International Trade and Innovation Dynamics with Endogenous Markups*

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18th September 2020

Abstract

Lower costs of international trade affect both firms' innovation incentives and their market power. We develop a dynamic general equilibrium model with endogenous innovation and endogenous markups to study the interaction between these effects. Lower trade costs stimulate innovation by large firms that are technologically close to their rivals. However, as innovators increase their productivity advantage over others, they also increase their markups. Our calibrated model suggests that a fall in trade costs which increases the trade-to-GDP ratio of the US manufacturing sector from 12% (its level in the 1970s) to 24% (its current level) increases productivity growth by 0.12 percentage points and the aggregate markup by 1.70 percentage points. Without the feedback effect of innovation on the productivity distribution, markups would actually have fallen.

JEL codes: F43, F60, L13, O31, O32, O33, and O41.
Keywords: International Trade, Markups, Innovation, R&D, Productivity.

*For helpful comments and discussions, we thank Sina Ates, Adrien Auclert, Paula Bustos, Nezih Guner, Giammario Impullitti, Chad Jones, Pete Klenow, Nic Kozeniauskas, Omar Licandro, Mark Roberts, Thomas Sampson, Chris Tonetti and Michael Waugh, as well as audiences at Bocconi University, Bank of Portugal, Bank of Spain, CEMFI, University of Nottingham, Stanford University, the 2019 E1-Macro Workshop, the 2019 Midwest Macro Meetings, 8th ZEW INNOPAT, DEGIT XXIV, EARIE 2019 and the GEP/CEPR Summer Trade Workshop. Part of this research was carried out while Schmitz was a Visiting Scholar at the Economics department of Stanford University, whose hospitality is gratefully acknowledged. The views expressed in this paper are those of the authors and do not necessarily coincide with those of the Bank of Spain or the Eurosystem. Any errors are our own.

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1 Introduction

A common view amongst economists is that international trade spurs innovation and economic growth. In the words of Robert Solow, "[r]elatively free trade certainly has the advantage that the possibility of increasing market share in world markets is a constant incentive for innovative activity" (Solow, 2007). In this paper, we emphasize one aspect of this issue that is often overlooked: trade-induced increases in innovation also have important side effects on competition. Indeed, if trade openness incentivises innovation, successful innovators acquire greater productivity advantages over their foreign and domestic competitors, and could use these to wield greater market power and charge higher markups.

To analyze the interaction between trade, innovation and competition rigorously, we develop a new two-country dynamic general equilibrium model with endogenous innovation and endogenous markups. Our calibrated model shows that in the absence of innovation (i.e., holding firm productivities fixed), lower trade costs would be associated with a lower aggregate markup. However, the endogenous innovation response to lower trade costs overturns this result, as it results in a more polarized productivity distribution, higher industry-level concentration, and thus an increase in the aggregate markup.

Our model considers two symmetric countries, Home and Foreign, and a continuum of industries. In each industry and country, the final good is assembled from three differentiated intermediates: one produced by a large Home firm (the "Home leader"), one produced by a large Foreign firm (the "Foreign leader"), and one produced by a competitive fringe of small firms. Leaders face a variable cost of exporting, while fringe firms do not participate in trade.

The behavior of leaders is at the heart of our model. The Home and the Foreign leaders in each industry engage in oligopolistic competition, while fringe firms have no market power and price at marginal cost. We follow Atkeson and Burstein (2008), and assume that leaders play a static Bertrand game at every instant. This implies that in equilibrium, leaders charge a markup that is increasing in their market share. Leaders can also invest into research and development (R&D) to generate innovations. Successful innovations allow them to increase their productivity, and therefore to gain market share and increase markups and profits. While fringe firms do not innovate, they may reduce their productivity gap with the leaders at some exogenous rate. Finally, each leader is shadowed by one potential entrant, which also invests in R&D and displaces the incumbent if it manages to generate an innovation.

What is the effect of lower trade costs in this model? Lower trade costs directly reduce the relative costs of exports and increase the market share of exporters. Therefore, they increase markups on exports and decrease markups on domestic sales. Furthermore, they lower the market share of zero-markup fringe firms. Keeping the productivity distribution fixed, the response of the aggregate markup only depends on the relative strength of these forces. In our calibrated model, where domestic leaders are the largest firms in most industries, we find that pro-competitive effects would dominate.

However, lower trade costs also affect innovation incentives, leading to changes in the productivity distribution. An important equilibrium feature that explains the innovation response in the model is that leaders' profits are S-shaped in their relative productivity. That is, the marginal gains from innovation are largest for firms which are technologically close to their competitors, and smallest for firms which are very far behind or very far ahead. Lower trade costs accentuate this S-shape, and therefore increase R&D and innovation mostly for leaders which are technologically close to their competitors. As these firms pull away from their rivals, the productivity distribution becomes more polarized, with a large share of industries in which one leader has a large advantage over all other firms. However, it is precisely in such concentrated industries that markups are highest. This explains our main finding: the feedback effect of innovation after a fall in trade costs ultimately triggers an increase in the aggregate markup. Such a feedback effect is absent in static models of trade with endogenous markups, or in dynamic models with exogenous markups.

To investigate the quantitative importance of this effect, we calibrate our model, targeting a series of moments reflecting the current state of the manufacturing sector in the United States. We then compare the resulting balanced growth path (BGP), with a trade-to-GDP ratio of 24%, to an alternative BGP with higher trade costs, in which the trade-to-GDP ratio is only 12% (roughly its value in the 1970s). We find that annual productivity growth is 0.12 percentage points higher in the low trade cost BGP, but the aggregate markup is also 1.70 percentage points higher. To decompose the sources of these changes, we analyze the transition dynamics from one BGP to another, considering a one-time permanent surprise reduction in trade costs. We find that the feedback effect from innovation is responsible for the entire markup increase. Indeed, on impact, when the productivity distribution is fixed, the fall in trade costs reduces the aggregate markup by 1.14 percentage points. However, over time, the innovation response and the ensuing polarization of the productivity distribution shift the aggregate markup back up.

Finally, we analyze welfare. Transitioning from the high to the low trade cost BGP increases the consumption-equivalent welfare of the representative household by 7.7%. Thus, despite rising markups, trade is strongly welfare-enhancing in our model. However, these gains are unequally shared, as profits increase more than wages. Overall, the large welfare gains from trade are due to a reduction in the various inefficiencies in our model economy. Confronting the decentralized equilibrium with the social planner solution, we show that lower trade costs reduce both static and dynamic misallocation, thus bringing the economy closer to the social optimum.

Related literature Our paper relates to different strands in the literature on international trade. Theoretical studies on the effect of trade on innovation and growth date back to the pioneering works of Grossman and Helpman (1991) and Rivera-Batiz and Romer (1991). Important recent contributions include Baldwin and Robert-Nicoud (2008), Sampson (2016), Akcigit *et al.* (2018), Hsieh *et al.* (2019), Perla *et al.* (2019) and Bloom *et al.* (2020). These studies show that the effect of trade on growth is a priori ambiguous: on the one hand, greater export opportunities increase market size and stimulate innovation, but on the other hand, stronger import competition may lower innovation incentives.[1] Nevertheless, the quantitative results of these papers suggest that the positive effects prevail and that they are large.

These theoretical findings are consistent with evidence from empirical studies, which generally find that exposure to trade increases innovation and technology adoption (Lileeva and Trefler, 2010; Bustos, 2011; Chen and Steinwender, 2019; Coelli *et al.*, 2020). There are, however, important qualifications: Aghion *et al.* (2017)

[1] Of course, it is also possible that import competition increases innovation incentives. Indeed, it is well-known that the effects of competition on innovation are non-monotonic (Aghion *et al.*, 2005).

argue that only the most productive firms are able to take advantage of export opportunities and increase innovation, while less productive firms only feel the squeeze of competition and innovate less. Furthermore, while most studies find positive innovation effects of greater export opportunities, the evidence on import competition is more mixed: while Bloom *et al.* (2016) find a positive effect of Chinese import competition on innovation for European textile firms, Autor *et al.* (2020) find a negative effect for manufacturing firms in the United States. Shu and Steinwender (2018) provide an overview of this literature.

There is also an extensive literature studying how trade affects competition and markups. The theoretical literature, dating back at least to Krugman (1979), shows that trade lowers the markups of domestic firms, but increases the markups of exporters (Melitz and Ottaviano, 2008; Arkolakis *et al.*, 2018). The empirical literature finds mixed results (De Loecker and Warzynski, 2012; De Loecker *et al.*, 2016; Brandt *et al.*, 2017; Feenstra and Weinstein, 2017). Finally, there is also a literature on the effect of trade on markup dispersion and misallocation (Epifani and Gancia, 2011; Edmond *et al.*, 2015; Asturias *et al.*, 2019).

Our paper builds on this extensive literature. However, its main focus is the interaction between markups and innovation, which has only been considered by a limited number of papers. Impullitti and Licandro (2016), Impullitti *et al.* (2018), Aghion *et al.* (2017) and Lim *et al.* (2018) all propose models with innovation and endogenous markups. These models emphasize that trade lowers markups for the least efficient firms (pushing some of them out of the market), while raising innovation and markups for the most efficient firms. Our paper proposes a different mechanism: we find that trade increases innovation mostly in industries in which firms are technologically close to their foreign and domestic competitors. In equilibrium, these greater efforts to pull away from competition result in a higher number of concentrated industries, and the aggregate markup increases through a composition effect. Finally, our model shares some features with Akcigit *et al.* (2018) and Cavenaile *et al.* (2019). While there are several modeling differences, the crucial distinction between these papers and ours is that Akcigit *et al.* (2018) study a model with exogenous markups, and Cavenaile *et al.* (2019) study a closed economy.

The remainder of the paper is structured as follows. Section 2 lays out our model and discusses its main features. Section 3 presents our calibration strategy, our main quantitative results and robustness checks. Section 4 analyses the welfare consequences of changes in trade costs. Finally, Section 5 concludes.

2 Model

2.1 Environment

Preferences Time is continuous, infinite, and indexed by $t \in \mathbb{R}_+$. There are two large open economies in the world, labeled Home (H) and Foreign (F). Each economy is populated by a representative household with discount rate $\rho > 0$. The representative household of country k is endowed with a fixed amount of time $\boldsymbol{L}^k$ each instant, which she supplies inelastically in her country's labor market. We assume throughout that both countries have the same labor endowment (i.e., $\boldsymbol{L}^H = \boldsymbol{L}^F = \boldsymbol{L}$).

The representative household's intertemporal utility function is

$$\boldsymbol{U}_0^k = \int_0^{+\infty} e^{-\rho t} \ln \boldsymbol{C}_t^k \mathrm{d}t, \tag{1}$$

where $\boldsymbol{C}_t^k$ stands for the household's consumption of a non-tradable final good. Consumption decisions are subject to the flow budget constraint:

$$\dot{\boldsymbol{A}}_t^k \leq r_t^k \boldsymbol{A}_t^k + w_t^k \boldsymbol{L} - \boldsymbol{P}_t^k \boldsymbol{C}_t^k, \tag{2}$$

with $\boldsymbol{A}_0^k > 0$ given. Here, w_t^k is the wage rate in country k, and $\boldsymbol{P}_t^k$ is the price of the final good. The household owns all domestic firms, and we assume that there are no international capital flows. Thus, the stock of wealth $\boldsymbol{A}_t^k$ is equal to the value of country-k assets, and the rate of return r_t^k is a priori country-specific.

Technology and competition The final good in each country is produced by a large number of firms operating under perfect competition. They produce the final good by assembling the output of a measure-one continuum of industries indexed by $j \in [0, 1]$, with a Cobb-Douglas technology:

$$\boldsymbol{Y}_t^k = \exp\left[\int_0^1 \ln Y_{j,t}^k \, \mathrm{d}j\right], \tag{3}$$

where $Y_{j,t}^k$ stands for the quantity of industry-j output used in country k. In each country k, the output of industry j is assembled using three intermediates. One intermediate is produced by a large Home firm (henceforth, the Home leader), and another one by a large Foreign firm (the Foreign leader). The third intermediate is produced by a country-specific competitive fringe. The fringe can be thought of as a large number of firms operating under perfect competition producing a homogenous product. The three intermediates are aggregated in a CES fashion, so that

$$Y_{j,t}^k = \left[(\omega_H)^{\frac{1}{\eta}} \left(y_{jH,t}^k \right)^{\frac{\eta-1}{\eta}} + (\omega_F)^{\frac{1}{\eta}} \left(y_{jF,t}^k \right)^{\frac{\eta-1}{\eta}} + (\omega_C)^{\frac{1}{\eta}} \left(y_{jC_k,t}^k \right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}. \quad (4)$$

Here, $y_{jH,t}^k$, $y_{jF,t}^k$ and $y_{jC_k,t}^k$ stand for the intermediates produced for the market of country k by the Home leader, the Foreign leader and the domestic competitive fringe of industry j.[2] η is the elasticity of substitution between intermediates, and we assume throughout that $\eta > 1$. Thus, it is easier to substitute between intermediates than between different industries (as final good production is Cobb-Douglas, the elasticity of substitution between industries is 1). Finally, the weights $\{\omega_c\}$ represent the quality of intermediates sold by producer c, holding $\sum_c \omega_c = 1$. We assume that qualities are fixed (that is, they cannot be improved by innovation). Furthermore, for symmetry, we assume throughout $\omega_H = \omega_F$.

The production of intermediates uses a simple linear technology:

$$y_{jc,t}^k = q_{jc,t} \ell_{jc,t}^k, \quad \text{for } c \in \{H, F, C_H, C_F\}$$

where $\ell_{jc,t}^k$ is labor used by producer c of industry j for its production in country k. $q_{jc,t}$ denotes the productivity of producer c. Home and Foreign leaders can increase their productivity through innovation, as we will describe below. When intermediates are exported, they are subject to an iceberg trade cost $\tau > 1$, so that τy units must be shipped to the other country for y units to arrive.

In each industry, the Home and Foreign leader interact strategically in a static Bertrand game. That is, at every instant and for each market, each leader chooses

[2] We assume that fringe firms do not export (i.e., industry j in Home does not use the intermediate produced by the Foreign fringe). This would be an equilibrium outcome if there were a small fixed cost of exporting. In the data, not all firms export and those that do are on average larger (e.g. Bernard *et al.*, 2018).

a price that maximizes its profits given the prices charged by all other firms. The fringes do not behave strategically, and charge a price equal to their marginal cost.

Innovation Leaders can increase their productivity by investing into R&D. We assume that by paying a flow cost equal to $\chi_i z^{\psi_i} \boldsymbol{Y}_t^k$ units of the final good (with $\chi_i > 0$ and $\psi_i > 1$), a leader generates a Poisson arrival rate of innovations z. A successful innovation improves the leader's productivity by a factor $1 + \lambda$, where $\lambda > 0$. Furthermore, we assume that there is an "advantage of backwardness": if the Home leader in a given industry currently has a productivity that is strictly lower than that of the Foreign leader, its innovation rate is equal to $z + \xi$, where $\xi > 0$ is a parameter.

We assume that in every industry, the fringes in Home and Foreign have the same productivity (i.e., $q_{jC_H,t} = q_{jC_F,t} = q_{jC,t}$). Fringe firms do not innovate. However, they can benefit from technological spillovers: if fringe productivity is strictly lower than the productivity of the least productive leader, then it increases at an exogenous Poisson rate ζ by a factor $1 + \lambda$.

Industry-level outcomes in our model crucially depend on firms' relative productivities. Given our assumptions, relative productivities can be summarized by two integers. First, we define the technology gap of the Home leader with respect to the Foreign leader, $n_{j,t} \in \mathbb{Z}$, as holding

$$\frac{q_{jH,t}}{q_{jF,t}} = (1 + \lambda)^{n_{j,t}}. \tag{5}$$

We say that Home is leading in industry j if $n_{j,t} > 0$, lagging if $n_{j,t} < 0$, and neck-to-neck with Foreign if $n_{j,t} = 0$. Second, we define the technology gap of the Home leader with respect to the fringe, $n_{Cj,t} \in \mathbb{N}$, as holding

$$\frac{q_{jH,t}}{q_{jC,t}} = (1 + \lambda)^{n_{Cj,t}}. \tag{6}$$

As the fringe can never become more productive than the least productive leader, $n_{Cj,t}$ is always non-negative, and holds $n_{Cj,t} \geq n_{j,t}$.

In our model's Balanced Growth Path (BGP) equilibrium, the innovation choices of Home and Foreign leaders generate an invariant distribution of technology gaps

(n, n_C) over industries. Assuming that there is an advantage of backwardness for lagging leaders (captured by the parameter ξ) and that the fringe is subject to technological spillovers (captured by the parameter ζ) is necessary to ensure the existence of such an invariant distribution, as these features prevent leaders from acquiring arbitrarily large technological advantages over each other and/or the fringe.

Entry and exit At every instant, incumbent leaders can be displaced by entrants. For each country-industry pair (k, j), there is one potential entrant, which by investing $\chi_e x^{\psi_e} \boldsymbol{Y}_t^k$ units of the final good generates a Poisson arrival rate of innovation equal to x.[3] An entrant that generates an innovation displaces the incumbent leader, who exits forever. Otherwise, entrants' innovations are equivalent to incumbents' innovations, i.e., they improve the productivity of the incumbent leader by a factor $1 + \lambda$.

Market clearing The final good of the economy is used for private consumption and for R&D. Thus, the aggregate resource constraint is

$$\boldsymbol{C}_t^k + \boldsymbol{R}_t^k = \boldsymbol{Y}_t^k, \tag{7}$$

where $\boldsymbol{R}_t^k$ stands for aggregate R&D at time t. Labor market clearing in turn requires that labor demand from domestic producers (fringe and domestic leaders) in each country k equals domestic labor supply:

$$\int_0^1 \left(\ell_{jk,t}^k + \ell_{jC_k,t}^k + \ell_{jk,t}^{k'} \right) \mathrm{d}j = \boldsymbol{L}^k. \tag{8}$$

for all $k, k' \in \{H, F\}$ with $k' \neq k$.

2.2 Equilibrium

Our analysis mostly focuses on a symmetric Balanced Growth Path (BGP) equilibrium, where both countries have the same wage and GDP, and aggregate variables grow at a constant rate. Thus, we postpone the discussion of shocks and transitions

[3] The assumption that R&D costs of incumbents and potential entrants grow linearly with GDP is necessary to guarantee the existence of a Balanced Growth Path.

between BGPs until Section 3.3. Furthermore, note that our model's structure allows us to separately analyze (static) pricing decisions and (dynamic) innovation decisions.

2.2.1 Pricing decisions, market shares and profits

Demand functions The representative household in each country k maximizes utility (1) subject to the flow budget constraint (2) and a no-Ponzi condition, taking the initial wealth level as given.[4] This yields the standard Euler equation:

$$\frac{\dot{\boldsymbol{C}}_t^k}{\boldsymbol{C}_t^k} = r_t^k - \rho \tag{9}$$

Final goods firms demand intermediate quantities $\left(y_{jH,t}^k, y_{jF,t}^k, y_{jC_k,t}^k\right)_{j\in[0,1]}$ from domestic and foreign firms. Their cost-minimization problem implies the demand functions

$$y_{jc,t}^k = \omega_c \left(\frac{p_{jc,t}^k}{P_{j,t}^k}\right)^{-\eta} \frac{\boldsymbol{P}_t^k \boldsymbol{Y}_t^k}{P_{j,t}^k}, \quad \text{where } P_{j,t}^k = \left[\sum_{c=H,C_k,F} \omega_c \left(p_{jc,t}^k\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}, \tag{10}$$

where $p_{jc,t}^k$ is the price of the intermediate produced by producer c in industry j for country k, and $P_{j,t}^k$ is the ideal price index of industry j in country k. By symmetry, aggregate GDPs are equal across countries. Thus, from now on we omit country superscripts for aggregate GDP $\boldsymbol{Y}_t$, and normalize the common price of the final good to $\boldsymbol{P}_t = 1$.

Pricing decisions In each industry j, the Home and Foreign leader compete in a static Bertrand game. That is, they choose the optimal price for their good (on the Home and Foreign markets), taking the prices charged by the fringes and by the other leader as given. As each industry is small with respect to the aggregate economy, leaders also take the aggregate wage and price index as given. However, they do realize that they have market power in their industry, and that their decisions affect the industry price indices $P_{j,t}^H$ and $P_{j,t}^F$.

[4] Wealth in the economy is equal to the value of all domestic firms (entrants and incumbents). In equilibrium, each country must hold a transversality condition ensuring that the present discounted value of wealth is zero in the limit of time.

The pricing problem of leaders is similar to Atkeson and Burstein (2008), and its solution is discussed in greater detail in Appendix A.1. Throughout, we describe the equilibrium conditions for the Home market, but the ones for the Foreign market are analogous (in particular, as there is no interaction between both markets, the leader's problem is separable across markets).[5]

The Home leader's optimal price on the Home market is

$$p^H_{jH,t} = \mu^H_{jH,t} \frac{w_t}{q_{jH,t}}, \quad \text{where} \ \ \mu^H_{jH,t} \equiv \frac{\frac{\eta}{\eta-1} - \sigma^H_{jH,t}}{1 - \sigma^H_{jH,t}}. \tag{11}$$

$\sigma^H_{jH,t}$ stands for the market share of the Home leader on the Home market. That is, the Home leader charges a markup $\mu^H_{jH,t}$ over its marginal cost of production, and this markup is an increasing function of its market share. This is because leaders with higher market shares effectively face a less elastic demand curve, and therefore have more market power. Formally, the market share of producer c in industry j and country k is defined as

$$\sigma^k_{jc,t} \equiv \frac{p^k_{jc,t} y^k_{jc,t}}{P^k_{j,t} Y^k_{j,t}} = \omega_c \left(\frac{p^k_{jc,t}}{P^k_{j,t}} \right)^{1-\eta}. \tag{12}$$

The Foreign leader's optimal price on the Home market is

$$p^H_{jF,t} = \mu^H_{jF,t} \frac{\tau w_t}{q_{jF,t}}, \quad \text{where} \ \mu^H_{jF,t} \equiv \frac{\frac{\eta}{\eta-1} - \sigma^H_{jF,t}}{1 - \sigma^H_{jF,t}}. \tag{13}$$

This condition is analogous to the one of the Home leader, except for the fact that the Foreign leader's marginal cost includes the variable trade cost τ.

Finally, as the fringe operates under perfect competition, its price holds

$$p_{jC_H,t} = \frac{w_t}{q_{jC,t}}. \tag{14}$$

Equations (11) to (14) pin down the equilibrium markups and market shares in every industry j as a function of firms' relative productivities. Indeed, Equation (12) shows that market shares only depend on relative prices, and the pricing equations

[5] Following Atkeson and Burstein (2008), we abstract from equilibria with dynamic collusion.

show that relative prices only depend on market shares and relative productivities. Appendix B provides further details for the solution of this system of equations.

For future reference, note that because relative productivities are fully characterized by the technology gap $\underline{n} \equiv (n, n_C)$, industry-level markups and market shares only depend on $\underline{n}$ and on the parameters η, τ and $\{\omega_c\}$. Thus, we henceforth identify an industry by its technology gap $\underline{n}$.

Profits From the above, it is easy to show that the profits of the Home and Foreign leaders in each market k are

$$\Pi^k_{c,t}(\underline{n}) = \pi^k_c(\underline{n})\boldsymbol{Y}_t, \text{ where } \pi^k_c(\underline{n}) = \left[\frac{\eta}{\sigma^k_c(\underline{n})} - (\eta - 1)\right]^{-1}, \tag{15}$$

and $\sigma^k_c(\underline{n})$ is the market share of firm c in country k in an industry characterized by a technology gap $\underline{n}$. Thus, profits are an increasing function of market shares and scale linearly with aggregate GDP.

Labor market clearing Home labor is employed by Home leaders (for domestic production and exports) and the Home competitive fringe. Using the demand equation (10), we can show that their respective labor demands are given by

$$\ell^H_{H,t}(\underline{n}) = \frac{\sigma^H_H(\underline{n})}{\mu^H_H(\underline{n})}\frac{\boldsymbol{Y}_t}{w_t}, \qquad \ell^F_{H,t}(\underline{n}) = \frac{\sigma^F_H(\underline{n})}{\mu^F_H(\underline{n})}\frac{\boldsymbol{Y}_t}{w_t}, \qquad \ell^H_{C_H,t}(\underline{n}) = \sigma^H_{C_H}(\underline{n})\frac{\boldsymbol{Y}_t}{w_t}. \tag{16}$$

Imposing labor market clearing then yields

$$\frac{w_t\boldsymbol{L}}{\boldsymbol{Y}_t} = \sum_{n=-\infty}^{+\infty}\sum_{n_C=0}^{+\infty}\varphi_t(\underline{n})\left(\sigma^H_{C_H}(\underline{n}) + \left(\frac{\eta-1}{\eta}\right)\sum_{k=H,F}\frac{\sigma^k_H(\underline{n})(1-\sigma^k_H(\underline{n}))}{\eta(1-\sigma^k_H(\underline{n})) + \sigma^k_H(\underline{n})}\right), \tag{17}$$

where $\varphi_t(\underline{n})$ stands for the mass of industries with technology gap $\underline{n}$ at time t. The technology gap distribution across industries is endogenous, and we will derive its equilibrium value below. Given this distribution, Equation (17) pins down the aggregate labor share.[6] Replacing the labor share into the expressions for firms' labor demands, we obtain employment and output levels for all industries.

[6] As noted earlier, we always have $n_{Cj,t} \geq n_{j,t}$ (as the fringe can never become more productive than the least productive leader). Thus, whenever $n_C < n$, $\varphi_t(n, n_C) = 0$.

Aggregate markups We can now define a measure of aggregate markups, our main focus. As in Grassi (2018) and Burstein *et al.* (2020), we define industry-level markups as the inverse of the industry-level labor share.[7] Equation (16) implies

$$\mu(\underline{n}) \equiv \left(\sum_{c=H,C_H,F} \sigma_c^H(\underline{n}) \Big(\mu_c^H(\underline{n}) \Big)^{-1} \right)^{-1}. \tag{18}$$

That is, the industry-level markup is a harmonic mean of firm markups, weighted by market shares. Likewise, we define the aggregate markup as the inverse of the aggregate labor share, $\boldsymbol{\mu}_t = \left(\frac{w_t \boldsymbol{L}}{\boldsymbol{Y}_t}\right)^{-1}$. It is easy to show that this is again a weighted harmonic mean of industry-level markups:

$$\boldsymbol{\mu}_t \equiv \left(\sum_{n=-\infty}^{+\infty} \sum_{n_C=0}^{+\infty} \varphi_t(\underline{n}) \Big(\mu(\underline{n}) \Big)^{-1} \right)^{-1}. \tag{19}$$

Taking stock Conditional on the productivity of each firm at time t, the equilibrium conditions described so far fully pin down output, wages and markups. However, the productivity distribution is endogenous, shaped by the innovation choices of entrants and incumbents. We now turn to analyzing these choices.

2.2.2 Dynamic R&D and entry problems

Choice problems As noted earlier, we focus on a symmetric BGP equilibrium, in which aggregate output in both countries grows at a common rate $g \equiv \frac{\dot{\boldsymbol{Y}}_t}{\boldsymbol{Y}_t}$. As aggregate R&D spending $\boldsymbol{R}_t^k$ grows at the same rate as aggregate output (a result that we verify later), consumption also grows at rate g. Using the Euler equation (9), this implies that $r_t^H = r_t^F = r = g + \rho$.

Our previous discussion shows that the dynamic problem of the Home leader in a given industry has only two state variables: the technology gap, $\underline{n}$, and aggregate GDP, $\boldsymbol{Y}_t$. Given these, the Home leader chooses an innovation rate $z_H(\underline{n})$ to maximize its value, taking as given the innovation policies of all other firms. We denote by $V_H(\underline{n}, \boldsymbol{Y}_t)$ the value function of the Home leader in an industry with technology gap $\underline{n}$ at time t. The Hamilton-Jacobi-Bellman (HJB) equation is

[7] Note that at the firm-level, the markup is also the inverse of the (firm-level) labor share.

$$
\begin{aligned}
rV_H(\underline{n}, \boldsymbol{Y}_t) = \max_{z_H(\underline{n})} \Bigg\{ & \Big(\pi_H^H(\underline{n}) + \pi_H^F(\underline{n})\Big) \boldsymbol{Y}_t - \chi_i \left(z_H(\underline{n})\right)^{\psi_i} \boldsymbol{Y}_t - x_H(\underline{n}) V_H(\underline{n}, \boldsymbol{Y}_t) \\
& + \Big(z_H(\underline{n}) + \mathbb{1}_{(n<0)}\xi\Big) \Big(V_H(n+1, n_C+1, \boldsymbol{Y}_t) - V_H(\underline{n}, \boldsymbol{Y}_t)\Big) \\
& + \left(x_F(\underline{n}) + z_F(\underline{n}) + \mathbb{1}_{(n>0)}\xi\right) \Big(V_H(n-1, n_C, \boldsymbol{Y}_t) - V_H(\underline{n}, \boldsymbol{Y}_t)\Big) \\
& + \zeta \Big(V_H(n, \max\left(n, 0, n_C - 1\right), \boldsymbol{Y}_t) - V_H(\underline{n}, \boldsymbol{Y}_t)\Big) \Bigg\} + \dot{V}_H(\underline{n}, \boldsymbol{Y}_t)
\end{aligned} \tag{20}
$$

The right-hand side of the HJB equation has the following parts. The first line captures flow profits from domestic sales and exports, the flow expenditure on R&D, and the fact that at rate $x_H(\underline{n})$, the Home leader is displaced by an entrant. The second line shows that the leader generates an innovation rate $z_H(\underline{n}) + \mathbb{1}_{(n<0)}\xi$, where $\mathbb{1}_{(n<0)}$ is an indicator function for the Home leader lagging behind the Foreign leader, equal to 1 if $n < 0$, and 0 otherwise. When the incumbent innovates, it increases its technology gap with respect to the Foreign leader and the fringe by one unit. The third line captures the arrival of Foreign innovations, at rate $x_F(\underline{n})$ (for Foreign entrants) and $z_F(\underline{n}) + \mathbb{1}_{(n>0)}\xi$ (for Foreign incumbents). Both of these events reduce the technology gap between the Home and the Foreign leader by one unit, but leave the technology gap with respect to the fringe unchanged. Finally, the forth line shows that at rate ζ, the fringe reduces its technology gap with respect to the Home leader by one unit.

Similarly, Home potential entrants in an industry with technology gap $\underline{n}$ choose an arrival rate of innovations solving

$$
\max_{x_H(\underline{n})} \Big\{ x_H(\underline{n}) V_H(n+1, n_C+1, \boldsymbol{Y}_t) - \chi_e \left(x_H(\underline{n})\right)^{\psi_e} \boldsymbol{Y}_t \Big\}. \tag{21}
$$

Upon innovation, the potential entrant becomes the new incumbent, increasing the technology gap with respect to the Foreign leader and the fringe by one unit.

Dynamic solution Due to the symmetry of our model, we note that we have

$$
V_H(n, n_C, \boldsymbol{Y}_t) = V_F(-n, n_C - n, \boldsymbol{Y}_t) \tag{22}
$$

for all t, and every technology gap (n, n_C) holding $n_C \geq \max(0, n)$. That is, the value functions of Home and Foreign leaders are symmetric.[8] Equation (22) is important because it implies that in order to solve for the optimal R&D choices, we only need to focus on the dynamic problem of Home firms.

We guess-and-verify that the value function of Home leaders is linear in aggregate GDP, so that $V_H(\underline{n}, \boldsymbol{Y}_t) = v_H(\underline{n})\boldsymbol{Y}_t$. After some straightforward algebra, we get

$$\begin{aligned}\Big(\rho + x_H(\underline{n})\Big)v_H(\underline{n}) = \max_{z_H(\underline{n})} \Bigg\{ & \pi_H^H(\underline{n}) + \pi_H^F(\underline{n}) - \chi_i\left(z_H(\underline{n})\right)^{\psi_i} \\ & + \Big(z_H(\underline{n}) + \mathbb{1}_{(n<0)}\xi\Big)\Big(v_H(n+1, n_C+1) - v_H(\underline{n})\Big) \\ & + \Big(x_F(\underline{n}) + z_F(\underline{n}) + \mathbb{1}_{(n>0)}\xi\Big)\Big(v_H(n-1, n_C) - v_H(\underline{n})\Big) \\ & + \zeta\Big(v_H(n, \max(n, 0, n_C - 1)) - v_H(\underline{n})\Big)\Bigg\},\end{aligned} \tag{23}$$

where we have used the fact that $\dot{V}_H(\underline{n}, \boldsymbol{Y}_t) = v_H(\underline{n})g\boldsymbol{Y}_t$ and $\rho = r - g$. The first-order condition for the incumbent's problem yields:

$$z_H(\underline{n}) = \left(\frac{v_H(n+1, n_C+1) - v_H(\underline{n})}{\chi_i\psi_i}\right)^{\frac{1}{\psi_i - 1}}. \tag{24}$$

Thus, innovation choices depend on the difference between the Home leader's current value and its value in case of a successful innovation. Likewise, the first-order condition of the entrant's problem (21) yields:

$$x_H(\underline{n}) = \left(\frac{v_H(n+1, n_C+1)}{\chi_e\psi_e}\right)^{\frac{1}{\psi_e - 1}}. \tag{25}$$

Given the value function of the Home leader, Equations (24) and (25) pin down the optimal R&D choices of Home leaders and entrants. Furthermore, using the

[8] For example, the value of a Home leader with a technology gap of 5 units with respect to the Foreign leader and 6 units with respect to the fringe is the same as the value of a Foreign leader with a technology gap of 5 units with respect to the Home leader (implying a technology gap of -5 from the viewpoint of the Home leader) and 6 units with respect to the fringe (implying a technology gap of $6 - 5 = 1$ between the Home leader and the fringe).

symmetry described by Equation (22), they can also be used to deduce the optimal R&D choices of Foreign leaders and entrants. To find these objects, we solve for the value function of the Home leader numerically. Appendix B contains further details.

The distribution of technology gaps Knowing firms' innovation choices, we can finally characterize the evolution of the equilibrium distribution of technology gaps, denoted $\varphi_t(\underline{n})$. First, for all technology gaps holding $n_C > 0$, we have

$$\begin{aligned} \dot{\varphi}_t(\underline{n}) = {} & i_H(n-1, n_C-1)\varphi_t(n-1, n_C-1) + i_F(n+1, n_C)\varphi_t(n+1, n_C) \\ & + \zeta\varphi_t(n, n_C+1) - \Big(i_H(n, n_C) + i_F(n, n_C) + \zeta\Big)\varphi_t(n, n_C), \end{aligned} \tag{26}$$

$$\text{where} \quad \begin{aligned} i_H(n, n_C) &\equiv z_H(n, n_C) + x_H(n, n_C) + \mathbb{1}_{(n<0)}\xi, \\ i_F(n, n_C) &\equiv z_F(n, n_C) + x_F(n, n_C) + \mathbb{1}_{(n>0)}\xi, \end{aligned}$$

are the total innovation rates in country H and F. Inflows into state (n, n_C) can occur through innovation of Home firms in state $(n-1, n_C-1)$, innovation of Foreign firms in state $(n+1, n_C)$, or catch-up by the fringe in state (n, n_C+1). Outflows from state (n, n_C) occur through innovation by any firm or catch-up by the fringe.

Second, for all technology gaps holding $n_C = 0$, we have

$$\dot{\varphi}_t(n, 0) = i_F(n+1, 0)\varphi_t(n+1, 0) + \zeta\varphi_t(n, 1) - \Big(i_H(n, 0) + i_F(n, 0)\Big)\varphi_t(n, 0). \tag{27}$$

Equation (27) differs from Equation (26) in two respects. On the inflows block, there is one term less: it is impossible to arrive into a state in which the Home leader is neck-to-neck with the fringe through Home innovation (as Home innovation implies that the leader is always at least one step ahead of the fringe). On the outflows block, there is also one term less, as fringe catch-up is impossible if the fringe is already neck-to-neck with the Home leader.

On the BGP, the distribution of technology gaps is invariant over time, that is, we have $\dot{\varphi}_t(\underline{n}) = 0$ for all technology gaps $\underline{n}$. Together with the fact that the distribution sums to one ($\sum_{n=-\infty}^{+\infty}\sum_{n_C=0}^{+\infty}\varphi_t(n, n_C) = 1$), this condition yields a system of linear equations pinning down the invariant distribution.

Knowing the technology gap distribution, we can solve for all aggregate outcomes.

In particular, we can derive an expression for the aggregate growth rate.

Lemma 1 *On the BGP, output in both countries grows at a constant rate given by*

$$g = \left(\sum_{n=-\infty}^{+\infty} \sum_{n_C=0}^{+\infty} \varphi(n, n_C) i_H(n, n_C) \right) \ln(1 + \lambda) .$$

Proof. See Appendix A.2.

Lemma 1 shows that output growth is proportional to the aggregate arrival rate of Home innovations. This does not imply that Foreign innovations or catch-up by the fringes do not contribute to growth. However, in equilibrium, aggregate Home innovation is equal to aggregate Foreign innovation and to aggregate fringe catch-up (indeed, this is a necessary condition for the existence of a invariant technology gap distribution).

Finally, the R&D share of GDP is given by

$$\frac{\boldsymbol{R}_t}{\boldsymbol{Y}_t} = \sum_{n=-\infty}^{+\infty} \sum_{n_C=0}^{+\infty} \varphi(n, n_C) \left(\chi_i \left(z_H(n, n_C) \right)^{\psi_i} + \chi_e \left(x_H(n, n_C) \right)^{\psi_e} \right) . \tag{28}$$

The R&D share is the same in both countries and constant over time. Thus, it is straightforward to see that aggregate consumption, which can be obtained residually from Equation (7), indeed grows at rate g.

This completes the discussion of our model's equilibrium conditions. Before discussing our quantitative results, the next section builds some intuitions by describing some important qualitative features of the BGP equilibrium.

2.3 Key properties of the model

2.3.1 Profits, market shares and markups

Figure 1 shows surface plots of the market shares of Home leaders, Foreign leaders and the Home fringe on the Home market, as a function of the industry's technology gap (n, n_C). Obviously, market shares are increasing in relative productivity. Thus, the Home leader has high market shares when it has high technology gaps n and n_C with respect to the Foreign leader and the fringe. Likewise, the Foreign leader and the fringe have high market shares if they enjoy a large advantage (respectively, for the fringe, a small disadvantage) with respect to the Home leader.

Figure 2 shows how market shares translate into profits and markups for the Home leader. Profits and markups are increasing in market share (recall Equations (13) and (15)), and therefore also increasing in the leader's technology gap with respect to its competitors. Moreover, profits and markups are higher in the domestic market than in the export market for all technology gaps, as the trade cost τ increases the marginal cost of exports above the marginal cost of producing for the domestic market.

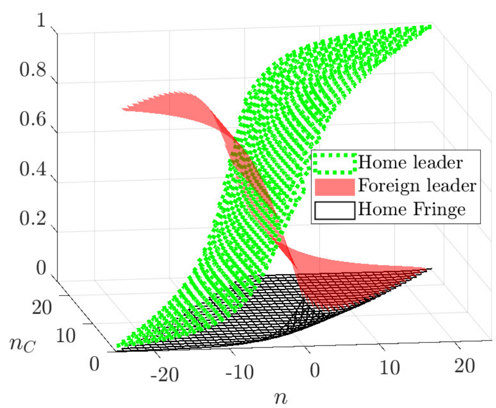

Figure 1: Market shares on the Home market. Notes: This figure plots the market shares of the Home leader, Foreign leader and Home fringe on the Home market, as a function of the technology gap (n, n_C). The figure is drawn with our baseline parameter values, listed in Table 1.

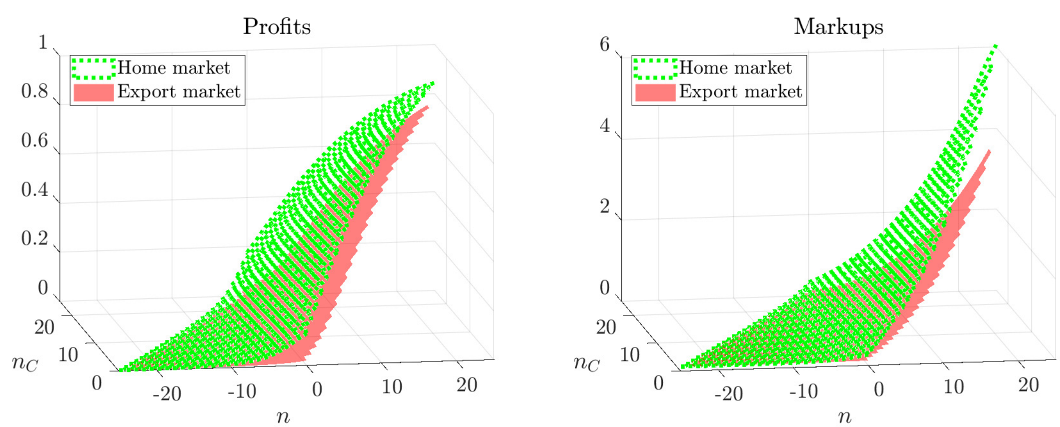

Figure 2: Profits and markups of the Home leader, in both markets. Notes: Profits are normalized by GDP, and markups are net (i.e., we plot $\mu - 1$, where μ is the gross markup defined in Equation (11)). The figure is drawn with our baseline parameter values, listed in Table 1.

Crucially, market shares and profits are S-shaped in the technological gap. To show this more clearly, Figure 3 plots a series of two-dimensional cuts through the three-dimensional surfaces of the previous figures. Starting from a technology gap $(n_0, 0)$, and considering three different values for n_0, it shows how Home market shares and total profits (the sum of profits on both markets) evolve when gradually increasing the technology gap from this starting point. The x-axis in these figures lists the increase in the technology gap (i.e., point x corresponds to a technology gap $(n_0 + x, x)$, which would be reached if the Home leader were to make x innovations).

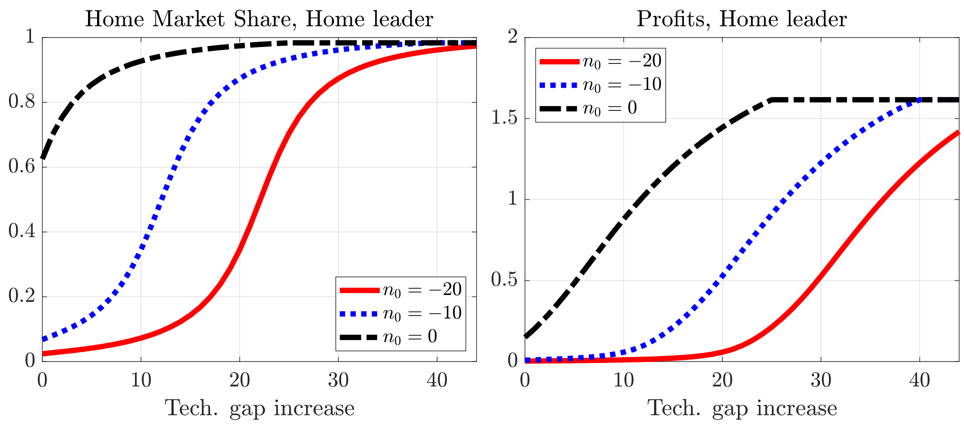

Figure 3: Home market shares and profits of Home leaders. Notes: This figure plots the market shares and profits of the Home leader for technology gaps $(n_0 + x, x)$, where x is given on the horizontal axis. The figure is drawn with our baseline parameter values, listed in Table 1.

The figure clearly illustrates the S-shape of market shares and profits.[9] When the Home leader has a high technology gap, its market share is close to 100%, and it gains little by increasing its productivity even further. Likewise, when the Home leader is far behind its Foreign counterpart, it captures a negligible share of the market, and its profits would also not increase much if it were to increase its productivity. Thus, leaders which are far behind or far ahead have little incentive to innovate. However, when leaders are neck-to-neck, each innovation implies a large change in market shares, and innovation is strongly profitable.

Finally, Figure 4 plots industry-level markups (defined in Equation (18)), as a function of the technology gap. Industry-level markups have a U-shape, being highest

[9] When solving the model, we impose an upper bound on technology gaps (see Appendix B). Thus, in Figure 3, market shares and profits become eventually constant. This does not affect our results, as we make sure that the measure of industries with the highest possible technology gap is negligible.

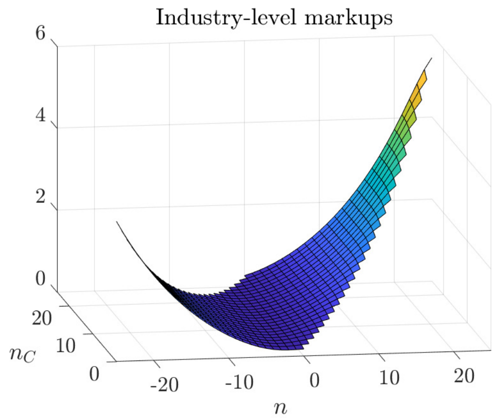

Figure 4: Industry-level markups. Notes: The figure is drawn with our baseline parameter values, listed in Table 1.

in industries in which one leader dominates the market. This is due to the fact that markups are increasing in market shares: when one leader (Home or Foreign) dominates an industry, it has both a high markup and a high weight in industry-level aggregates.

2.3.2 R&D policies and technology gap distribution

Figure 5 shows the value and innovation policy function of Home leaders, as a function of the industry's technology gap. Figure 6, in turn, shows Home entry rates. The value of leaders is increasing in the technology gap, as greater technology gaps imply higher profits. Thus, entry rates are also increasing, as a higher value of incumbency makes entry more attractive.

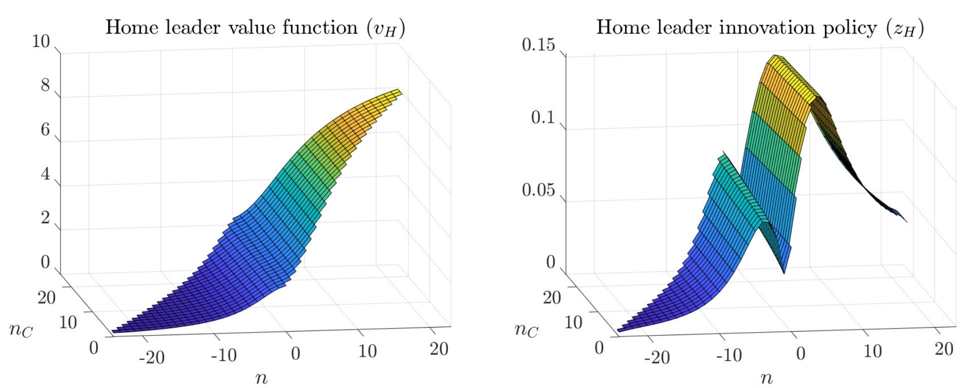

Figure 5: Value function and innovation policy of the Home leader. Notes: The figure is drawn with our baseline parameter values, listed in Table 1.

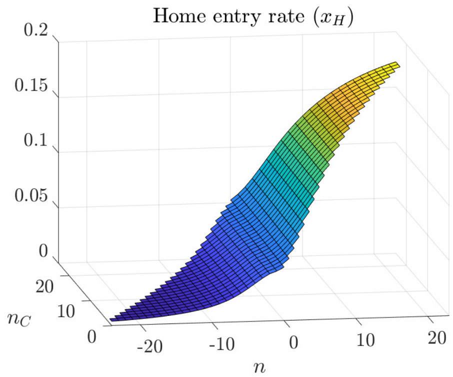

Figure 6: Home entry rate. Notes: The figure is drawn with our baseline parameter values, listed in Table 1.

The innovation policy function, in turn, has an inverse U-shape. This is a direct consequence of the S-shape of the profit function: as innovation is most valuable for leaders with low technology gaps, these leaders invest most in R&D. Furthermore, the innovation policy function has a dip around the neck-to-neck state ($n = 0$). This is due to the fact that laggards benefit from an advantage of backwardness, which increases their innovation rate by ξ. Leaders with a small negative or zero technology gap have less incentives to invest in R&D, as innovations would lead them to lose this advantage (and, at $n = 1$, confer it to their Foreign competitor). However, this feature does not play an important role for our quantitative results.

Finally, the top panel of Figure 7 plots the invariant distribution of technology gaps in the (n, n_C) space, and the lower panels show the corresponding marginal distributions of n and n_C. The marginal distribution of the technology gap between leaders is bell-shaped, symmetric and centered around $n = 0$ (the neck-to-neck state), while that of relative productivity between Home leader and fringe is left-tailed. These distributions are shaped by innovation. On the one hand, higher innovation rates around small technology gaps generate an inflow of firms toward higher n and n_C states. As opposing forces, the advantage of backwardness (ξ) and fringe catch-up (ζ) parameters push for higher shares of firms in lower technology gap states. The relative strength of these forces shapes the invariant distribution.

We are now ready to proceed to a quantitative analysis of the effects of trade openness on innovation and markups. The next section lays out our calibration strategy and our main results.

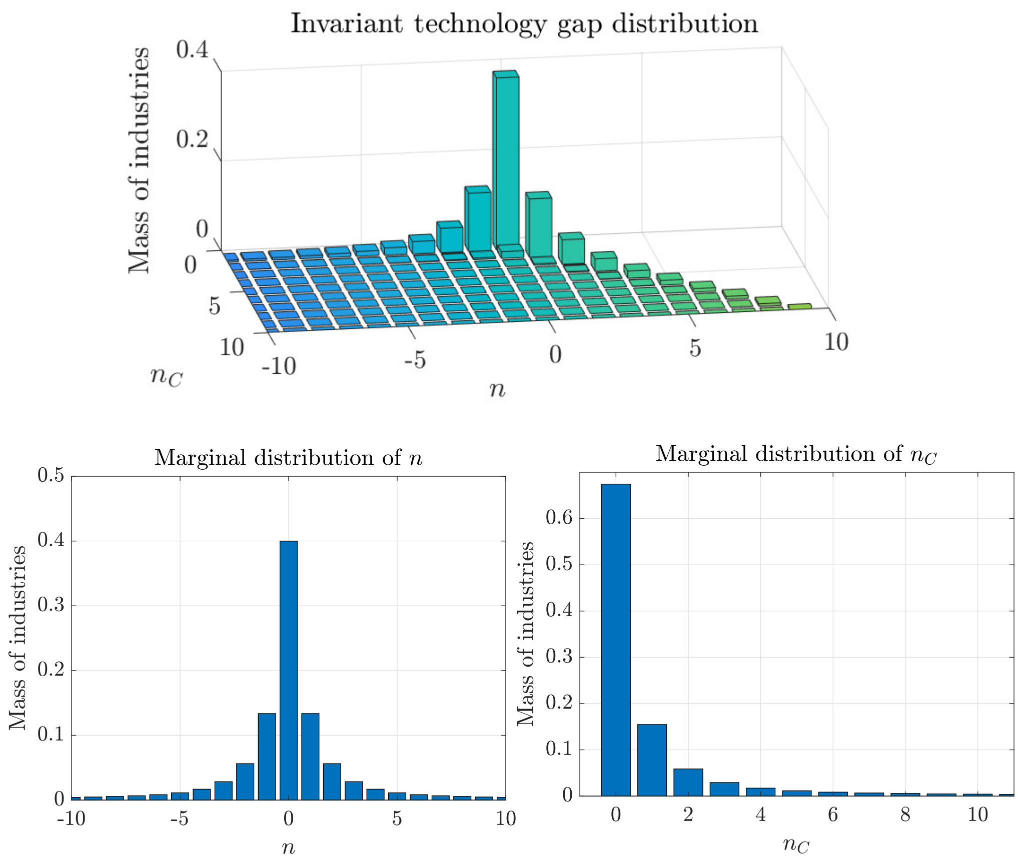

Figure 7: Joint distribution of technology gaps (upper panel), and marginal distributions of n and n_C (lower panel). Notes: The figure is drawn with our baseline parameter values, listed in Table 1.

3 Quantitative Analysis

3.1 Calibration Strategy

Our baseline calibration is designed to reflect the current state of the US manufacturing sector. We calibrate our model at the annual frequency, and need to choose eleven parameter values: the discount rate ρ, the leader's quality level ω_H, the within-industry elasticity of substitution η, the innovation step size λ, the catch-up rates ξ and ζ, the variable trade cost τ, and the scale and curvature parameters in incumbents' and potential entrants R&D cost functions, χ_i, χ_e, ψ_i and ψ_e.

We set the discount rate to $\rho = 0.02$, and the curvature of the R&D cost functions to $\psi_i = \psi_e = 2$, a standard choice informed by empirical studies on the cost elasticity of R&D spending (Akcigit and Kerr, 2018). We set the values of the remaining eight parameters using indirect inference, choosing parameters in order to minimize the distance between a series of model-generated moments and their data equivalents. We target nine moments, summarized in Table 2.

Parameter	**Value**	**Description**
Calibrated externally		
ρ	0.02	Discount rate
ψ_i	2	R&D cost elasticity (incumbents)
ψ_e	2	R&D cost elasticity (entrants)
Calibrated internally		
λ	0.087	Innovation step size
χ_i	1.370	R&D cost scale, incumbents
χ_e	23.179	R&D cost scale, entrants
η	11.161	Within-industry elasticity of substitution
τ	1.275	Variable trade cost
ω_H	0.493	Quality of Home leader
ξ	0.235	Catch-up rate for lagging leaders
ζ	5.446	Catch-up rate for fringes
Period	1 year	

Table 1: Baseline calibration. Notes: Internally calibrated parameters are obtained by indirect inference, targeting the moments listed in Table 2.

Four moments are taken from aggregate data. First, we target the average rate of Total Factor Productivity growth in US manufacturing between 1997 and 2017, which, according to EU KLEMS, was 1.58% per year.[10] Second, we target the ratio of aggregate R&D spending to value added. The average for this ratio between 1997 and 2016, computed with the OECD's ANBERD (for R&D) and STAN (for value added) databases, is 9.8%. Third, we target the aggregate import share, using trade data from the US Census Bureau (as described in Schott, 2008) and sales data from the NBER-CES Manufacturing Database (Becker *et al.*, 2013). In 2011, the last available year of the NBER-CES database, the aggregate import share, defined as $\frac{\text{Imports}}{\text{Shipments}-\text{Exports}+\text{Imports}}$, was 23.5%. We also compute industry-level import shares, and target their standard deviation across industries, which is 21.3% (over 388 industries).[11]

Moment	Model	Data	Data Source
A. From aggregate data			
Productivity growth	1.61%	1.58%	EU KLEMS, 2019 Release
R&D share of value added	8.3%	9.8%	OECD
Import share	24.0%	23.5%	US Census Bureau, NBER-CES
Standard deviation of import shares	18.1%	21.3%	US Census Bureau, NBER-CES
B. From firm-level data			
Average markup	33.0%	35.4%	Compustat
Standard deviation of markups	49.5%	48.1%	Compustat
Entry rate	5.2%	6.5%	US Census Bureau
Contribution of entrants to growth	27.0%	25.7%	Akcigit and Kerr (2018)
Employment share of the fringe	17.5%	18.2%	US Census Bureau, NSF

Table 2: Targeted moments: model versus data. Notes: All data moments refer to the US manufacturing sector. Appendix B describes how we compute these moments in the model.

The remaining five moments are informed by firm-level data. First, we estimate firm-level markups using the Compustat database of publicly listed (manufacturing) firms, following the methodology of De Loecker *et al.* (2020). We then compute a sales-

[10] See https://euklems.eu/ (2019 release).

[11] In the data, exports are lower than imports, as the United States had a current account deficit in 2011. In our model, trade is always balanced. Thus, we scale down industry-level imports in the data, multiplying them with the aggregate export-to-import ratio. We ignore industries with missing trade data and industries in which exports are larger than shipments.

weighted average of firm-level markups in every year. The average of this measure over the period 1997-2015 is 35.4%, and the average of the within-year standard deviation of markups is 48.1%. Second, we target the firm entry rate, taken from the US Census Bureau's Business Dynamics Statistics (BDS) database. The average entry rate in manufacturing between 1997 and 2014 was 6.5%. Third, we target the total contribution of entrants to TFP growth. Akcigit and Kerr (2018) find that 25.7% of productivity growth in the United States is due to entrants.[12] Finally, we target the employment share of fringe firms. In our model, leaders are characterized by the fact that they invest in R&D, while the fringe does not. Using data from the National Science Foundation to measure the employment of manufacturing firms that do R&D, and the BDS database to measure total employment, we find that between 2008 and 2016, firms spending on R&D represented on average 81.8% of manufacturing employment. Thus, we target a fringe employment share of 18.2%.

Appendix B contains further details on model moments, and on the numerical implementation of the indirect inference algorithm. Table 1 shows the parameter values obtained, and Table 2 reports the values of the targeted moments in the model and in the data. Even though the model is over-identified, it fits the data well. We obtain an elasticity of substitution of $\eta = 11$, which is high, but not out of line with the related literature (in Section 3.4, we consider robustness checks for this parameter). Furthermore, note that R&D costs for entrants (scaled by χ_e) are considerably higher than R&D costs for incumbents (scaled by χ_i). Indeed, all else equal, entrants have higher innovation incentives than incumbents, due to the classic Arrow replacement effect. However, the data suggests that incumbents contribute more to productivity growth, and our model rationalizes this by them having lower R&D costs.

3.2 Markups and innovation for different levels of trade costs

We are now ready to analyze the effect of trade on innovation and markups. To do so, we first compare the BGP equilibria of our model for different levels of the trade cost τ, while keeping all other parameters at their baseline values.

In particular, our main comparison confronts our baseline BGP (reflecting the

[12] A recent study by Garcia-Macia *et al.* (2019) comes to similar conclusions, finding that entrants accounted on average for 21.1% of US productivity growth between 1993 and 2013.

current state of US manufacturing) to an alternative BGP in which the trade-to-GDP ratio is only half as high (corresponding roughly to its level in the 1970s).[13] Henceforth, we refer to these two BGPs as the "low trade cost" and the "high trade cost" BGPs.

3.2.1 Market shares, markups and profits

Figure 8 shows how Home market shares and markups depend on trade costs. It plots the percentage difference in these variables when passing from the high to the low trade cost BGP. In the low trade cost BGP, exporters (i.e., Foreign leaders) have lower relative costs. Thus, as shown in the left panel of Figure 8, the market share of Foreign leaders is higher, while the market shares of Home leaders and Home fringes are lower. As a result, with lower trade costs, markups of Home leaders on domestic sales are lower, while markups of Foreign leaders on exports are higher (see the right panel of Figure 8).

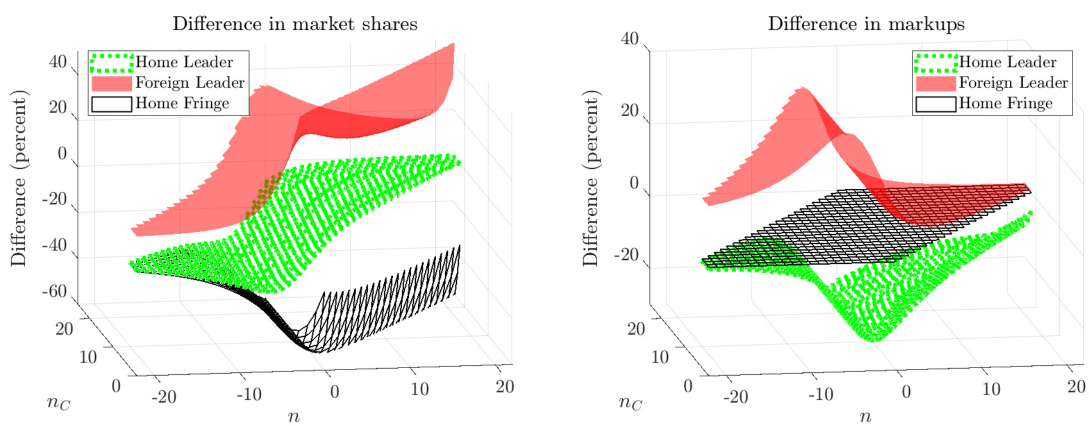

Figure 8: Percentage difference in market shares and markups between BGPs. Notes: This figure plots the percentage difference in Home market shares and markups between the high trade cost BGP and the low trade cost BGP, for different levels of the technology gap. Percentage differences for a variable x are computed as $100 \cdot \left(\frac{x_{\tau_{\text{low}}}}{x_{\tau_{\text{high}}}} - 1\right)$.

Traditionally, when assessing the effect of trade on markups, the literature has focused on the pro-competitive effect of import competition (the fall in markups of the Home leader). However, in our model, this effect is counteracted by increasing markups on exports, and zero-markup fringe firms losing market share. In fact, the

[13] In this alternative BGP, we set $\tau = 1.452$, 13.9% higher than in the baseline calibration.

market share of the fringe decreases more than the market share of the Home leader, as the Home leader optimally lowers its markup to dampen the fall in its market share.

Figure 9 plots the percentage difference in industry-level markups between the two BGPs. It shows an intuitive pattern: in industries where the Home leader has a high market share (i.e., a large technology gap with respect to the other firms), the pro-competitive effect dominates, and industry-level markups are lower in the low trade cost BGP. However, in industries where the Home leader has a small market share, the anti-competitive effects dominate, and industry-level markups are higher in the low trade cost BGP. Figure 9 shows that in our calibration, industry-level markups decrease for a majority of industries. This is a direct consequence of the (empirically realistic) fact that the Home leader is the firm with the largest Home market share in most industries. As we show more formally later on, this implies that if the technology gap distribution were unchanged between BGPs (i.e., if there were no endogenous innovation), lower trade costs would imply a lower aggregate markup.

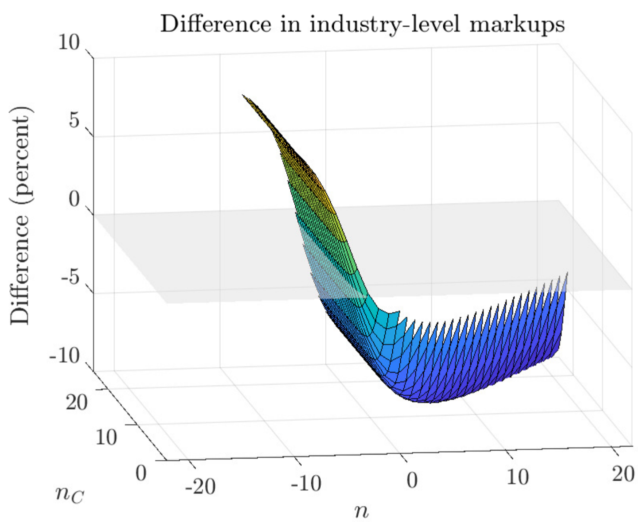

Figure 9: Percentage difference in industry-level markups between BGPs.
Notes: This figure plots the percentage difference in industry-level markups between the high trade cost BGP and the low trade cost BGP, for different levels of the technology gap.

Finally, Figure 10 plots the percentage difference in total profits of Home leaders between both BGPs. Lower trade costs imply that leaders lose market share on their domestic market, but gain market share on their export market. Thus, lower trade costs imply higher profits for firms with high technology gaps (which export a lot), and lower profits for firms with low technology gaps (which mainly sell domestically).

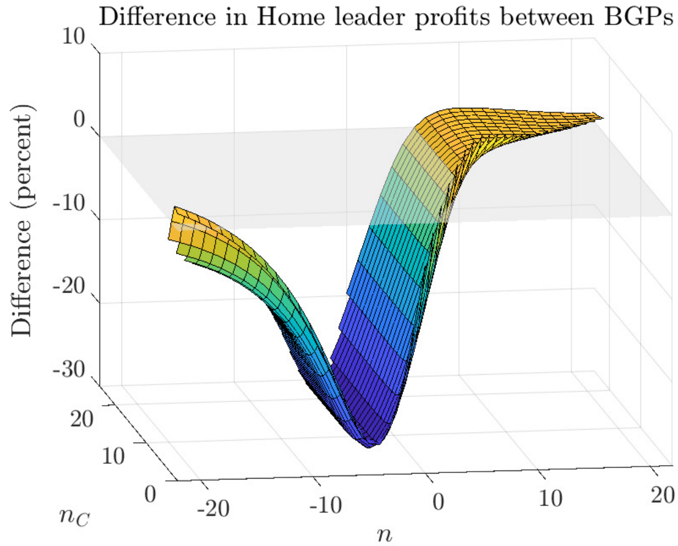

Figure 10: Difference in Home leader profits between BGPs. Notes: This figure plots the percentage change in total Home leader profits (defined as $\pi_H^H(\underline{n}) + \pi_H^F(\underline{n})$) when passing from the high to the low trade cost BGP, as a function of the industry's technology gap.

Crucially, Figure 10 also shows that lower trade costs accentuate the S-shape of profit functions: they reduce profits mainly for leaders which are technologically close to their rivals, while profits of leaders which are far ahead or far behind hardly change. Intuitively, with lower trade costs, leaders compete on a more equal footing, and this increases the importance of relative productivity. Indeed, when trade costs are high, relative productivity is almost irrelevant: trade costs shield the Home leader from Foreign competition on the Home market, and prevent it from making large profits from exports. When trade costs are low, instead, relative productivity becomes decisive. These differences in profits are the key driver of differences in innovation behavior between both BGPs. We turn to this issue next.

3.2.2 R&D choices and the technology gap distribution

Figure 11 plots the percentage differences in the innovation rates of Home leaders and in Home entry rates between the two BGPs. The left panel shows that in the low trade cost BGP, innovation rates are higher for leaders with technology gaps around zero, but lower for leaders which are either far ahead or far behind. Indeed, as we have shown above, lower trade costs lower the profits of neck-to-neck leaders most strongly. Therefore, these leaders now have a higher incentive to escape their current state through innovation. The right panel shows that entry rates mimic profits: they increase for industries with high technology gaps (where lower trade costs mainly imply higher export opportunities) and decrease for industries with low technology gaps (where lower trade costs mainly imply higher import competition).

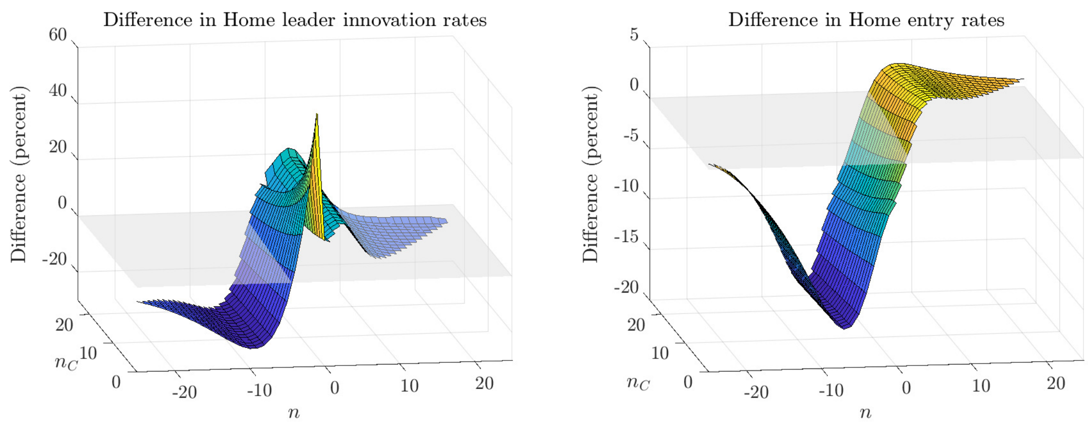

Figure 11: Difference in innovation rates between BGPs. Notes: This figure plots the percentage difference in the innovation rate of the Home leader (z_H) and the Home entry rate (x_H) between the high and the low trade cost BGP, as a function of the technology gap.

These differences in firms' innovation behavior imply important changes in the invariant distribution of technology gaps, shown in Figure 12. The left panel plots the distribution of the technology gap between leaders, n, for both BGPs. As we have just seen, with low trade costs, innovation rates are higher in industries in which the technological distance between the Home and the Foreign leader is low. Therefore, there is a lower mass of such industries in equilibrium, and a higher mass of industries in which one leader has a large technological advantage over the other one. In other words, with lower trade costs, the technology gap distribution is more polarized. The right panel plots the distribution of the technology gap between the Home leader and the fringes, n_C. This distribution is shifted to the right with lower trade costs, as leaders innovate more in an economy with lower trade costs. Thus, they pull ahead of fringe firms, which do not innovate.[14]

[14] Moreover, the catch-up speed of the fringe does not depend on trade costs.

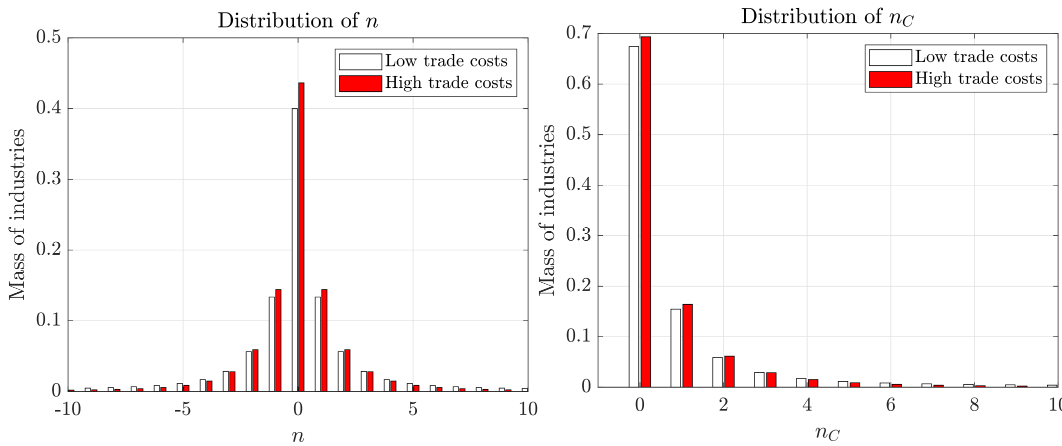

Figure 12: The invariant distribution of technology gaps for different levels of trade costs.

Summing up, lower trade costs induce a more polarized technology gap distribution, with a higher share of industries dominated by one leader. However, as we have seen earlier, these are precisely the industries in which markups are highest. Thus, all else equal, the shift in the technology gap distribution (fully driven by innovation) is a force that tends to increase the aggregate markup. This force, which we call the innovation feedback effect, has been overlooked in the literature so far. In the next section, we will discuss its quantitative importance.

3.2.3 Aggregate outcomes and magnitudes

Figure 13 plots the BGP values of some key aggregate variables for different trade costs. The high and low trade cost BGP values of τ are marked by vertical lines.

The first panel plots the trade share of GDP. While the trade share is a non-linear function of τ, it is roughly linear around our baseline calibration value, and the trade elasticity (computed for a 1% increase in trade costs) is 3.6. This is close to standard values in the literature (e.g., Costinot and Rodriguez-Clare (2014) use an elasticity of 5 in their review). Thus, even though we did not target this moment, our model yields a realistic relation between variable trade costs and the level of trade.

The second panel shows that the rate of productivity growth depends negatively on the trade cost. Indeed, as we have shown before, with lower trade costs, innovation incentives are higher for leaders that are technologically close to their rivals. As Figure 12 shows, most leaders are in such states, so the overall effect of lower trade costs is to boost R&D and innovation (as shown in the third panel).

The forth panel shows our main result: the aggregate markup (as defined in Equation (19)) is higher for lower levels of trade costs. This is due to the innovation feedback effect. As we have discussed above, lower trade costs actually lower markups for the majority of industries. However, by spurring innovation for firms in technologically close industries, they also lead to a polarization of the technology gap distribution (shown in the fifth panel), and therefore to a larger percentage of high-markup industries. Figure 13 shows that this innovation feedback effect dominates, so that the aggregate markup is higher when trade costs are low.

Finally, the sixth panel shows that the employment share of the fringe is lower when trade costs are low. This is a direct consequence of the fact that the fringe is most prone to losing market share to imports.

Magnitudes Figure 13 shows that the rate of productivity growth is 0.12 percentage points (or 8.1%) higher in our baseline low trade cost BGP than in the high trade cost BGP (in which the trade-to-GDP ratio is only half as large). However, aggregate markups are also substantially higher, by 1.70 percentage points (or 7.2%). Compared to a pseudo-autarky BGP (in which trade costs τ are set to such a high value that the trade-to-GDP ratio is smaller than 0.1%), the rate of productivity growth is 0.29 percentage points (or 22%) and markups are 1.92 percentage points (or 8%) higher in the baseline.

These results suggest that lower trade costs stimulate growth, but are accompanied by an increase in the aggregate markup. As we have argued above, the rise in the aggregate markup is mostly driven by the innovation feedback effect, the main novel aspect put forward in our paper. In the next section, we further illustrate this point by explicitly decomposing the aggregate markup change into the part driven by the innovation feedback effect, and the part driven by other factors.

3.3 Quantifying the innovation feedback effect

In our model, changes in trade costs affect the aggregate markup through two channels: changes conditional on a given technology gap distribution (“direct effects”) and changes in the technology gap distribution itself (“innovation feedback effects”).

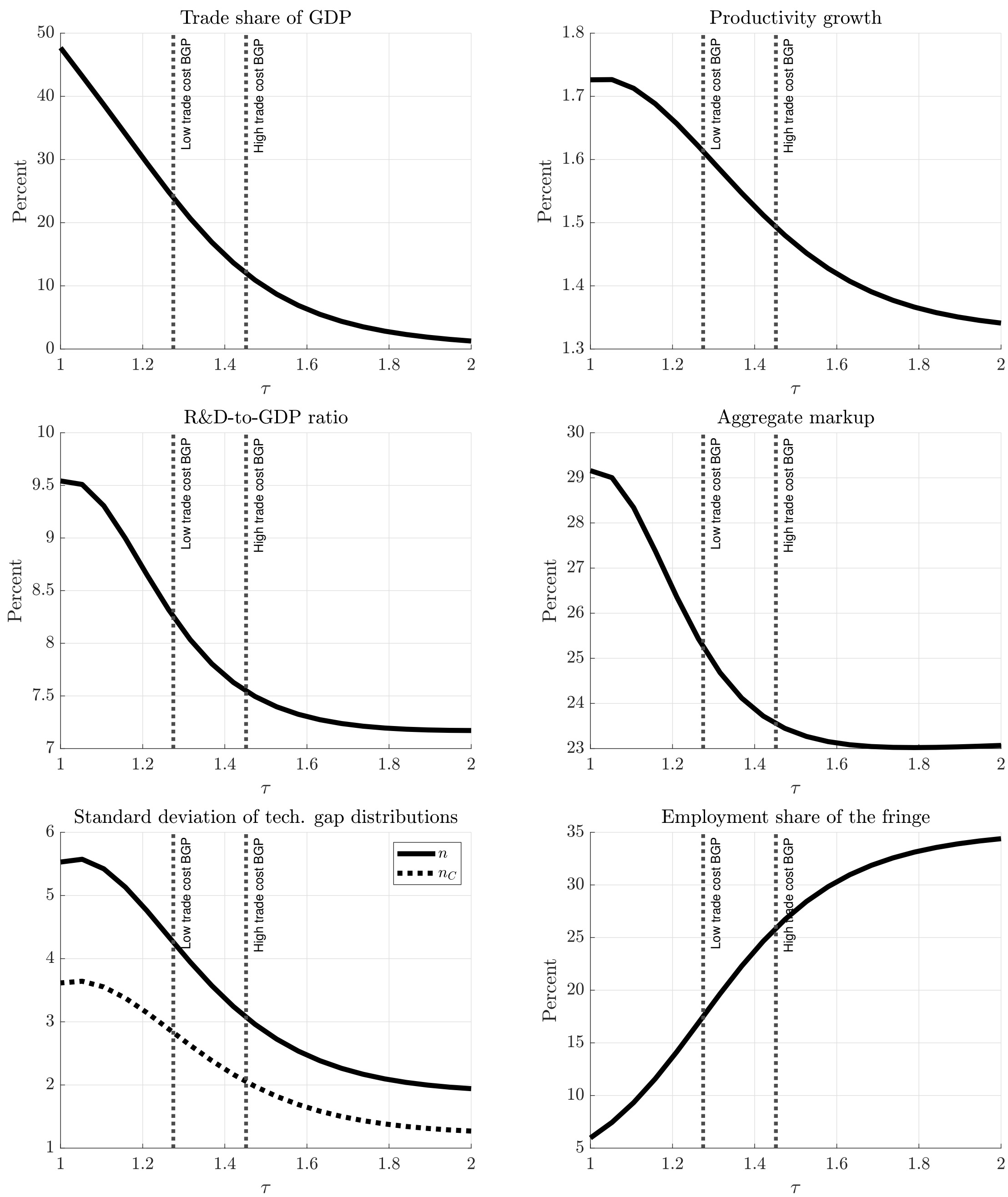

Figure 13: Aggregate BGP outcomes for different trade costs. Notes: The figure shows aggregate outcomes for BGPs obtained with different values of trade costs τ. All other parameter values are at their baseline values throughout.

To assess the relative contribution of these two channels, it is useful to explicitly consider transition dynamics.

Precisely, we assume that the economy is initially in the high trade cost BGP, and is hit by a permanent and unexpected shock which instantly lowers trade costs to their low trade cost BGP level. The economy then gradually converges to the low trade cost BGP, and Appendix B.3 describes how we solve for the transition path. This analysis allows us to distinguish direct and innovation feedback effects on markups. Indeed, on impact, the surprise fall in trade costs changes markups in all industries, but does not affect the technology gap distribution, which is a state variable. Over the transition, markups conditional on the technology gap distribution are fixed, and changes in the aggregate markup are entirely due to shifts in the technology gap distribution. Thus, the impact response captures the direct effect, and the additional change over the transition captures the innovation feedback effect.

Columns (1) and (2) in Table 3 list the values of key aggregate variables in both BGPs, and Column (3) shows the percentage point difference between both BGPs. In Column (4), we report the change in aggregate variables that occurs on impact and is therefore attributable to direct effects. Column (5) instead shows the response that occurs during the transition, due to the innovation feedback effect.

Panel 1 shows that in a transition from the high trade cost BGP to the low trade cost BGP, the aggregate markup falls by 1.14 percentage points on impact. This is due to a classic pro-competitive effect of trade through import competition, lowering the market shares and markups of Home leaders. However, eventually, the aggregate markup ends up being 1.70 percentage points higher in the low trade cost BGP. This increase is entirely due to the shift in the technology gap distribution during the transition, i.e., to the innovation feedback effect. In total, the innovation feedback effect thus accounts for a 2.84 percentage point $(1.70-(-1.14))$ increase in the aggregate markup, about 12.1% of the initial aggregate markup.

For other aggregate variables, such as the growth rate, the trade share or the employment share of the fringe, the innovation feedback effect is less relevant, as most changes occur on impact. Also, the innovation feedback effect reinforces the impact response, and does not turn it around as it is the case for markups.

Panels 2 and 3 of Table 3 consider a transition from autarky to the low trade cost

	(1)	(2)	(3)	(4)	(5)
Variable	$\text{BGP}_{\text{initial}}$	$\text{BGP}_{\text{final}}$	**Total change**	**Impact**	**Transition**
Panel 1. *Transition from high trade cost BGP to low trade cost BGP*					
Productivity growth	1.49%	1.61%	+0.12	+0.08	+0.04
Aggregate markup	23.55%	25.25%	+1.70	−1.14	+2.84
Trade share	11.98%	23.95%	+11.97	+10.51	+1.46
Fringe emp. share	25.90%	17.51%	−8.39	−7.68	−0.71
Panel 2. *Transition from autarky BGP to low trade cost BGP*					
Productivity growth	1.32%	1.61%	+0.29	+0.25	+0.04
Aggregate markup	23.33%	25.25%	+1.92	−2.47	+4.39
Trade share	0%	23.95%	+23.94	+21.87	+2.07
Fringe emp. share	35.36%	17.51%	−17.85	−17.00	−0.85
Panel 3. *Transition from autarky BGP to free trade BGP (with $\tau = 1$)*					
Productivity growth	1.32%	1.73%	+0.41	+0.33	+0.08
Aggregate markup	23.33%	29.16%	+5.86	−3.35	+9.21
Trade share	0%	47.69%	+47.64	+47.17	+0.47
Fringe emp. share	35.33%	5.97%	−29.36	−28.67	−0.69

Table 3: The quantitative importance of the innovation feedback effect. Notes: Differences in Columns (3) to (5) are stated in percentage points. The algorithm that computes the transition dynamics between different BGPs is described in Appendix B.3.

BGP, and a transition from autarky to a free trade BGP (in which $\tau = 1$). In both cases, qualitative effects are similar: the aggregate markup falls on impact, but the innovation feedback effect eventually raises it again. The size of the effect is higher for larger changes in trade costs: from autarky to the baseline BGP, the innovation feedback effect represents 18.8% of the initial markup, and from autarky to free trade, it represents 39.5%.

So far, we have described how innovation and markups change in response to a change in trade costs. In the next section, we analyze how these changes affect consumer welfare.

3.4 Robustness Checks

This section briefly discusses the results of several robustness checks for our main results. Robustness checks are discussed in greater detail in Appendix C.

Different markup targets The last years have seen an extensive debate on markup measurement. Comparing the results of different studies suggests that estimates obtained with the method of De Loecker *et al.* (2020) are at the higher end of the literature. For robustness, we therefore consider an alternative calibration where we assume that markup targets are only half as high as our estimated values. This reduces our target for the average markup to 17.7%, and our target for the standard deviation of markups to 24.1%.

Using this new calibration, we again compare our baseline BGP to a high trade cost BGP, in which the trade-to-GDP ratio is half as large as in the baseline. Analyzing the transition from high to low trade costs (as in Section 3.3), we find that the aggregate markup falls by 0.82 percentage points on impact, but that the innovation feedback effect then raises it again by 1.79 percentage points, or 11.1% of the initial level (almost exactly as in the baseline, where the corresponding number was 12.1%).

The within-industry elasticity of substitution Our calibrated within-industry elasticity of substitution is $\eta = 11.16$, close to the value of $\eta = 10$ used in Atkeson and Burstein (2008). Nevertheless, it is important to consider how our results change for somewhat higher or lower values of this parameter. To do so, we exogenously set

η to values of 7 and 16, and recalibrate all internally calibrated parameter values to match the baseline targets. As shown in Table C.3 in the Appendix, markup results for the transition from a high to a low trade cost BGP are quantitatively similar to our baseline results.

Fixed cost of exporting In our model, all leaders are exporters. In the data, this is obviously not the case. To make the model more realistic along this dimension, we introduce a fixed cost of exporting (as described in greater detail in Appendix C). We calibrate this extended model targeting the same moments as in the baseline, and adding a new target for the percentage of leaders that export. As Table C.3 in the Appendix shows, our results are again unchanged: for a given technology gap distribution, lower trade costs lower the aggregate markup. However, taking into account the innovation feedback effect, the aggregate markup rises again.

4 Gains from Trade

4.1 Consumption-Equivalent Welfare

Balanced Growth Path Comparison We start by comparing welfare between economies on Balanced Growth Paths with different trade costs. On a BGP, the welfare of the representative consumer is given by:

$$\boldsymbol{U}_0 = \frac{\ln(\boldsymbol{C}_0)}{\rho} + \frac{g}{\rho^2} \tag{29}$$

where $\boldsymbol{C}_0$ is the initial level of consumption and g is the rate of economic growth.[15] In order to compare two BGPs A and B, we derive a consumption equivalent welfare measure γ, defined as the percentage increase in consumption that a household in BGP B would require to be indifferent between living in BGP A or B. Using Equation (29), we can show that:

[15] To compute the initial level of output and consumption, we normalize for each BGP the level of productivity of all Home leaders to one at time $t = 0$, i.e. $q_{jH,0} = 1$, $\forall j$.

$$\gamma = \frac{\boldsymbol{C}_0^A e^{\frac{g^A - g^B}{\rho}}}{\boldsymbol{C}_0^B} - 1 \tag{30}$$

Using this formula, we find that the consumption-equivalent welfare gain from moving from the high to the low trade cost BGP is 9.2%. Moving from autarky to the low trade cost BGP or to the free trade BGP generates welfare gains of 21.5% and 41.9%.

Thus, our model implies large welfare gains from trade. However, it is worth pointing out that these gains are unequally shared, as corporate profits increase more than wages. Considering a fictitious household earning all the labor income of the economy, we find that the consumption-equivalent welfare gain from moving from the high to the low trade cost BGP would be only 7.7%. By contrast, the corresponding number for a household earning all the profit income is 15.5%, i.e. roughly twice as high.

Transition Dynamics Next, we analyze welfare gains taking into account transition dynamics. As in Section 3.3, we assume that the economy starts in the high trade cost BGP and is hit by an unexpected and permanent shock, which instantly lowers the trade cost to its low baseline calibration value.

To compute welfare gains, we compare the transitioning economy (labeled A) to a counterfactual economy (labeled B) which remains on the high trade cost BGP throughout. Our consumption-equivalent welfare gain γ, making a representative household in B indifferent between the two regimes, is then given by:

$$\frac{\ln(\boldsymbol{C}_0^B)}{\rho} + \frac{g^B}{\rho^2} = \int_0^\infty e^{-\rho t} \ln(\boldsymbol{C}_t^A(1+\gamma))\mathrm{d}t \tag{31}$$

We find that the shock to trade costs raises welfare by 7.7% in consumption-equivalent terms. This number is somewhat lower than the one obtained when comparing BGPs (9.2%), as the growth rate of the economy increases gradually during the transition. Transitioning from autarky to low trade costs or to free trade generates consumption-equivalent welfare gains of 19.1% and 36.7%, respectively.[16]

In our model, welfare gains are driven by three different mechanisms. First, lower trade costs directly raise the level of consumption. Second, lower trade costs stimulate innovation, and therefore increase productivity growth. Third, lower trade costs affect the equilibrium dispersion of markups, and this affects the allocation of labor across firms.[17]

To get an idea on the relative importance of these channels, we can compute the consumption-equivalent welfare gain from decreasing trade costs in a counterfactual scenario in which we keep innovation policies (and thus the technology gap distribution) fixed at their high trade cost values. In that case, we find a welfare gain of 2.6% in consumption-equivalent terms, about 34% of the total welfare gain from lower trade costs. Thus, roughly two-thirds of consumption-equivalent welfare gains are due to changes in innovation behavior and to their feedback effects.

4.2 Social Planner Solution

To better understand the sources of welfare gains in our model, we compare the decentralized equilibrium (DE) with the allocation of a Social Planner (SP) who maximizes global welfare. Appendix D derives the SP solution formally and provides additional discussion.

The DE solution differs from the SP allocation because of static and dynamic inefficiencies. Statically, labor is misallocated across firms in the DE because different firms charge different markups. Dynamically, the DE solution has a suboptimal allocation of resources between consumption and R&D, and of R&D between firms. The social and private returns to innovation differ for two reasons: (i) firms do not internalize that future innovators will benefit from their own innovations (a positive externality); and (ii) firms do not internalize that part of their (private) gains from

[16] These welfare gains are comparable to recent findings in the literature. For example, Hsieh *et al.* (2019) find a 37% increase in welfare for a transition from autarky to their baseline calibration of trade costs. Perla *et al.* (2019) find gains of 10.8% for a 10% reduction in trade costs, while we find 7.7% for a roughly 14% reduction in trade costs. Both of these papers are calibrated to US data.

[17] Computing misallocation as the gap between the DE and SP initial levels of output, or $1-\boldsymbol{Y}_0/\boldsymbol{Y}_0^*$, we find that opening up to trade (from autarky to the BGP with low trade costs) reduces this gap by 16%. By comparison, Edmond *et al.* (2015) find that opening up to trade reduces misallocation by one-fifth.

innovation are associated with a decrease in the value of other firms through business stealing (a negative externality).

In the SP solution, consumption-equivalent welfare gains for moving from the high to the low trade cost BGP are equal to 6.8%. This number is smaller than the one we found for the DE solution (9.2%), showing that a reduction in trade costs lowers the wedge between the DE allocation and the Pareto frontier. Thus, the large gains from trade found in the previous section are partially due to a reduction in misallocation of labor and R&D between firms, and of resources between consumption and R&D. In particular, we find that the SP growth rate is almost invariant to the level of trade costs (increasing only by 0.3% when moving to the low trade cost BGP). Thus, the DE underinvests in innovation, and lower trade costs alleviate this problem.

5 Conclusion

Our analysis suggests that greater openness to international trade spurs innovation, but has important side effects on competition. Specifically, the fact that lower trade costs induce many firms to escape the competition of their rivals leads to a polarization of the productivity distribution, and a larger share of industries dominated by a single firm. As markup are highest precisely in such industries, this innovation feedback effect increases the aggregate markup.

Our quantitative analysis for the US manufacturing sector shows that the innovation feedback effect can be substantial. For a shock that doubles the trade-to-GDP ratio (from its level in the 1970s to its current level), the innovation feedback effect raises the aggregate markup by around 10%. This suggests that globalization may be an indirect contributor to the large increase in concentration and markups observed in many developed economies over the last decades.

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