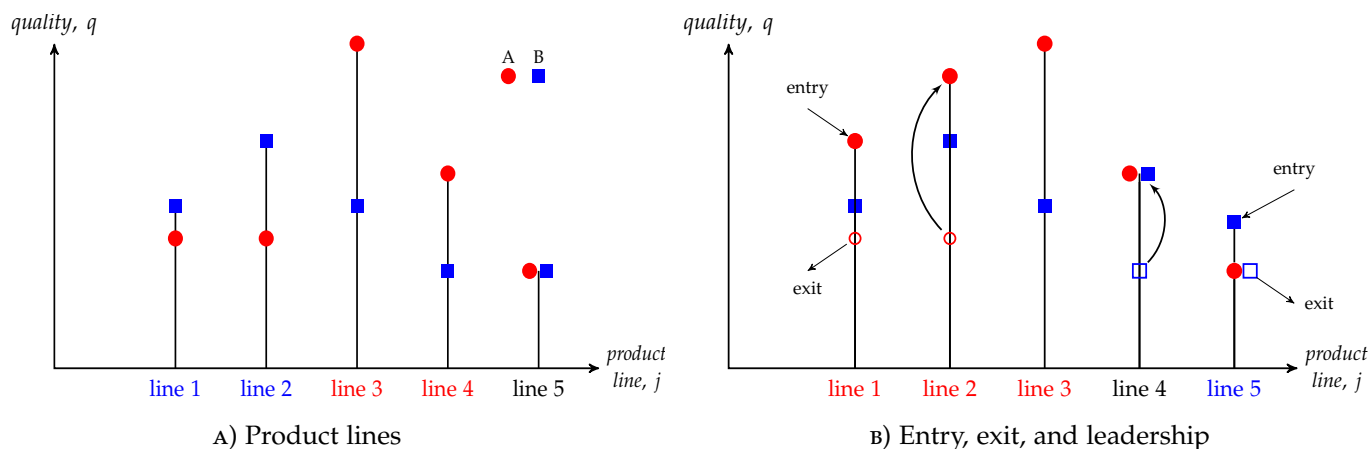


Figure A.3: Evolution of product lines

*Notes:* Panel A exhibits the positions of competing incumbent firms with heterogeneous quality gaps in a set of product lines. Firms from country *B* (designated by blue squares) are technological leaders in the first two lines, firms from country *A* (red circle) are leaders in the next two lines, and firms are in neck-and-neck position in the last line. Panel B illustrates the effects of innovation by incumbents and entrants and the resulting dynamic of entry, exit, and technological leadership. Empty squares or circles denote the previous position of firms that innovate or exit.

<sup>50</sup>As opposed to the simple average, the weighted average multiplies the state-level effective credit by the fraction of total U.S.-based patents registered in that state.

position. The right panel exhibits how these positions evolve. Country  $A$  seizes technological leadership in the first two lines in two different ways. In line 1, an entrant from  $A$  enters with a large enough quality improvement, moving ahead of the previous leader, who is from  $B$ , and also driving the previous domestic incumbent out of business. In line 2, the incumbent from  $A$  generates an innovation with a step size that is larger than the existing gap, which enables it to surpass the previous leader. While there is no change in line 3, firms become neck-and-neck in line 4 as a result of a successful innovation by the incumbent from  $B$ . In line 5, an entrant innovation from  $B$  breaks the neck-and-neck competition and brings the technological leadership to  $B$ , while also forcing the country's previous incumbent to exit.

Lastly, notice that changes in technological leadership may not result in business stealing when trade costs exist. Consider line 2, where country  $B$ 's final-good producers initially buy domestic inputs from the technologically superior domestic intermediate producer. Even if technological leadership changes hands in this line, country  $B$ 's final good producers may still prefer buying domestic intermediate inputs instead of importing the better-quality foreign input if trade costs make it unprofitable despite the quality advantage of country  $A$ 's firm.

## B.2 Imperfect Observability of Quality

As discussed in footnote 32, the final-goods producers observe the quality of the foreign good only imperfectly. Therefore, they may choose to produce using one variety (domestic or foreign) even if the true effective quality gap implies the other one is the better option. This assumption ensures a smooth transition path. Let us provide an example to show how this assumption works.

Recall that the export cutoff was defined by the following relationship:

$$m \log \lambda \geq (1 - \beta) \left[ \frac{1}{\beta} \log(1 + \kappa) - \log \left( \frac{\bar{Q}_{Bt} Q_{At}}{\bar{Q}_{At} Q_{Bt}} \right) \right].$$

The smallest integer  $m^X \in \mathbb{N}$  that satisfies this relationship is the export cutoff. First, notice that the *iid* error has a bearing on the optimal variety decision of the final-good producer only around the export/import cutoffs. Suppose that the true

effective technology gap between two firms is  $m$ . If  $m^X \notin [m - 1/2, m + 1/2]$ , the imperfectly observed quality of the foreign variety would not alter the decision of the final-goods producer. Now let us consider the other case. Suppose that  $m^* = 13.7$  makes the expression above hold with equality. Then, a firm would need to open the gap at least 14 steps to be able to export, if the true quality was observed by the foreign buyer with certainty. But, in the setting with imperfect observability, even if a foreign firm is 14 steps ahead, the observed technology gap may fall anywhere in  $[13.5, 14.5]$  with equal probability. Consequently, there is a 20 percent chance that the quality of the foreign good was observed at a value that makes the observed gap below 13.7. In that event, importing would become seemingly unprofitable for the final-good producer, and the foreign firm would not be able to export its good.

This adjustment ensures a smooth numerical transition, removing any discontinuity—especially, in the implied equilibrium wage rates—that may arise when the export/import cutoffs change endogenously from one integer to another.

### B.3 Proof of Lemma 1

We confirm this lemma by the guess-and-verify method. Conjecture the following form:  $V_{cmt} = qv_{mt}$ . Substituting this expression into equation (14), we get:

$$\begin{aligned} r_{At}v_{Amt}q - \dot{v}_{Amt}q &= \max_{x_{Amt}} \Pi(m)q - (1 - s^A) \alpha_A \frac{(x_{Amt})^{\gamma_A}}{\gamma_A} q \\ &\quad + x_{Amt} \left[ \sum_{n_t=m+1}^{\bar{m}} \mathbb{F}_m(n_t) v_{Ant} \lambda^{(n_t-m)} q - v_{Amt}q \right] + \tilde{x}_{Amt} [0 - v_{Amt}q] \\ &\quad + \left( x_{B(-m)t} + \tilde{x}_{B(-m)t} \right) \sum_{n_t=-m+1}^{\bar{m}} \mathbb{F}_{-m}(n_t) \left[ v_{A(-nt)}q - v_{Amt}q \right]. \end{aligned}$$

Dividing all sides by  $q$ , we obtain the desired result:

$$r_{At}v_{Amt} - \dot{v}_{Amt} = \max_{x_{Amt}} \left\{ \begin{aligned} &\Pi_t(m; \tau^A, \tau^B) \bar{w}_{ct}^{\frac{\beta-1}{\beta}} - (1 - s^A) \alpha_A \frac{(x_{Amt})^{\gamma_A}}{\gamma_A} \\ &+ x_{Amt} \sum_{n_t=m+1}^{\bar{m}} \mathbb{F}_m(n_t) \left[ \lambda^{(n_t-m)} v_{Ant} - v_{Amt} \right] + \tilde{x}_{Amt} [0 - v_{Amt}] \\ &+ \left( x_{B(-m)t} + \tilde{x}_{B(-m)t} \right) \sum_{n_t=-m+1}^{\bar{m}} \mathbb{F}_{-m}(n_t) \left[ v_{A(-nt)} - v_{Amt} \right] \end{aligned} \right\}.$$

## B.4 Proof of Proposition 1

We consider a version of the model economy with two symmetric countries that abstracts from firm entry, features quick catch-up by followers, and minimizes the incentives for quality improvements. First, we take  $\tilde{\alpha}_c \rightarrow \infty$  implying zero entry in both countries. Second, innovations improve a leader's position by a single step—i.e.,  $\mathbb{F}_m(n = m + 1) = 1, \forall m \geq 0$ . Third, we set  $\mathbb{F}_m(n = 0) = 1, \forall m < 0$ , to allow any innovating follower to reach neck-and-neck position. Fourth, we assume that  $\lambda = 1 + \varepsilon$ , where  $\varepsilon$  is arbitrarily close to zero, implying that quality improvements from innovations are minuscule. Therefore, innovation incentives are driven by business-stealing and escape-competition effects, emphasizing the dynamic effect of openness and competition on innovation.

In this environment firm values can be written as

$$\begin{aligned} rv_{-\bar{m}} &= -\frac{x_{-\bar{m}}^2}{2} + x_{-\bar{m}} [v_0 - v_{-\bar{m}}] \\ rv_{-m} &= -\frac{x_{-m}^2}{2} + x_{-m} [v_0 - v_{-m}] + x_m [v_{-m-1} - v_{-m}] \\ rv_0 &= -\frac{x_0^2}{2} + x_0 [v_1 - v_0] + x_0 [v_{-1} - v_0] \\ rv_m &= 2\pi - \frac{x_m^2}{2} + x_m [v_{m+1} - v_m] + x_{-m} [v_0 - v_m] \\ rv_{\bar{m}} &= 2\pi - \frac{x_{\bar{m}}^2}{2} + x_{\bar{m}} [v_{\bar{m}} - v_{\bar{m}}] + x_{-\bar{m}} [v_0 - v_{\bar{m}}] \end{aligned}$$

with  $m \in \{1, \dots, \bar{m} - 1\}$ .<sup>51</sup> Note that  $v_{-m} = v_{-\bar{m}}$  and  $v_m = v_{\bar{m}}$  satisfy the set of equation for  $m > 0$ . This implies that we have three distinct firm values and innovation rates, and that  $x_{\bar{m}} = x_m = 0$ .

Now we show  $x_0 > 0$ ,  $x_{-\bar{m}} > 0$  and  $x_0 > x_{-m} = x_{-\bar{m}}$ .

1.  $v_{\bar{m}} > v_0$  : Assume not such that  $v_0 \geq v_{\bar{m}} = v_1$ . Then  $[v_1 - v_0] \leq 0$ , and  $x_0 = 0$ . This implies  $v_0 = 0 \geq v_{\bar{m}} = v_1$ . But  $v_0 = 0$  would mean  $rv_{\bar{m}} = 2\pi - x_{-\bar{m}}v_{\bar{m}}$  and thus  $v_{\bar{m}} > 0$ , a contradiction. Therefore  $x_0 > 0$ .

---

<sup>51</sup>Lemma 1 applies also in this environment. For the sake of the argument, we assume that neck-and-neck firms have zero profits. We also drop country identifiers thanks to symmetry.

2.  $v_0 > v_{-\bar{m}}$ : Assume not such that  $v_{-\bar{m}} \geq v_0$ . Then  $x_{-\bar{m}} = 0$  implying that  $v_{-\bar{m}} = 0 \geq v_0$ . This is possible only if  $x_0 = 0$ . But since  $v_{\bar{m}} > v_0$  as shown above,  $x_0 > 0$ , a contradiction. Therefore  $x_{-\bar{m}} > 0$ .
3.  $[v_{\bar{m}} - v_0] > [v_0 - v_{-\bar{m}}]$ : Assume not such that  $[v_0 - v_{-\bar{m}}] \geq [v_{\bar{m}} - v_0]$ . This means  $v_0 < 0$  unless  $x_0 = 0$ . If  $v_0 < 0$ , it is a contradiction by step 2. If  $x_0 = 0$  meaning that  $v_0 = 0$  it is a contradiction by step 1. Therefore  $[v_{\bar{m}} - v_0] > [v_0 - v_{-\bar{m}}]$  and  $x_0 > x_{-m} = x_{-\bar{m}} > x_{\bar{m}} = x_m = 0$ .

Proposition 1 formalizes the fact that the positive effect of foreign competitive pressures on innovation incentives becomes the strongest when firms compete against rivals producing goods of similar quality. This effect is analogous to the one in closed-economy, step-by-step models—namely, the “escape-competition” effect—but it gains an international aspect in the context of a small open economy. Moreover, notice that, in our general model, the international structure modifies the escape-competition effect in more subtle ways than merely shifting the origin of the competitive pressure from domestic to foreign. In fact, the intensification of innovation as a result of international competition arises at two points in our generalized model instead of one because of trade costs. Firms have an incentive to escape competition for two similar yet distinct reasons: to capture domestic profits (defensive R&D); and to capture export markets (expansionary R&D). These important dynamic effects, reflecting again market size and selection channels, are completely absent in a static comparison.

## B.5 Value Functions

**Value Functions for Boundary Gaps.** Two boundary cases complete the exposition of incumbents’ problem: when the incumbent is  $\bar{m}$ -steps ahead:

$$\begin{aligned}
r_{At} V_{A\bar{m}t}(q) - \dot{V}_{A\bar{m}t}(q) = \max_{x_{A\bar{m}t}} & \left\{ (\pi L_A + \pi^* L_B) q - (1 - s^A) \alpha_A \frac{(x_{A\bar{m}t})^{\gamma_A}}{\gamma_A} q \right. \\
& + x_{A\bar{m}t} [V_{A\bar{m}t}(\lambda q) - V_{A\bar{m}t}(q)] + \tilde{x}_{A\bar{m}t} [0 - V_{A\bar{m}t}(q)] \\
& \left. + \left( x_{B(-\bar{m})t} + \tilde{x}_{B(-\bar{m})t} \right) \sum_{n_t=-\bar{m}+1}^{\bar{m}} \mathbb{F}_{-\bar{m}}(n_t) [V_{A(-n)t}(q) - V_{A\bar{m}t}(q)] \right\},
\end{aligned}$$

and  $\bar{m}$ -steps behind<sup>52</sup>

$$\begin{aligned}
r_{At} V_{A(-\bar{m})t}(q) - \dot{V}_{A(-\bar{m})t}(q) = \max_{x_{A(-\bar{m})t}} & \left\{ - (1 - s^A) \alpha_A \frac{(x_{A(-\bar{m})t})^{\gamma_A}}{\gamma_A} q \right. \\
& + x_{A(-\bar{m})t} \sum_{n_t = -\bar{m}+1}^{\bar{m}} \mathbb{F}_{-\bar{m}}(n_t) \left[ V_{Ant}(\lambda^{(n_t+\bar{m})} q) - V_{A(-\bar{m})t}(q) \right] \\
& + \tilde{x}_{A(-\bar{m})t} \left[ 0 - V_{A(-\bar{m})t}(q) \right] \\
& \left. + (x_{B\bar{m}t} + \tilde{x}_{B\bar{m}t}) \left[ V_{A(-\bar{m})t}(\lambda q) - V_{A(-\bar{m})t}(q) \right] \right\}.
\end{aligned}$$

The last term in the value function of  $\bar{m}$ -step-behind incumbent reflects a form of cross-border knowledge spillovers: When a leader at the maximum gap  $\bar{m}$  innovates, the follower in this sector automatically sees its technology jump by a measure  $\lambda$ . In each period this spillover keeps laggard firms in the innovation race, preventing them from falling too far behind. Because the innovation technology is the same for all firms, laggards always have a chance to catch up.

**Entrant Firm Value.** Recall that entry is directed at individual product lines and a successful entrant improves on the active domestic incumbent's technology. The problem of an entrant that aims at a product line where the domestic incumbent is  $m > 0$  ( $m < 0$ ) steps ahead (behind) is as follows:

$$\tilde{V}_{cmt}(q) = \max_{\tilde{x}_{cmt}} \left\{ - \frac{\tilde{\alpha}_c}{\tilde{\gamma}_c} (\tilde{x}_{cmt})^{\tilde{\gamma}_c} q + \tilde{x}_{cmt} \sum_{n_t = m+1}^{\bar{m}} \mathbb{F}_m(n_t) V_{cnt}(\lambda^{(n_t-m)} q) \right\}. \quad (\text{A.1})$$

Again,  $\mathbb{F}_m(\cdot)$  denotes the probability distribution of potential step sizes, from which a random step will realize conditional on having an innovation. An entrant who fails to innovate exits the economy. Solving this problem leads to the following

---

<sup>52</sup>These value functions assume that  $\bar{m}$ -step ahead leader captures both the domestic and the foreign market—i.e., the quality advantage at the largest gap is enough to cover the trade costs.

equilibrium value of the entrant firm:

$$\tilde{V}_{cmt}(q) = \left(1 - \frac{1}{\tilde{\gamma}_c}\right) \tilde{\alpha}_c (\tilde{x}_{cmt})^{\tilde{\gamma}_c} q > 0,$$

which is independent of the production line's index  $j$  and is determined by the current gap size.

## B.6 Aggregation and the Distribution of Leadership

The growth rate of this economy is determined by the changes in aggregate quality across intermediate goods,  $Q_{cmt}$ . In order to analyze the evolution of aggregate quality, and breaking it down into its various sources, we need to consider all possible scenarios of innovation outcomes and keep track of the resulting changes in quality levels across product lines at each gap size. Changes in  $Q_{Amt}$  are characterized by the following expressions:

$$\begin{aligned} \dot{Q}_{Amt} &= \sum_{s=-\tilde{m}}^{m-1} \mathbb{F}_s(m) (x_{Ast} + \tilde{x}_{Ast}) \lambda^{m-s} Q_{Ast} + \sum_{s=m+1}^{\tilde{m}} \mathbb{F}_{-s}(-m) (x_{B(-s)t} + \tilde{x}_{B(-s)t}) Q_{Ast} \\ &\quad - \left[ x_{Amt} + x_{B(-m)t} + \tilde{x}_{Amt} + \tilde{x}_{B(-m)t} \right] Q_{Amt} \\ \dot{Q}_{A\tilde{m}t} &= \sum_{s=-\tilde{m}}^{\tilde{m}-1} \mathbb{F}_s(\tilde{m}) (x_{Ast} + \tilde{x}_{Ast}) \lambda^{\tilde{m}-s} Q_{Ast} \\ &\quad + \left[ (x_{A\tilde{m}t} + \tilde{x}_{A\tilde{m}t}) (\lambda - 1) - x_{B(-\tilde{m})t} - \tilde{x}_{B(-\tilde{m})t} \right] Q_{A\tilde{m}t} \\ \dot{Q}_{A(-\tilde{m})t} &= \sum_{s=-\tilde{m}}^{\tilde{m}-1} \mathbb{F}_s(\tilde{m}) (x_{Bst} + \tilde{x}_{Bst}) Q_{A(-s)t} \\ &\quad + \left[ (x_{B\tilde{m}t} + \tilde{x}_{B\tilde{m}t}) (\lambda - 1) - x_{A(-\tilde{m})t} - \tilde{x}_{A(-\tilde{m})t} \right] Q_{A(-\tilde{m})t} \end{aligned}$$

The first equation is the generic expression that describes the change in the aggregate quality of intermediate goods produced by firms from country  $c$  at position  $m$ . The first sum captures the addition of new incumbents improving to gap  $m$ . An innovation with step size  $\lambda^{m-s}$  by a domestic incumbent or entrant at position  $s < m$  happens with probability  $\mathbb{F}_s(m)$ , and it implies that the domestic incumbent in that product line will reach gap  $m$ . The second sum captures the addition of product lines, where the position of the domestic incumbent worsens to  $m$  from a better

one. An improvement by foreign incumbents or entrants from position  $-s < -m$  to  $-m$ , which occurs with probability  $\mathbb{F}_{-s}(-m)$ , hits the domestic incumbent in that product line enjoying the position  $s > m$  and brings it down to gap  $m$ . The third component in the equation captures the fact that any innovation in a product line where the domestic incumbent is at position  $m$  causes a change in its position and, thus, a negative change in the aggregate quality index across product lines of position  $m$ . The other two equations describe the boundary cases. In case of  $\bar{m}$ , notice that innovation by the domestic incumbent or entrants does not change the gap between the domestic incumbent and the foreign follower due to spillover effects, but it raises the average quality by the step size. Reciprocally, any innovation by the foreign incumbent or entrant improves the quality of the good that the most laggard domestic incumbents produce because of spillover effects.<sup>53</sup>

The laws of motion that determine the measure of product lines where the incumbent from country  $c$  is at position  $m$  are described by

$$\begin{aligned}
\dot{\mu}_{A\bar{m}t} &= \dot{\mu}_{B(-\bar{m})t} = \sum_{s=-\bar{m}}^{\bar{m}-1} \mathbb{F}_s(\bar{m}) (x_{Ast} + \tilde{x}_{Ast}) \mu_{Ast} - \mu_{A\bar{m}t} (x_{B(-\bar{m})t} + \tilde{x}_{B(-\bar{m})t}) \\
&\quad \sum_{s=m+1}^{\bar{m}} \mathbb{F}_{-s}(-m) (x_{B(-s)t} + \tilde{x}_{B(-s)t}) \mu_{Ast} \\
\dot{\mu}_{Amt} &= \dot{\mu}_{B(-m)t} = + \sum_{s=-\bar{m}}^{m-1} \mathbb{F}_s(m) (x_{Ast} + \tilde{x}_{Ast}) \mu_{Ast} \\
&\quad - [x_{Amt} + x_{B(-m)t} + \tilde{x}_{Amt} + \tilde{x}_{B(-m)t}] \mu_{Amt} \\
\dot{\mu}_{A(-\bar{m})t} &= \dot{\mu}_{B\bar{m}t} = \sum_{s=-\bar{m}}^{\bar{m}-1} \mathbb{F}_s(\bar{m}) (x_{Bst} + \tilde{x}_{Bst}) \mu_{A(-s)t} - \mu_{A(-\bar{m})t} (x_{A(-\bar{m})t} + \tilde{x}_{A(-\bar{m})t}).
\end{aligned} \tag{A.2}$$

The drivers of the dynamics are the same as in the case of aggregate quality indices, except that step sizes are not relevant in determining the changes in  $\mu$ . Notice that the change in the measure of position- $m$  product lines in a country corresponds to the change in the measure of position- $(-m)$  product lines in the other country. Moreover, because there is a unit measure of intermediate product lines we have  $\sum_m \mu_{cm} = 1$ . Therefore, information on  $2\bar{m} - 1$  measures is enough to describe the distribution of product lines according to the technological gap size between the two active incumbents from each country.

---

<sup>53</sup>The evolution of the variables for country  $B$  is given reciprocally.

## C Additional Validation Exercises

**Validation Exercise II: Tariff Reduction and Shift in Innovation Intensity.** As another test, we present a case study on the link between trade barriers and firms' innovation efforts. Our model implies that because of intensified competition around trade thresholds, which are determined by trade costs, firms increase their innovation efforts in these regions. One way to detect this relationship in the data is to focus on firms' innovation behavior in a specific sector and its evolution over time with respect to changes in trade barriers in that sector. To perform such an analysis, we map USPTO patent data to Standard International Trade Classification (SITC) industries (revision 2) and concentrate on the manufacturing sector, which makes up about half of patenting activity, over a period with substantial reductions in tariff rates.<sup>54</sup> Data on tariffs are available from the World Integrated Trade Solution (WITS) database of the World Bank. Studying tariff reductions in a specific sector instead of a cross-industry comparison allows us to proceed without resorting to using a reliable estimate of industry-specific trade costs—known to be notoriously difficult to obtain (Anderson and van Wincoop, 2004; Hummels and Lugovskyy, 2006)—as long as non-tariff barriers are not rising over time.

Figure A.4a shows the decline in the tariff rates to which U.S. manufacturing imports and exports were subject over the 1990s.<sup>55</sup> On average, both barriers were 2 percent lower between 1997 and 2004 than between 1989 and 1993, in part as a result of the Uruguay round of the General Agreement on Tariffs and Trade completed in 1994 and other bilateral trade agreements. In parallel, Figure A.4b depicts the innovation intensity of incumbent patentees in the U.S. manufacturing sector with respect to their technological position relative to foreign competitors, again before

---

<sup>54</sup>Crosswalks mapping USPTO data to SITC industries are from Lybbert and Zolas (2014).

<sup>55</sup>The tariff data on WITS go back to 1989. The United States is one of the few countries that reports tariffs on imports reliably across time and trade partners. We use the same sample of trade partners as in the original analysis (Canada, Germany, France, Italy, Japan, and the U.K.) and weight the average effective tariff to manufacturing imports from each of them by their patent share in the USPTO data in 1988. Similar reductions in tariffs are observed when accounting for larger groups of countries as well. Tariffs on U.S. manufacturing exports are more limited, reported only by Canada and Japan. We use the Japanese series, as Japan constitutes about half of foreign patents registered in the United States by the late 1980s. Finally, we use the broad sector grouping for manufacturing in WITS data, which comprises chapters 6 (manufactured products) and 8 (miscellaneous manufactured articles) of the SITC classification (excluding non-ferrous metals with the code 68).

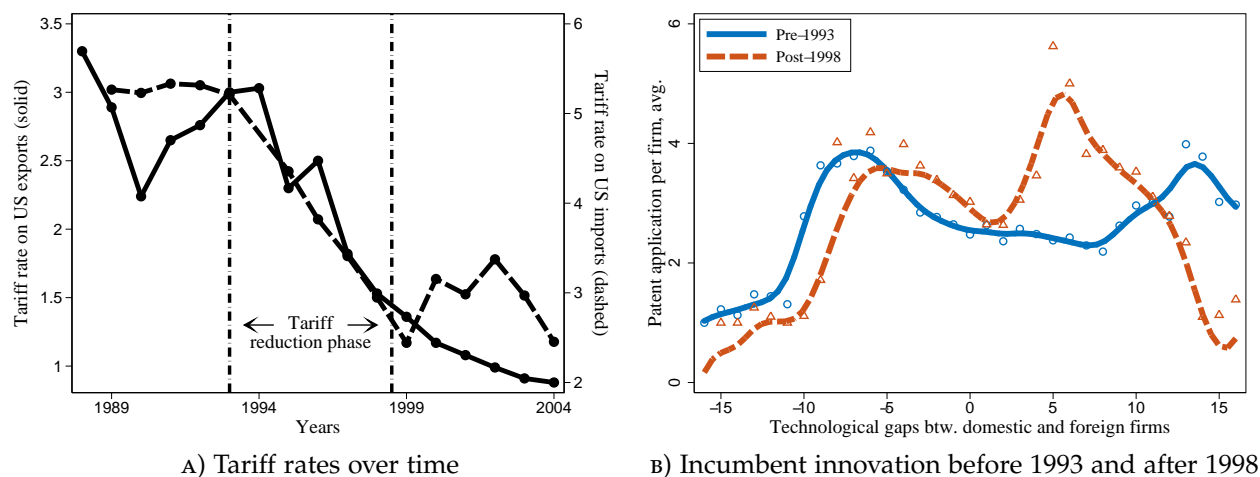


Figure A.4: Tariffs and incumbents' innovation intensity across technology gaps in manufacturing

Notes: Panel A shows the reduction in the average effective tariff rates applied to U.S. imports and exports of manufactures after the Uruguay round of the GATT. Tariff rates applied by or to goods of individual countries are obtained from WITS and are weighted by the patenting intensity of the trade partners in the USPTO data. Panel B shows the change in the innovation intensity of incumbent U.S. patentees in the manufacturing sector across technology gaps. The hollow markers designate actual data points (circles for the earlier period and triangles for the later), and the lines are fit using smoothing splines.

and after the mid-1990s.<sup>56</sup> Noticeably, incumbent-innovation intensity in the manufacturing sector exhibits a double-peaked profile in line with our findings for the complete set of patents in the USPTO data. Moreover, we observe that the period of tariff reductions coincides with an inward shift of peaks in incumbents' innovation intensity profile across technology gaps. This observation mirrors the predictions of our model: Lower bilateral trade barriers imply that firms with a lesser technology advantage over their competitors start exporting, making the competition for markets stiffer at smaller technology gaps and thereby resulting in peaks closer to (purely technological) neck-and-neck position (at gap zero).

**Validation Exercise III: Entrant Innovation vs. Leadership.** Entry is another source of business stealing in the model. However, in contrast to incumbents, potential entrants are not subject to immediate competitive pressures from the other

<sup>56</sup>We constructed the innovation intensity of incumbents in the manufacturing sector over technology gaps following similar steps to those described in Section 3, except that we used SITC subindustries instead of patent classes as the unit of analysis. In line with the WITS data, we used the same specification of the manufacturing sector, which consists of SITC chapters 6 and 8.

country's firms. Therefore, the shape of entrants' R&D effort profile, demonstrated in Figure A.5a, reflects mainly the market size effect around the two cutoffs and not a direct effect of foreign competition.

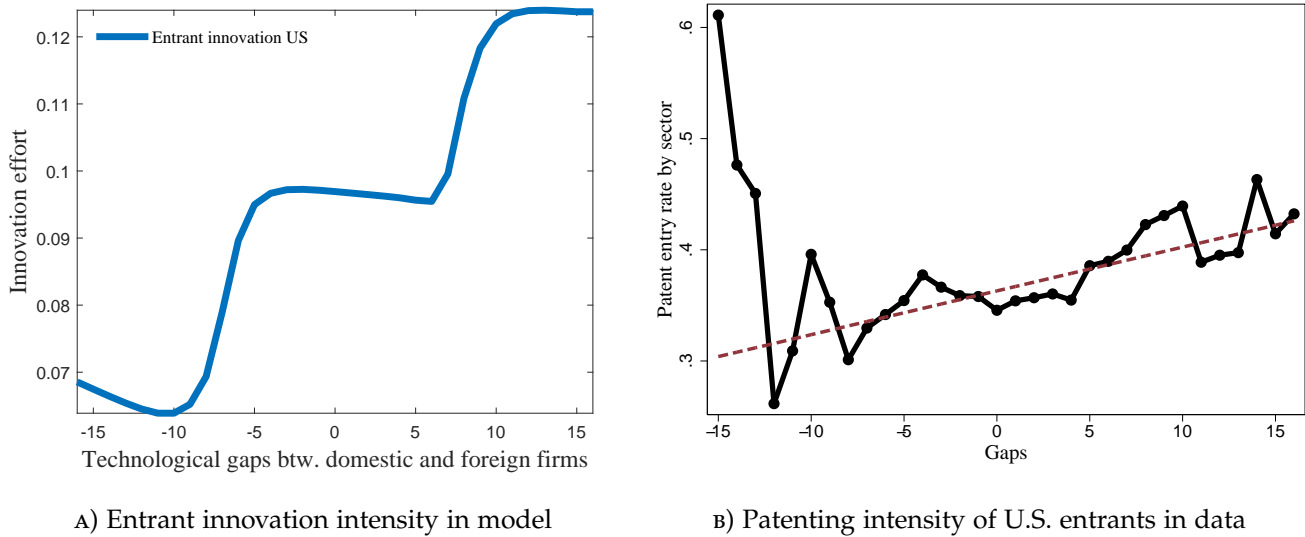


Figure A.5: Entrant innovation effort and leadership

Notes: Panel A shows the innovation intensity of U.S. entrant firms in the balance growth path of calibrated economy. Panel B shows the average entry rate of patents applied for by the U.S. firms that appear in a sector in the USPTO data for the first time across technology gaps (for the creation of the technology gaps, see Figure 5). Number of patents by new patentees is weighted by the number of all patents registered by U.S. residents. The fitted dashed line shows predicted values from a weighted linear regression of average entry rate on bins weighted by the number of sector-year observations in each bin.

Because entry to the highest gaps implies access to export markets, it is more profitable, leading to a higher entry effort aimed at these positions. Figure A.5b shows that this is indeed the case in the USPTO patent data, where we again classified sectors into bins according to the technological lead, as in Figure 8b. The solid black line in the figure depicts the flow of new patents (normalized by the number all U.S. patents in that sector-year observation to eliminate sectoral differences in patenting intensity) registered by U.S. residents that appear for the first time in a sector, averaged out across sector-year observations between 1975 and 1995 in each bin.<sup>57</sup> The dashed line shows the density-weighted regression line for 33 technology gaps. We observe that the entry intensity is higher for sectors where existing U.S. firms have larger technological leads over their foreign competitors.

<sup>57</sup>Observations of the same sector over different years constitute separate entries in Figure A.5b.

**Validation Exercise IV: Credit Elasticity of R&D** The ultimate source of growth in our model is innovation. Therefore, when analyzing the effect of policies on aggregate outcomes, a correct measurement of the responsiveness of innovative activity to policy changes is of utmost importance. In order to evaluate our estimated model's implications in that regard, we now investigate the empirical elasticity of innovative activity to R&D credits and compare it with its model counterpart.

In order to measure the credit elasticity of innovation, we exploit the state-level variation in the dates when credit policies came into action and conduct a simple firm-level regression analysis using the Compustat database. The regression specification is as follows:

$$\ln Y_{jst} = \beta_0 + \beta_1 \ln SC_{st} + \beta_2 \ln Y_{jst-1} + \psi_j + \psi_t + u_t, \quad (\text{A.3})$$

where  $\psi_j$  and  $\psi_t$  represent firm and year dummies, respectively, and  $u_t$  is the error term.  $SC_{st}$  is the tax credit level in state  $s$  where firm  $j$  operates. For the dependent variable  $Y$ , we use both R&D and patent counts. We utilize two different specifications for this regression that differ in the inclusion of the lagged value of the dependent variable. The results are summarized in Table A.1. All versions (represented by columns of the table) reveal the positive effect of state level R&D tax credits on the firms' innovative activities. This effect is also robust to the existence of lagged values of the dependent variable in the regression.

The first column of Table A.1 shows that, on average, the elasticity of R&D spending with respect to changes in R&D credit is 3.15. To ensure the quantitative validity of firms' response to policy changes in our model, we derive the model counterpart of the same statistic. We first compute the log-difference in R&D expenditure for incumbent firms of country  $A$  in each position  $m$  right before and after the subsidy change from  $s_{75-81}^A$  to  $s_{81-95}^A$ . Following the same steps used to create empirical variables, the average elasticity of R&D spending to subsidy is given by

$$\int_0^1 \frac{d \log \left( \alpha_A x_{Aj1981}^{\gamma_c} q_{j1981} \right)}{d \log \left( 1 + s_{1981}^A \right)} dj = \sum_m \frac{d \log \left( \alpha_A x_{Am1981}^{\gamma_c} Q_{Am1981} \right)}{\log \left( 1 + s_{81-95}^A \right) - \log \left( 1 + s_{75-81}^A \right)}.$$

This model statistic has a value of 2.29 in contrast to 3.15 in the data. It implies

Table A.1: The effect of R&D tax credit on innovation (excl. federal credits)

Dep. Var.:	$\ln(R\&D_t)$ (1)	$\ln(R\&D_t)$ (2)	$\ln(Patents_t)$ (3)	$\ln(Patents_t)$ (4)
$\ln(State\ credit_t)$	3.153 (10.92) <sup>***</sup>	0.524 (2.12) <sup>**</sup>	2.948 (10.93) <sup>***</sup>	1.203 (4.28) <sup>***</sup>
$\ln(R\&D_{t-1})$	-	0.631 (106.67) <sup>***</sup>	-	-
$\ln(Patent_{t-1})$	-	-	-	0.499 (72.83) <sup>***</sup>
Year Dummy	Yes	Yes	Yes	Yes
Firm Dummy	Yes	Yes	Yes	Yes

*Notes:* The table lists the results obtained from different OLS specifications that illustrate the effect of (U.S. state-level) tax credits on U.S. firms' innovation. t-statistics are provided in parentheses. <sup>\*\*\*</sup>, <sup>\*\*</sup>, and <sup>\*</sup> denote significance at 1 percent, 5 percent, and 10 percent, respectively.

that, in the model, an increase in R&D subsidy induces a solid response of R&D expenditure, in line with its empirical counterpart, although its strength is somewhat weaker than in the data. Note that the empirical economy-wide elasticity is likely to be lower than state-level elasticity due to reallocation of resources across states; therefore, it is also reassuring to see that our simulated macro elasticity is below the state-level empirical estimate.

## D Additional Figures

Figure A.6 replicates Figure 8b incorporating patents with assignee id "0" in the analysis. The inclusion of these patents leads to sharper peaks.

Figure A.7 shows the effect of tariff and R&D policies on the model-implied time path of average technological lead of U.S. firms over their competitors. Increasing unilateral protection leads to a relatively lower path, while higher subsidies result in a uniformly higher path relative to the one in the case of no policy intervention.

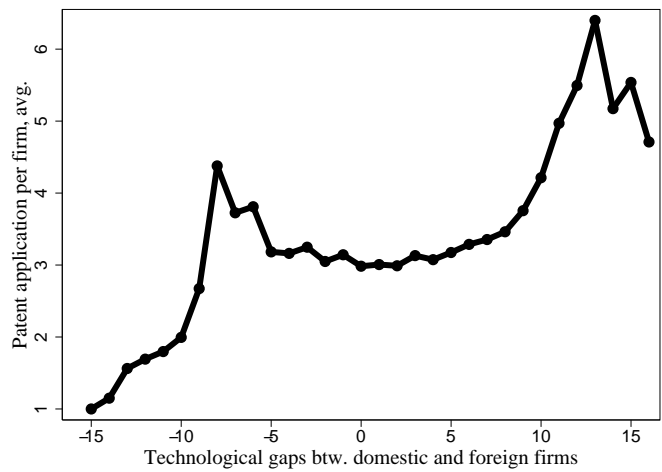
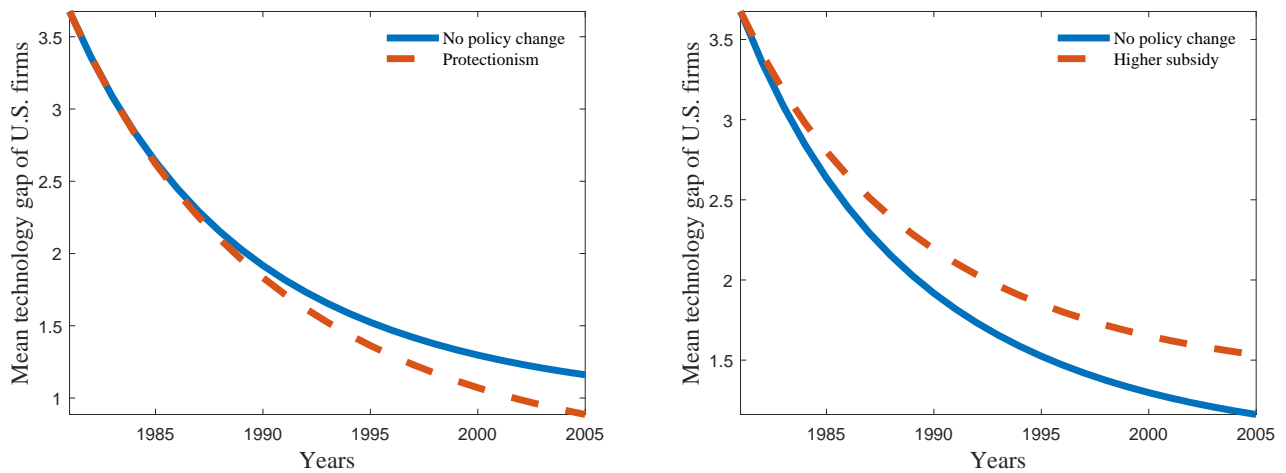


Figure A.6: Patenting intensity in USPTO data, including assignee id "0"



A) 5.5-percentage-point unilateral tariff hike

B) Actual R&D policy

Figure A.7: Average technology lead of the U.S. firms, after policy intervention

Figure A.8a compares the optimal unilateral tariff policy for the United States in two different cases: when the policy set includes only non-negative tariffs (baseline) and when negative tariffs (import subsidies) are accessible. In the latter case, the optimal tariff rate continues to decline below zero as the policy horizon extends, exposing more domestic firms to foreign competition, which incentivizes them to intensify their innovation effort. Figure A.8b shows the optimal unilateral tariff rate

when the R&D decisions are assumed to remain the same path as in the baseline economy—i.e., when they do not respond to policy changes. In that regard, this experiment abstracts from dynamic responses to policy changes, and the optimal tariff rate is chiefly driven by static considerations. In this counterfactual analysis, the optimal tariff level remains positive through any policy horizon and never declines to zero. (The reason that it is slightly less than the calibrated tariff level is the benefit from accessing better quality imports when tariffs are reduced, which is weighed against losses in domestic profits and tariff revenue.) This result emphasizes again that the dynamic gains drive the decline in the optimal rate over longer horizons in the original analysis. In this case, there is no scope for achieving dynamic gains by reducing further the tariff, thereby exposing more domestic firms to foreign competition and, thus, incentivizing them to increase their innovation effort.

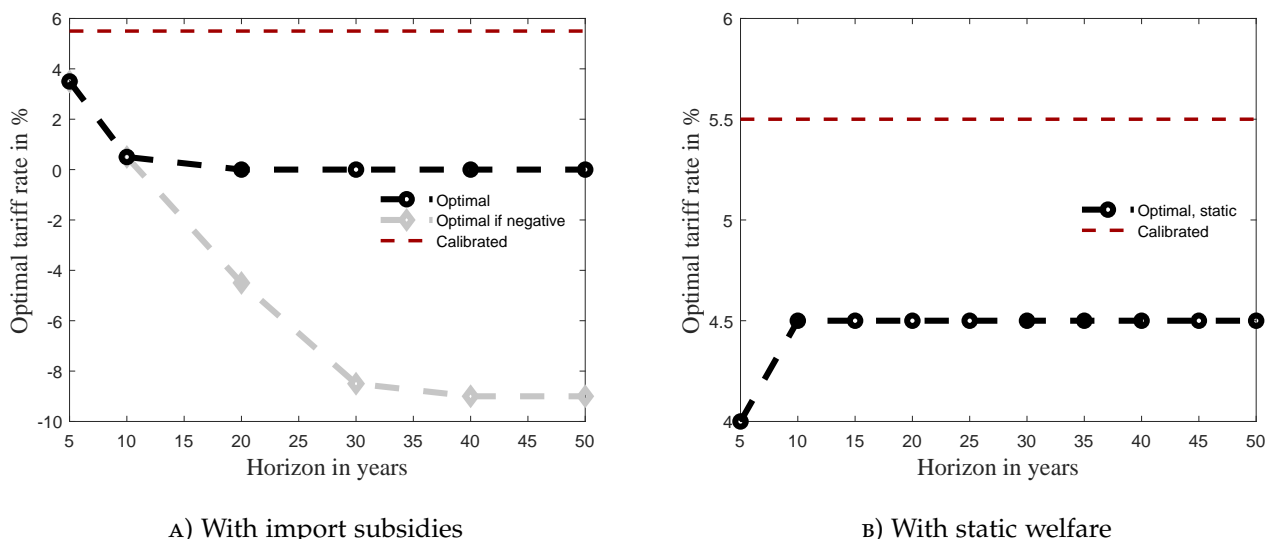


Figure A.8: Optimal tariff policy in alternative specifications

Notes: Panel A compares the optimal unilateral tariff policy for the United States in two different cases—when only non-negative tariffs are accessible (baseline) and when negative tariffs are attainable. Panel B shows the optimal tariff policy in a static version, where R&D decisions remain fixed at their baseline paths.

Figure A.9 compares the time path of the relative wages ( $\omega_{At} \equiv \bar{w}_{At}/\bar{w}_{Bt}$ ) in the baseline environment (the solid line) and in the alternative economy with higher unilateral tariffs in country A after 1981 (the dashed line). The unilateral tariff increase clearly pushes up  $\omega_{At}$ , decreasing the competitiveness of the domestic firms (see equations 9 and 10).

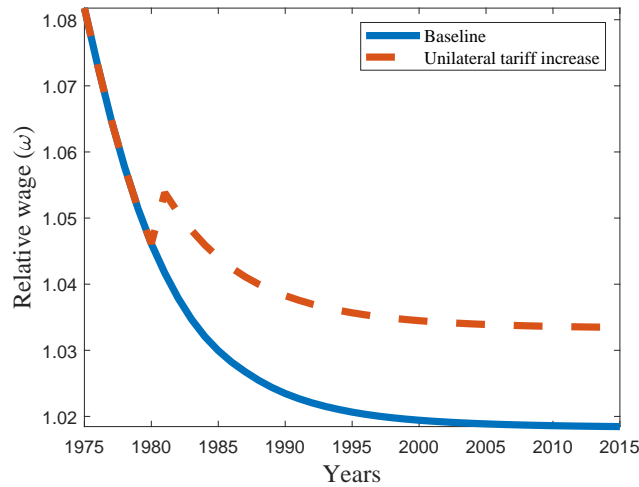


Figure A.9: Relative wages

Notes: The figure compares the time path of the relative wages ( $\omega_{At} \equiv \bar{w}_{At} / \bar{w}_{Bt}$ ) in the baseline environment (the solid line) and in the alternative economy with higher unilateral tariffs in country *A* after 1981 (the dashed line).

## E Foreign Retaliation and Optimal Policy Revisited

In order to understand the effect of foreign retaliation on the design of trade policy, we analyze our policy alternatives under the assumption that any change in tariffs imposed by the home country is perfectly matched by the foreign one.<sup>58</sup> Figure A.10 shows the optimal joint policy in this modified setting with bilateral tariff changes (circled black lines), in juxtaposition with the results obtained in the benchmark setting (blue lines).

The optimal policy again liberalizes the economy's trade regime as much as possible over longer horizons and suggests lower rates than in the baseline in shorter horizons. This finding is expected, as there are stronger incentives for this choice when the foreign country retaliates. In this case, protectionist policies limit not only the market for imports to the home country but also exports from the home country, because the tariff changes are replicated by the foreign trade partner. The effects of retaliatory tariff increases on the U.S. incumbents are demonstrated in

<sup>58</sup>The introduction of the Smoot-Hawley Tariff Act in the United States during the early stages of the Great Depression provides an example of how the unilateral introduction of trade policies could trigger retaliatory responses from trade partners, potentially harming the domestic economy.

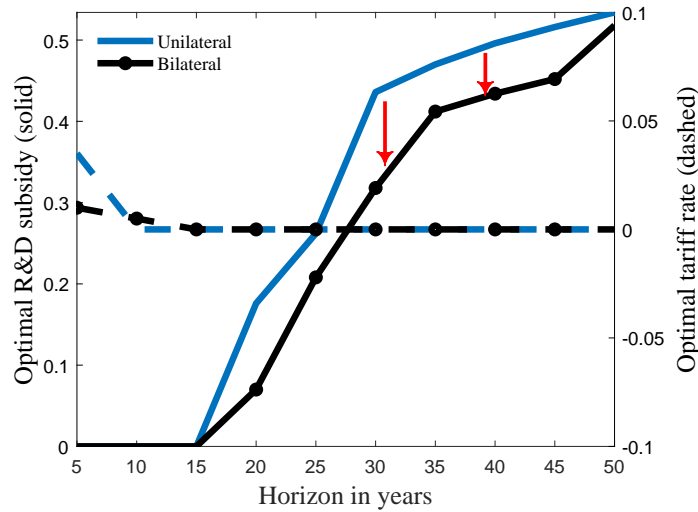


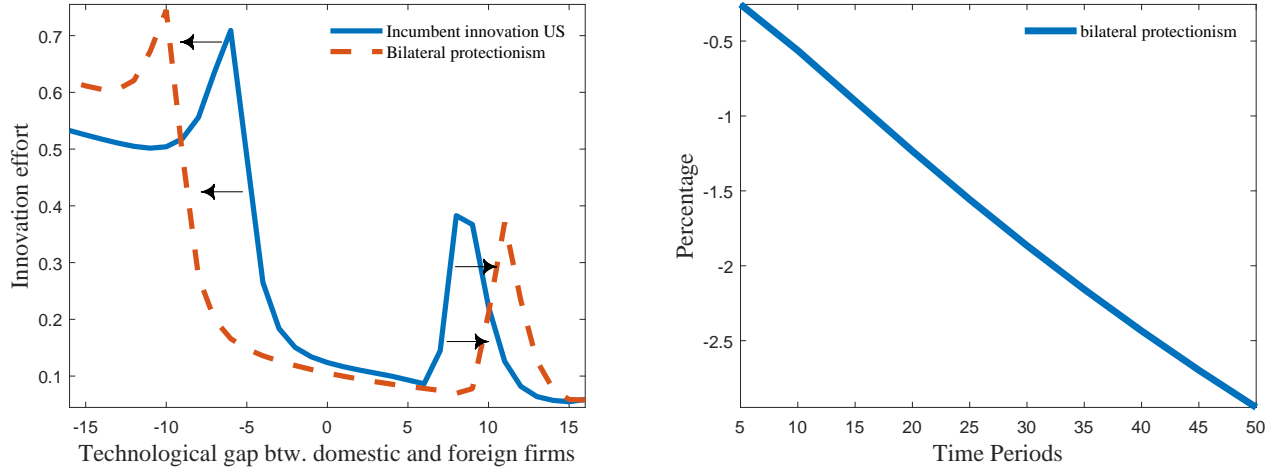
Figure A.10: Optimal joint policy in unilateral and bilateral tariff changes

Notes: The figure compares horizon-dependent optimal joint policy in case of (trade-policy) retaliation to that in the baseline.

Figure A.11a. As opposed to unilateral actions, the cutoff for exports increases, making them accessible to only a small group of firms. With the export cutoff rising as a result of higher trade barriers, a reduction in innovative activity—driven by similar reasons explained in the analysis of unilateral policies—occurs now for a wider range of firms.<sup>59</sup> Conversely, liberal policies expand the export market of the home country and stimulate innovation for a large set of firms via a more intense expansionary R&D motive, as discussed in Section 4.1 (Figure 15b). Given that most U.S. incumbents are in technologically superior positions, the optimal trade policy under the assumption of retaliation favors these firms by opening up export markets, at the expense of a few laggard firms losing their markets to foreign importers.

While there are no significant qualitative differences in the schedule of optimal R&D subsidy levels, quantitatively, the optimal levels are lower than in the previous experiment (no retaliation of trade policy). The rationale behind this finding is

<sup>59</sup>Retaliatory tariff measures lead to substantial welfare losses in the United States. Figure A.11b displays the consumption-equivalent welfare loss resulting from a 5.5 percent increase in bilateral tariff rates (R&D policies remaining unchanged), which reaches about 3 percent over a 50-year horizon—about three times the size of the loss generated by the unilateral tariff increase of the same magnitude. Higher bilateral tariffs also hurt foreign households, leading to a 2.7% decline in welfare in consumption-equivalent terms over a 50-year horizon.



A) Aggregate U.S. innovation over bilateral tariffs

B) Welfare under bilateral protectionism

Figure A.11: Innovation and welfare in bilateral trade policy actions

Notes: Panel A illustrates the effect of a bilateral increase in tariffs on the innovation effort profile of U.S. incumbent firms over technology gaps in BGP. Panel B shows the consumption-equivalent welfare change over different time horizons in response to a bilateral 5.5-percentage-point tariff increase.

again the innovation-boosting effect of more open economies, which we discussed in relation to our findings illustrated in Figure 14b. When both countries reduce tariff levels, competition intensifies for a large chunk of firms, incentivizing them to innovate, which, in turn, reduces the magnitude of underinvestment in R&D and the need for aggressive R&D subsidies.

## F Sensitivity and Robustness

We provide various robustness checks for our main results, and Table A.2 summarizes the optimal policies implied by the re-calibrated models in each experiment. The resulting optimal unilateral trade policies are almost the same as in the baseline calibration except for only minor differences in relatively shorter horizons. Over the longer ones, zero tariffs again become optimal (Panel B of Table A.2). Therefore, in the remainder, we will focus on the sensitivity of optimal R&D subsidies to alternative calibrations, which are summarized in Panel A of Table A.2. The welfare implications of optimal policies are shown in Table A.3.

Table A.2: Optimal policies in alternative scenarios

Horizon in years	Panel A: optimal subsidy rate						Panel B: optimal tariff rate					
	5	10	20	30	40	50	5	10	20	30	40	50
<i>Baseline</i>	0%	0%	26%	50.5%	56%	67%	3.5%	0.5%	0%	0%	0%	0%
<i>Lower <math>\bar{m}</math></i>	0%	0%	26%	48.5%	60%	64.5%	4%	0.5%	0%	0%	0%	0%
<i>Cumulative patents</i>	0%	18.5%	54.5%	65.5%	72%	75%	3.5%	0%	0%	0%	0%	0%
<i>Higher discount</i>	0%	0%	25%	49.5%	54.5%	65.5%	4%	1%	0%	0%	0%	0%
<i>Lower price elasticity</i>	0%	0%	18%	43%	54%	62.5%	4%	1%	0%	0%	0%	0%
<i>Logarithmic utility</i>	0%	0%	16%	44%	56.5%	68%	4%	1%	0%	0%	0%	0%

## F.1 Lower Maximum Technology Gap $\bar{m}$

We begin with the robustness of the baseline results to the value of the maximum technology gap that can separate two incumbent firms. In our baseline, this value is set to  $\bar{m} = 16$ . As a robustness check, we calculate the empirical gap distribution by setting  $\bar{m} = 10$  and recalibrate our model accordingly. The second row in Panel A of Table A.2 presents the profile of optimal unilateral R&D policy over different horizons. A comparison to the first row, which replicates the baseline results, shows that the results are very similar to those found in the baseline calibration. Hence, we conclude that our original findings are robust to the values of  $\bar{m}$ .

## F.2 Dropping the U.K.

As shown in Figure 1, the U.K. has a similar productivity and innovation performance to the United States in the late 1970s, in stark contrast with the other advanced competitors of the United States. Conjecturing that idiosyncratic factors may have negatively separated the U.K. from its peers, we recalibrate our model using data that exclude the U.K. For this exercise, we re-weight our targets using data on the remaining five foreign countries and re-compute the empirical gap distribution. Figure A.12a shows that the shift in the initial distribution caused by dropping the U.K. is minuscule, which is also the case with the other targets. Consequently, the parameter values obtained by this alternative calibration, as well as the quantitative results, barely differ from the baseline; hence, we do not repeat them here.

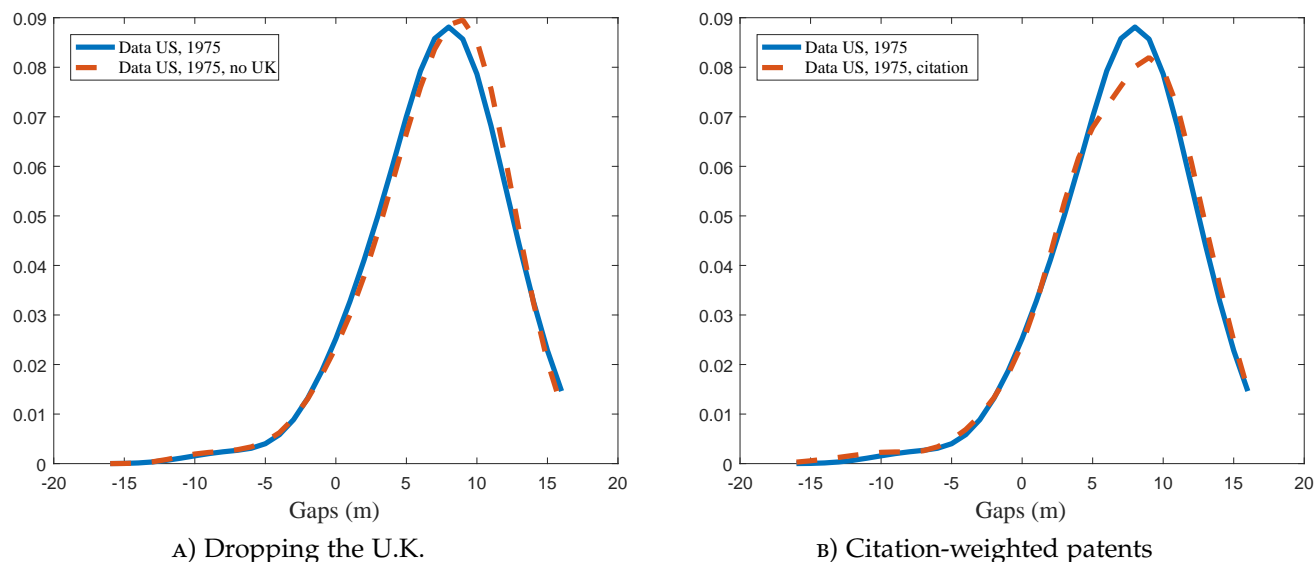


Figure A.12: Alternative initial technological gap distribution

*Notes:* The figure contrasts alternative initial technological gap distributions (red dashed lines) with the baseline (solid blue lines). Panel A depicts the version omitting the U.K., while panel B shows the version based on citation-weighted patents.

### F.3 Quality-adjusted Patents

In this exercise, we test the robustness of our analysis to the use of citation-weighted patent counts when forming moments from the data, as well as the empirical technology gap distribution. Using citation-weighted patents implies about a 4 percent higher share for Japan among all countries in 1975 at the expense of Germany, the share of which declines by the same amount. As illustrated in Figure A.12b, this reshuffling leads to only minimal changes in the empirical technology gap distribution, which also holds true for other moments. As a result, the calibration output is very similar to baseline, as one would expect, when using the alternative measure. Therefore, we skip the rest of the results generated by this alternative calibration.

### F.4 Gap Distribution Based on Cumulative Patent Count

In our baseline calibration, we match the shift in the empirical gap distribution from 1975 to 1981, where we generate the distributions using patent counts in individual

years.<sup>60</sup> In this exercise, we test the robustness of our results to computing the empirical gap distributions based on the cumulative patent counts starting from 1965. Doing so, we measure the evolution of technological leadership based on the cumulative patent stock. In particular, when we compute the U.S. patent share in a sector in a certain year, as in Figure 5, we use the patents registered in that sector between 1965 and the particular year of interest. For example, to generate the empirical gap distribution in 1975, we rank sectors using information from patents registered between 1965 and 1975 instead of 1975 alone. As can be expected, the shift in the empirical gap distribution is less pronounced in this method, because the country shares of patent stocks vary more slowly. Therefore, in Figure A.13a the distribution in 1981 is to the right of the baseline one.

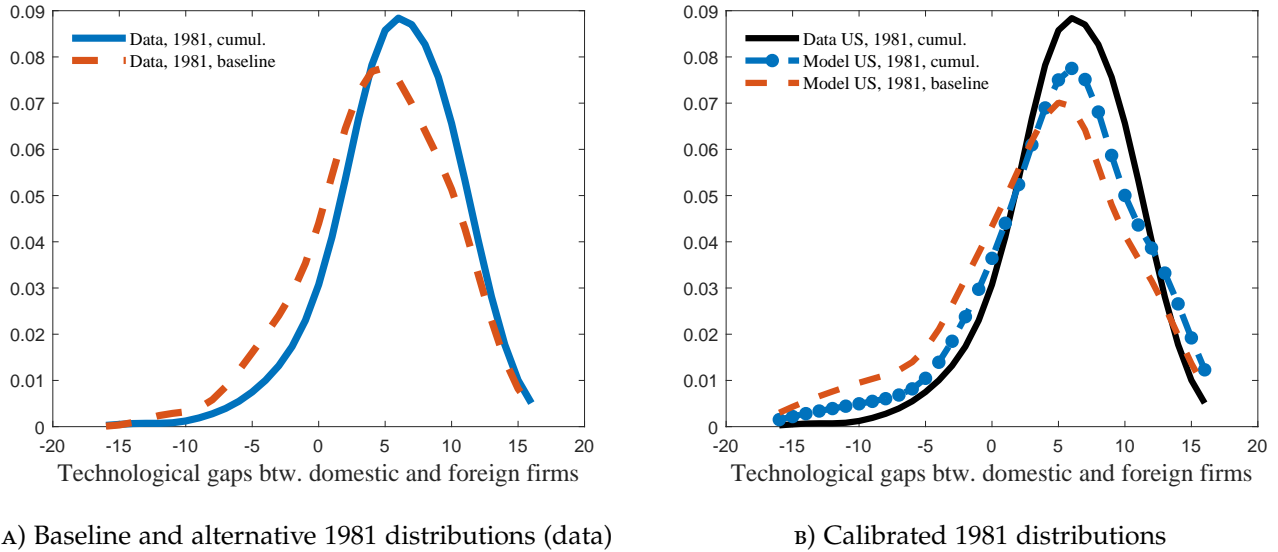


Figure A.13: Calibration with alternative empirical gap distribution

Notes: Panel A contrasts empirical 1981 technological gap distributions in the alternative method (solid blue line) and the baseline (red dashed line). Panel B contrasts model-generated 1981 technological gap distributions.

The slower shift in the gap distribution leads to some changes in the values of calibrated parameters. Notably, the calibration yields a higher  $\phi$ —implying a relatively smaller chance of large-step innovations—and a higher  $\lambda$ . Consequently, the implied optimal R&D subsidy profile (row 3 in Panel A of Table A.2) is noticeably

<sup>60</sup>One reason for starting in 1975 is that in the raw USPTO data, the number of patents that are assigned to a technology class is much smaller before the mid-1970s compared to subsequent years.

higher than that in the baseline calibration. The reason for this result is that with a higher step size  $\lambda$ , the magnitude of underinvestment is larger in this economy, calling for higher R&D subsidies.<sup>61</sup> Consequently, the implied change in welfare is also considerably larger than in the baseline economy. All told, while this experiment suggests higher optimal subsidy, our main results are robust to the use of the alternative empirical gap distribution.

Table A.3: Welfare implications of optimal policies in alternative scenarios

Horizon in years	Welfare change with									
	optimal subsidy rate					optimal tariff rate				
	10	20	30	40	50	10	20	30	40	50
<i>Baseline</i>	0.0%	0.1%	0.6%	1.6%	2.7%	0.2%	0.5%	0.9%	1.3%	1.6%
<i>Lower <math>\bar{m}</math></i>	0.0%	0.1%	0.7%	1.7%	2.9%	0.1%	0.4%	0.7%	1.0%	1.2%
<i>Cumulative patents</i>	0.0%	1.0%	3.0%	5.5%	8.1%	0.1%	0.2%	0.3%	0.5%	0.6%
<i>Higher discount</i>	0.0%	0.1%	0.6%	1.4%	2.3%	0.1%	0.5%	0.9%	1.2%	1.4%
<i>Lower price elasticity</i>	0.1%	0.0%	0.4%	1.2%	2.1%	0.1%	0.4%	0.7%	0.9%	1.2%
<i>Logarithmic utility</i>	0.1%	0.0%	0.5%	1.6%	3.1%	0.1%	0.5%	0.9%	1.3%	1.6%

Notes: The table presents the consumption-equivalent change in welfare in alternative scenarios for different horizons. For the optimal policy levels, see Table A.2.

## F.5 Higher Discount Rate $\rho$

The baseline calibration uses a discount rate of 1 percent. To test the sensitivity of our results to this parameter, we also ran an alternative calibration, setting the discount rate to 2 percent. Our calibration outcome as well as the optimal policies in this exercise differ from the baselines results only slightly. As shown in row 4 of Panel A Table A.2, the level of optimal R&D subsidies is slightly lower, which would be expected given the higher rate with which households discount the future.

<sup>61</sup>As in Schumpeterian creative destruction models, the intertemporal spillovers—the fact that an innovation raises the quality level permanently—creates a wedge between the social and private discount rates, as the private firm internalizes these benefits only partially (to the extent of the rents it can capture over its life). Intertemporal spillovers imply that the social planner cares more about the future than the owner of the private firm, and the wedge between the discount rates increases in the step size  $\lambda$ —the parameter that determines the proportional quality gain from innovation.

Not surprisingly, the higher discount rate also implies a somewhat smaller welfare gain from increased subsidies, as shown in Table A.3. Given the relatively minor differences from the baseline, we conclude that our baseline findings are robust to the choice of the discount rate.

## F.6 Lower Price Elasticity (Higher $\beta$ )

In our model, the price elasticity of demand for intermediate goods is  $\beta^{-1}$ , which also shapes the trade elasticity. In this exercise, we test the robustness of our results to this elasticity. In particular, we decrease this elasticity setting  $\beta = 0.55$  and recalibrate the model, which then produces a trade elasticity closer to five in the BGP. The fifth row in Panel A of Table A.2 presents the implications of the re-calibrated model for optimal R&D policy. Again, the findings are similar to the baseline, except for some difference in subsidy levels. The lower level of optimal subsidies reflects the fact that a higher level of  $\beta$  decreases the share of profits in aggregate income and the rents from innovation for firms. As a result, the extent of underinvestment, which the subsidies are supposed to correct for, are diminished. As would be expected, these lower optimal subsidy levels imply somewhat lower welfare gains than those obtained in the baseline economy.

## F.7 Logarithmic Utility

In this experiment, we test the robustness of our results to the shape of the utility function. To do so, we re-calibrate the model with logarithmic utility instead of quadratic CRRA in the baseline. As shown in the final row of Table A.2, optimal policies broadly align with the baseline. A nuance is that optimal R&D subsidies are lower for relatively shorter horizons but become higher when the horizon in consideration goes beyond four decades. A similar path arises with the welfare implications. With a lower degree of relative risk aversion, consumers have a proclivity for higher growth, and deviations in the path of consumption lead to larger variations in welfare. When longer horizons are considered, policies that enhance growth are preferred, justifying higher rates of optimal R&D subsidy.

## G Foreign Competition and Domestic Innovation

A recent strand of papers in the empirical trade and firm dynamics literature has made notable, and seemingly contradictory, contributions to a heated topic: the effect of foreign competition on innovative activity of domestic firms. Bloom et al. (2016) argue that Chinese import competition induced innovative activity in exposed domestic sectors in Europe (see also Coelli et al., 2016, Gorodnichenko et al., 2010, and Iacovone, 2012), whereas Autor et al. (2020) argue the opposite using data on U.S. firms and sectors (see also Hashmi, 2013 and Hombert and Matray, 2015), and yet a third set of papers including Aghion et al. (2017) find ambiguous results.

Our model can help reconcile these seemingly contradictory observations. Examining the effect of rising import competition illustrates that the response of aggregate innovation crucially depends on the sectoral composition of domestic firms in terms of their technological competence relative to the foreign competitors. As a result, import competition has a non-monotonic impact on aggregate innovation, given the innovation profile in Figure 8a.

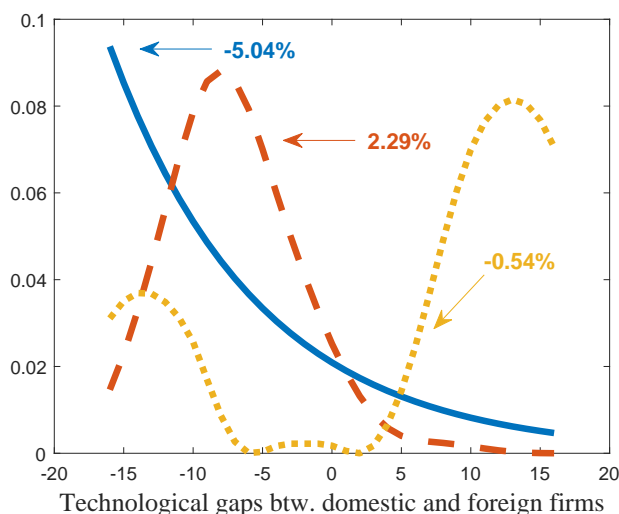


Figure A.14: Effect of unilateral trade liberalization on aggregate innovation

*Notes:* The figure contrasts the change in aggregate innovation caused by trade liberalization in various sectors defined by different initial technological gap distributions. Specified values show percentage change in aggregate sectoral innovation.

Our exercise considers three economies that differ in their technology position relative to the foreign competitor. One economy is in a relatively laggard initial

condition—i.e., in most sectors, their firms are distant followers—another one is in a relatively frontier position, and the third one is an intermediate case. To generate intensifying import competition in our model, we consider a 50 percent decline in tariffs. As is evident from the earlier discussion of unilateral protectionist policies, this change shifts the import cutoff to the right, creating heterogeneous effects on firm innovation: firms that fall further behind decrease their innovation effort, while those that become closer intensify theirs. The aggregate effect depends on the distribution of sectors across relative technological positions. Figure A.14 illustrates this point. The values in the figure show the percentage change in the industry-level innovation rate in response to lower tariffs one year after the tariff change. In the economy with the largest mass of the relatively most laggard sectors, the effect is negative, while it becomes positive as the technological gap distribution shifts to the right. The reason is that the economy with less negatively skewed distribution includes relatively more firms that happen to be around the new import cutoff, feeling the more intense threat of losing markets and therefore innovating more.

The comparison of the intermediate and the frontier economy, however, reveals that more advanced economies are not necessarily poised to benefit from intensifying foreign competition. The result hinges again on the share of firms in each economy that increase their innovative activity the most with intensifying competition. Even though the economy on the right is the most advanced one—that is, its average technological lead over its trade partner is highly positive—a relatively large mass of laggard firms is responsible for an overall decline in aggregate innovation. These firms, now with their chances of capturing a market being diminished, become discouraged and decrease their innovation efforts in response to the intensified foreign competition, and in this case, this decline becomes the dominant force.

In sum, our analysis indicates that the impact of trade liberalization on the liberalizing economy's aggregate innovation could be positive or negative depending on the initial relative technology gap between the competing countries. Moreover, even a relatively very advanced economy might experience a reduction in aggregate innovation, if it has enough sectors discouraged by foreign competition.