Low-wage Import Competition, Innovation and Growth*

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Abstract

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This paper revisits the competition-innovation debate in light of the recent empirical evidence on the effects of increased exposure to China product competition. From the empirical perspective the evidence is mixed. Faced with fiercer competition, firms in European countries innovate more whereas for the US the effects are negative. In theory, two competing forces are in place. On one hand, more intense competition decreases the profit stream by decreasing markups, the standard *Schumpeterian effect*. On the other hand, competition may increase the firm's incentives to gain a technological lead over its competitor increasing the firm's ability to charge higher markups, the *escape competition effect*. The extent to which one of the forces dominates will depend on the technological distance between competitors. We argue that changes in the distinct initial level of exposure to foreign competition between Europe and the U.S. can account for part of the responses empirically observed. We build a model of step-by-step innovation carried by incumbents that are subject to an entry shock that replaces the follower with a new, one step ahead competitor. We calibrate the model to the U.S. and Europe, pre and post China's WTO accession. The results suggest a stronger negative effect on innovation for the U.S. relative to Europe.

Keywords: Low-wage competition, Schumpeterian growth model, gap distribution, China shock, innovation
JEL Codes: O31,O33,O40,O41,O47,O51,O53

1 Introduction

Despite considerable amount of research on the relationship between competition and innovation it still remains an open question[1]. Moreover, the cornerstones endogenous growth models share the same baseline mechanism through which private incentives lead to R&D effort and, consequently, to long run growth: the prospect of profits coming from monopoly rights over new ideas. To the extent that more intense competition may change the profit stream accruing to the firm's invention, new competitors can ultimately shape a country's long run growth.

This paper investigates the mechanisms behind the competition and innovation relationship in the context of a growth model with endogenous markups. This feature of the model is well suited to the investigation of the effects of more intense competition because it allows a more flexible response of the innovation incentives to changes in the competition environment.

The starting point of this research is the recent empirical evidence that shows completely opposite responses of firm-level innovation in developed countries to increased exposure to imports from low wage countries such as China. While the evidence for European countries suggest that firms within sectors more exposed to low wage imports granted more patents, increased IT intensity, their measured TFP (conditional on survival) and R&D expenditure, for the U.S., the effect has been in the opposite direction. Controlling for the trend in patenting, the firm-level evidence suggests less innovation and R&D (Bloom et al. (2015); Autor et al. (2016)). A natural question that arises is: What does explain such differential responses to virtually the same competition shock? Moreover, what are the implications of these responses to long-run growth?

From the theory point of view there are two main effects of increased competition on innovation incentives. On one hand, increased competition may decrease profits accruing for a new product by decreasing markups and lead to lower incentives to innovate. This is what is sometimes referred as the standard *Schumpeterian effect*. On the other hand, more intense competition may induce firms to innovate to increase further the lead over its competitor's technology - which allows them to charge higher markups and increase profits. This is referred as the *escape-competition effect*. The extent to which one of the effects dominate depends, ultimately, on the techonological distance between leaders and followers (Aghion et al. (2005)). For this reason, the endogenous distribution of gaps between leaders and followers play an important role in determining the aggregate effect of fiercer competition on innovation and, consequently, on output growth. In this

[1]See Cohen (2010) and Gilbert (2006) for comprehensive surveys on the literature.

paper, we argue that differences in the initial level of exposure to foreign competition, measured by the probability with which the follower is replaced in each industry, as well as the magnitude of the change of the competition environment can explain part of the differences in the innovation responses between the U.S. and Europe to low wage import competition.

Guided by the empirical evidence, we build a model of step-by-step innovation in which leaders and followers strategically compete in innovation, which gives rise to an endogenous distribution of gaps. The key ingredient in this model is the entry shock that replaces the follower, at some rate, with a new one step ahead competitor. Next, we calibrate the balanced growth path of the model to match U.S. economy in 2000 before Chinese accession to the WTO in 2001. Then, we use the entry shock to match the exposure to imports from China both in the U.S. in 2006, the same time period covered in the empirical literature, and for a combination of European countries in the same years. With the calibrated model we are able to measure the change in innovation decisions of leaders and followers to an increase in the entry shock, conditional on their productivity gap, and in the average innovation in the economy taking into account the new gap distribution. Finally, we decompose the effect of the increased competition from low wage countries into its within gap effect on innovation decisions, the combined escape-competition and Schumpeterian effects, and the composition effect on the gap distribution.

The results suggest that the combination of an initially lower level of the competitive fringe shock and a higher increase in the period (more than doubled) imply a stronger decrease in the average innovation intensity in the U.S. relative to Europe. Additionally, there is a considerable heterogeneity across gaps. For instance, firms in low gap industries tend to exhibit higher drops in the innovation effort relative to high gap industries in face of increased competition. Nevertheless, this effect is less pronounced for European firms. Also, in contrast to previous literature the escape-competition effect tend to dominate the Schumpeterian effect for leaders in high gap industries instead of "neck-and-neck" industries, thus increasing innovation effort in these gaps. The opposite holds in low gap industries. For that reason the composition effect tend to strengthen the negative effect since the increase in the competitive fringe shock shifts more firms into lower gaps where the effect of competition is likely to be negative.

Finally, the relative contribution of both the within gap effect and the between gap effect significantly differ between the U.S. and Europe. In the former, both effects account for roughly 30% of the decrease in the productivity growth rate, although the composition effect is somewhat higher. In the latter, the within gap effect accounts for almost 64% of the smaller decrease in the productivity growth which amounts to 1.7 times the composition effect's contribution.

The theoretical framework used here builds on the literature of Schumpeterian models of endogenous growth (Aghion et al., 2001, 2005; Acemoglu and Akcigit, 2012). The common feature of these models is the strategic interaction between two firms in each market that spend resources in R&D in order to innovate and, consequently, gain market leadership. Since firms compete *à la Bertrand* the follower's productivity level in this market limits the leader's ability to charge infinite prices and markups. At the same time, since innovation is a forward looking decision, followers also invest in order to catch-up and possibly overcome the leader. As a result, the model endogenously generates a gap distribution that, along with the optimal innovation decisions, determine the long-run output growth rate. Following the recent literature, we add an entry shock that replaces the follower in industries in which the U.S. (analagously, Europe) has a lead with a new one-step ahead competitor (Akcigit and Ates, 2019a,b). The difference here is in the nature of the shock. The replacement shock is exogenous in our setting and only takes place in industries where the U.S. or European firm has a lead or it affects the Chinese firm in industries with the same productivity level. Thus, the model is able to isolate the effect of more intense competition stemming from the bottom of the gap distribution mirroring the empirical import shock from less technologically developed countries.

This paper is related to the empirical literature on the effect of low-wage countries import competition on firm innovation. In addition to the already mentioned papers, Buono (2012) analyses the impact of low wage competition and credit constraints in Italian firms. Chakravorty et al. (2022) and Iacovone et al. (2011) provide additional evidence on the Chinese surge in competition in firm innovation in the U.S. and Mexican firms. Kueng et al. (2016) show a negative effect of Chinese imports on all types of innovation for Canadian firms, but specially stronger for process innovation. Lelarge and Nefussi (2008) show that Southern competition drives R&D spendings in both intensive and extensive margin in French firms and is associated with quality upgrading of the exports. Li and Zhou (2017) argue that U.S. firms respond differently from import competition whether high-wage or low-wage, increasing R&D and patenting in the former case while reducing innovation in the latter. Also, Martin and Mejean (2014) present evidence of quality improvement of French firm's exports in face of low-wage import competition, suggesting that import competition lead firms in developed countries to specialize in higher quality goods. This paper contributes to the empirical literature on the effect of low-wage countries import competition by uncovering the mechanisms in place when there is an increase in the competition environment, in this case, defined as the entry of a new competitor.

This paper is also related to the endogenous growth literature (Romer, 1990; Aghion and Howitt, 1992; Aghion et al., 2001; Acemoglu and Akcigit, 2012). More closely related recent papers on Schumpeterian models with ste-by-step innovation are Akcigit and Ates (2019a) and Akcigit and Ates (2019b), that use the endogenous markups model to investigate the causes of several trends in the U.S. economy as well as the declining productivity growth. Bento (2020) analyzes the competition innovation relationship in a static cournot setting. Also, Akcigit et al. (2018) use a open economy version of the step-by-step model to investigate the role of import tariffs and R&D subsidies as policy responses to foreign competition. Lastly, Bloom et al. (2014) seek to rationalize the results in Bloom et al. (2015)'s paper with a model of "trapped factors" in which Chinese import competition induce firms to relocate these factors to innovation while providing micro evidence on stronger positive effects within industries with more trapped factors. This paper contributes to this debate by flexibly allowing for not only positive but also negative responses. Also, it highlights the heterogeneity in innovation responses originated from the technological distance across firms. Lastly, it also contributes to the competition-innovation theory in that it extends the basic Schumpeterian step-by-step innovation models allowing for entry which gives rise to the mechanisms in a more realistic framework.

The rest of the paper proceeds as follows. Section 2 presents the motivating evidence on the differential innovation efforts by technological distance to the frontier and discuss the main empirical literature on the effect of the Chinese import competition on firm-level innovation. Section 3 describes the step-by-step innovation model with the replacement shock that we referred as the *competitive fringe shock* model. Section 4 describes the data used for 2000 and 2006, the same period analyzed in the empirical literature, and the model calibration of the balanced growth path. Section 5 shows the quantitative innovation responses of firms to increased competition in the U.S. and Europe, while providing a decomposition of the main effects. Finally, Section 6 concludes.

2 Motivating Evidence: Distance to the frontier-driven innovation responses

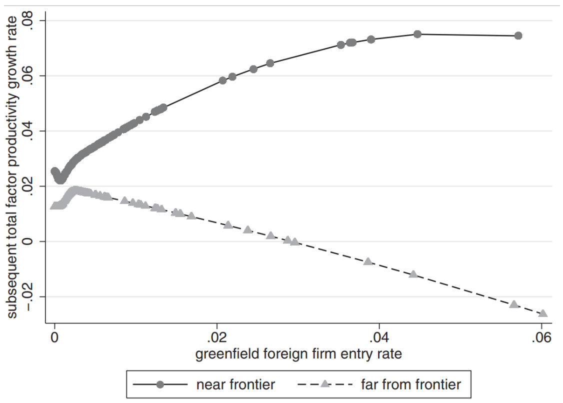
This section presents the empirical evidence motivating the heterogeneous innovative responses of firms in the developed countries to increased competition from low-wage countries such as China. We begin by providing some suggestive evidence that incumbent firms may react differently to entry threat in terms of innovation depending on its relative distance to the technology frontier. Next, we focus on the empirical literature that estimates the firm-level innovation responses in developed countries to a competition shock as measured by an increase in the sectoral imports from China. As mentioned previously, the evidence shows that while in a set of European countries the increased competition led to an increase in measures of innovation input and outputs, for the U.S. the increase in imports from China decreased the patenting behaviour relative to the trend.

Figure 1 below, obtained from Aghion et al. (2009), shows the differential reaction to entry threat of incumbent firms that are close relative to distant from the technological frontier. The figure depicts the average total factor productivity growth of incumbent establishments within an industry-year pair for the period 1987-1993 against greenfield foreign firm annual entry rate across industries in the United Kingdom. The distance to the frontier is defined by dividing a labor productivity index in the U.S. industry by the incumbent in the respective U.K. industry. The annual greenfield foreign entry rate is measured by the share of industry employment of entrants that are foreign owned, that did not operate in the same industry before and begin production in at least one new facility in the given year.

As the figure suggests there is a positive correlation between entry threat proxied by the greenfield foreign entry rate and the productivity growth across industries for incumbents that are close to the technology frontier. In contrast, the correlation is weaker or even negative for incumbents far from the frontier. As argued by the authors this correlation holds as a causal effect when they assess this relationship exploring the market reforms implemented in the wake of the Single Market Program in Europe and the domestic product market reforms in the U.K. as instruments in a IV strategy for the endogenous greenfield foreign firm entry. Moreover, the results are consistent with the Schumpeterian model prediction that increased entry competition should spur innovation in incumbent firms that are close to the technology frontier because these firms can preserve profitability by doing so, thus managing to survive entry. Nevertheless, incumbents that are far from the frontier are discouraged from innovation since frontier entry would depress profitability even though they succeed in innovation.

The effect on the former group of firms is similar to the escape competition effect, already discussed in the introduction section, whereas the effect on the latter set of firms is the well known Schumpeterian effect. The model in this paper takes one step further arguing that not only the entry of frontier firms but also better firms at the bottom of the gap distribution have important and differential effects depending on the technological distance between incumbent firms across industries. Also, the industry composition along with the distance from the frontier ultimately shape the overall effect on innovation and output growth.

Figure 1: INCUMBENTS INNOVATION RESPONSE TO ENTRY IN INDUSTRIES BELOW AND ABOVE MEDIAN DISTANCE TO THE FRONTIER



Source: Aghion et al. (2009).

To this end, it is important to discuss the main recent empirical papers that try to address the question of what is the effect of low-wage import competition on domestic innovation decision at the firm-level in developed countries. On this matter, Bloom et al. (2015) show evidence that the increased import competition coming from low-wage countries, specially China, led to an increase in the technical change in European countries. More specifically, they regress a set of innovation outcomes such as patenting, IT intensity and TFP measures at the firm-level across four-digit industries and twelve European countries against a measure of industry import exposure to Chinese competition. In order to deal with the endogeneity that might arise from the demand shocks internal to the domestic markets they exploit the removal of quotas on apparel and textiles that followed the Chinese accession to the the WTO in 2001. They argue that although there were negotiations in place at the time, there was uncertainty regarding the actual implementation of the agreement. Therefore, the heterogeneous removal of quotas across industries allow them to identify the change in import exposure that is driven solely by the productivity shock stemming from China productivity growth across industries.

Their results show a positive effect on all innovation related outputs within firms in industries most affected by increased import competition. Interestingly, the impact is consistent across innovation inputs, such as increases in R&D, management quality and skilled workers share. However, they find a negative impact on prices and profitability which make their result all the more puzzling. They also show evidence of between firms reallocation of decreasing employment and survival probabilities of initially low technology firms. In a robustness section, they provide evidence that there is little or no effects on technical change when they look at developed countries import competition. This result is striking when we compare it with the previous evidence shown by Aghion et al. (2009). In addition, it brings a new discussion whether the competition spurred by better competitors at the bottom of the productivity or quality distribution has some differential effects on innovation and what the underlying mechanisms might be. The model presented in this papers addresses this point by assuming that the competitive fringe shock replaces the follower in each gap industries and shows that this entry in the bottom of the gap distribution changes the within gap optimal innovation incentives, and thus the endogenous gap distribution.

In line with this literature on the effect of low-wage import competition from China and domestic innovation (or the effect of entry in the bottom of the distribution), Autor et al. (2016) provide evidence on this relationship for the U.S. firms. In their regression, they focus mainly on the patenting behaviour of publicly listed firms (also, on corporate entities patents, by measuring patenting at the technology-class level) as the innovation output and a measure of import penetration of Chinese competitors. Their comprehensive data work has two main important deviation from Bloom et al. (2015)'s paper. First, using an algorithm that exploit internet based machine learning algorithms they are able to improve considerably the match of patents assignees to publicly held companies in the Compustat compared to previous attempt, thus delivering a dataset that go way back before the Chinese abnormal growth in trade as of 1975 to 2013. Second, their identification strategy make use of the measure of import competition across industries in other country, more specifically U.K., as in instrument for the change in the import penetration from China in order tackle the endogeneity problem stemming from the domestic market productivity shocks that would affect both patenting and imports from China and spuriously generate a positive relationship.

These main departures from the empirical evidence for European innovation responses have important implications. First, they are able to better control for pre trends across industries. In fact, as they show, while the electronics and computer sectors experienced a high growth in patenting in the decades before the Chinese exposure (before 1991) and high change in the import penetration in the exposure years, the chemicals and petroleum sectors showed an actual decline in patenting in the decades before exposure and a low increase in the import penetration in the exposure period. The fail to control for these previous trend might induce a positive relationship that is not driven by the supply shock but by sectoral trends. Additionally, they are able to run placebo tests on the patenting behaviour that pre dates the shock. Second, their IV strategy allows them to investigate the effect in a broader set of industries (not only apparel an textiles, although Bloom et al. (2015)'s paper offer a robustness result that includes all the sectors). As a result, they find that firms and industries in sectors that face higher increases in import penetration from China patent less relative to the trend. Accordingly, they also show that increased import penetration led to decreases in firm global R&D expenditures, global sales, global employment and profit growth.

What is interesting about these results is the fact that it is in line with the standard expanding varieties growth models (Romer, 1990) and the early Schumpeterian growth models (Aghion and Howitt, 1992), but it is at odds with part of the empirical literature in IO on the product market competition and growth relationship (Aghion et al., 2014). Aghion et al. (2005) offer a way to apparently reconcile these findings in a second generation of Schumpeterian model which embeds two main mechanisms through which competition affect innovation decision: the escape-competition and the Schumpeterian effect. In their model, there are two firms in each industry and two possible states of the nature: either they have the same productivity, in which case firms may collude and split the monopoly rents, or they differ by one step, in which case the leader takes all the profits although it cannot innovate. In this scenario, firms in the "neck-and-neck" industry (i.e., the same productivity) have incentives to innovate whenever there is an increase in competition that decrease their ability to share the monopoly profits so that the gain of becoming the leader increases. However, laggards in the "unleveled" industries have less incentives to innovate in face of higher competition in that the post innovation share of monopoly profits would be lower thus decreasing the marginal gain of innovation (from zero profits to smaller profits). Therefore, the overall effect would depend on the composition of the industry. Whenever most of the industries are neck-and-neck more competition spurs aggregate innovation and the opposite holds when most industries are unleveled.

Nevertheless, the Aghion et al. (2005)'s model can only account for the effect of more intense competition on the aggregate not sectoral innovation. Also, the model relies on a very stark assumption of collusion under equality of productivities only needed to highlight the main mechanisms in place. Hence, the model in this paper aims to provide an explanation for the results in the above empirical literature in terms of the main mechanisms while reconciling it with the theory. In doing so, the model assumes a more realistic environment of the change in competition as an entry shock (instead of the share of profits under collusion) that replaces the follower with a one step ahead new competitor. This assumption not only improves over the previous theoretical literature but also, it is in line with the empirical literature suggesting that the increased competition stems from better competitors in the bottom of the gap distribution (that is, the Chinese competitors relative to their developed countries counterpart). In addition, it opens the possibility of within industry differential impact between countries. The step-by-step nature of innovation implies that there is always incentives to innovate in order to gain a lead over the competitor, to escape-competition and charge higher markups. The competitive fringe shock introduces the Schumpeterian effect through which the value of the firm decreases, increasing the likelihood of facing a new better competitor, and makes it harder for leaders to reach higher gaps, thus closing the gap distribution. Therefore, the within gap effect on the innovation decision will depend on how the entry shock changes the shape of the firm's value as function of the gap.

There are two potential ways of interpreting the findings of the empirical literature. One way is to consider the differential effects in industries between the U.S. and European countries as the within gap net effect. Alternatively, we could think of the differential within industry effect as the total result when also taking into account the gap composition. In general, lower gaps tend to present higher innovation efforts. Thus, an increase in the shock parameter shifts the distribution to lower gaps so that innovation tend to increase. Either way, the model is able to accommodate the within industry differential responses of firm-level innovation between countries.

Finally, the resulting effect will depend on the magnitude of the change as well as the initial level of the competitive fringe shock that shape both the escape-competition and Schumpeterian effect within each industry gap. Yet, the aggregate effect is shaped by these three main mechanisms: the escape-competition effect, the Schumpeterian effect and the composition of gaps. Laying down the competitive fringe shock model is the goal of the next section.

3 Model of Competitive Fringe Shock

In this section, we describe the endogenous growth model which features endogenous markups and the competitive fringe shock. Both features are important in order to tackle the question in hand, that is, the effect of increased competition on optimal innovation decision and the consequent effect on growth. The model builds on the early literature of step-by-step innovation (Aghion et al., 2001; Acemoglu and Akcigit, 2012) in which incumbents in each product line market invest in innovation in order to gain technological lead over its competitor. There is a continuum of intermediate goods used to competitively produce the final good. In each of the product lines two firms compete in prices (Bertrand competition) and take over the entire market as a result. In this setting, the innovation technology allows leading firms to increase profits by charging higher markups depending on its technological distance relative to the laggard. The followers, on the other hand, do not enjoy profits but act as if there is a competitive fringe with a second best technology that limits the leader's ability to charge higher prices. Yet, the innovation incentives are still in place for the followers since they pursue the forward looking innovation decision in order to catch up with the leader and possibly take over the market. As a consequence of the firm's strategic interaction the model generates an endogenous distribution of technological gaps as the optimal innovation depends on the technological distance between followers and leaders.

The model shares the main mechanisms on how competition affects innovation as in previous works (Aghion et al., 2005), that is, the Schumpeterian effect that discourage laggard innovation by lowering post innovation gains; and the escape-competition effect that encourage innovation in order to gain market power. However, we enrich the model allowing for leaders innovation in sectors in which firms differ in terms of productivity (in line with Aghion et al. (2001), Acemoglu and Akcigit (2012), Akcigit and Ates (2019a,b)) and, more importantly, the source of the change in the competitive environment is no longer the collusion assumption when firms share the same productivity level, but rather is a competitive fringe shock that replaces the follower by a one step ahead new competitor. One could consider this change not only a step forward in terms of building a more realistic setting but, also, this subtle but important deviation from the previous literature delivers two novel implications for the effects of competition in the model. First, in each gap industry, the Schumpeterian effect also affects leaders even though they are not being replaced, by decreasing the gain in value resulting from innovation. Second, an increase in competition through a higher probability of replacement decreases the average gap in the economy, as opposed to the increase highlighted in Aghion et al. (2005). These two implications act in opposite directions in terms of innovation response to increased competition. While the former would decrease within gap innovation efforts, the latter might increase innovation since firms tend to innovate more in lower gaps. The latter effect is sometimes called the composition effect.

Before starting the detailed description of the model it is important to highlight that the model considered here is a closed economy endogenous growth model. Although the empirical literature estimate the effect of increased competition in a trade context, the empirical strategy tries to identify the supply shock in order to isolate the effect on firm-level innovation within sector and to deal with potential confounders, for instance, the increased market access that followed Chinese WTO entry (a demand shock). Since this paper aims to speak to this literature the closed economy assumption arises naturally, allowing the model to focus on the market incentives in the shocked country. All the mathematical derivations are left to the Appendix.

3.1 Preferences

Time is continuous. There is a representative agent that consumes the final good and supply labor inelastically. The consumer preferences is given by the following log-utility function:

$$\mathcal{U}_t = \int_t^{\infty} \exp(-\rho(s-t)) \log C_s ds$$

where C_t is the consumption of the final good at t, and $\rho > 0$ is the inter-temporal discount rate. The consumer budget constraint is given by

$$C_t + \dot{A}_t = w_t L + r_t A_t$$

where A_t is total assets at time t, which equals the sum of the value of each firm - the only asset in this economy; w_t is the wage rate and r_t is the interest rate, both in time t. For simplicity we normalize the labor supply $L = 1$.

3.2 Firms production and innovation technology

In this economy the final good is produced competitively using a continuum of intermediates according to the following production function:

$$\log Y_t = \int_0^1 \log y_{it} di \tag{1}$$

where y_{it} is the amount of the variety i, in time t, used as input.

Each variety is produced by two firms $j = A, B$ that produce their own version of variety i that, in turn, happens to be perfect substitutes, that is, $y_{it} = y_{Ait} + y_{Bit}$[2]. Also, the intermediate firms produce the variety with linear technology in labor $y_{jit} = q_{jit}\ell_{jit}$, where q_{jit} is the firm productivity.

Since firms compete *à la Bertrand* in each product line, the productivity difference is going to be key determinant of production and innovation decisions. In particular, the cost advantage derived from higher productivity allows the leader not only to charge

[2]In the calibration section we consider firm A as been the U.S./European firm and firm B as the Chinese competitor, but for now we keep the more general formulation.

higher markups but also to take over the entire market. Hence, the productivity is defined as:

$$q_{jit} = \lambda^{N_{jit}}$$

where $\lambda > 1$ is the innovation step size and $N_{jit} = 1, 2, ...$ is the number of innovations that happened for firm j, in variety i's product line, at time t. Whenever $q_{Ait} > q_{Bit}$ we will say that firm A is the leader and firm B is the follower in product line i, the opposite holds when $q_{Ait} < q_{Bit}$. Whenever $q_{Ait} = q_{Bit}$ we say that firms are neck-and-neck. Therefore, the gap between firms in each product line is given by

$$\frac{\lambda^{N_{Ait}}}{\lambda^{N_{Bit}}} \equiv \lambda^{m_{Ait}}$$

where $m_{Ait} = N_{Ait} - N_{Bit}$ is the gap between the number of innovations experienced by the leader (the firm A in this case) and the follower. This is going to be crucial in this analysis since we will be able to solve for all the endogenous variables only as a function of the gap between firms' productivity. For computational reasons we assume that there is an upper bound in the number of gaps by which a firm can lead, that is, $m_{Ait} = \{0, 1, ..., \bar{m}\}$.

The innovation technology is such that firms in each product line hire labor in order to perform R&D. As a result, an innovation may arise with a Poisson rate x. Thus, the R&D technology gives rise to the cost function that we parametrize as[3]

$$\ell^R_{jit} = \theta_j \frac{x_{jit}^{\eta_j}}{\eta_j} \tag{2}$$

where ℓ^R_{jit} is the research labor and x_{jit} is the innovation rate of firm j in product line i at time t. $\theta_j > 0$ is the cost shifter whereas $\eta_j \geq 1$ is the curvature parameter, both differ between the two firms.

Once the innovation arises for the leader the firm's technology increases by one step, i.e., the new technology after innovation is λq_{jit}. For the followers, in turn, one innovation is enough to catch-up with the leader's technology. Additionally, following the recent growth literature (Akcigit and Ates (2019a,b)) that emphasizes the importance of the knowledge spillover between the leaders and followers in explaining the declining dynamism of the U.S. economy, we assume that there is an exogenous rate, κ, at which the follower innovates even in the absence of R&D investment. In a sense, even though the follower is not allowed to copy the leaders technology, there is some external learning

[3]The R&D technology is simply the inverse of the cost function.

that allows the follower to upgrade its own technology. Therefore, the follower's innovation intensity comprises an endogenous innovation decision and a knowledge spillover, i.e., $x_{-jit} + \kappa$.

Competitive fringe shock

In order to make the mechanisms as clear as possible, we assume that there is a *competitive fringe* shock that replaces the follower only in product lines in which firm A (U.S. or Europe) has a lead[4]. By contrast, there is no competitive fringe shock in product lines in which firm B has a lead.

Therefore, in each instant, there is a Poisson flow rate δ at which firm B (Chinese competitor) is replaced in a product line by another firm B that is one step ahead. This shock has several implications. First, if neither the leader, firm A, nor the follower succeed in innovation the leader might go down one step in face of the new competitive fringe. Thus, it will change the innovation decision based on its new position. Second, since the shock affects the marginal gain in value from innovation it may decrease the innovation effort within each gap. The ultimate effect on each gap though will be determined by the change on the concavity of the value function (which determines the marginal benefit of the innovation). Finally, the shock discourages innovation by the follower, firm B, since it drives the firm value down to zero. It is worth emphasizing, that this effect on the followers is the main difference between the competitive shock and a change in the knowledge spillover parameter.

As highlighted in the introduction, our goal is to understand the increased competition from China following the WTO entry and its implication for firm innovation decision. Thus, we can interpret the change in the competitive fringe shock as the change in the access to new markets in developed countries for Chinese firms. Moreover, this formulation of the replacement shock allows the model to connect with the empirical evidence, since it opens room for differential within sector responses of firm level innovation to increases in competition resulting from the combined effect of the within gap response and the composition effect, as opposed to differential aggregate innovation responses featured in previous growth models.

[4] In gap zero product lines we still assume that the shock only replaces firm B, for concreteness. This assumption helps to match the small import share from China in the period for both the U.S. and European countries, the proxy for the measure of Chinese competitors in the model.

3.3 Equilibrium and Aggregation

In this section we solve for the equilibrium production and innovation choices as well as the aggregate variables of interest.

Representative Agent

The log-utility assumption along with the consumer problem imply that the growth rate of consumption and the economy interest rate are related through the euler equation:

$$g_t = r_t - \rho \tag{3}$$

Final and Intermediate good firms

The final good firms choose the amount of variety i's intermediate input to maximize profits in a competitive market. Thus, the log-log production function delivers the following input demand with unitary elasticity:

$$y_{it} = p_{it}^{-1} Y_t \tag{4}$$

In each product line the firms' output are perfect substitutes. Bertrand competition then implies that, in equilibrium, the price is set to the follower's marginal cost. Suppose that $q_{Ait} \geq q_{Bit}$. Therefore, with linear technology in labor, the firm A's optimal price takes the simple form

$$p_{Ait} = \frac{w_t}{q_{Bit}} \tag{5}$$

In other words, the follower technology prevents the leader to charge monopoly prices and leads to limit pricing instead.

Thus, the optimal quantity decision of the intermediate firm is given by

$$y_{Ait} = \begin{cases} \frac{q_{Bit}}{w_t} Y_t, & \text{if } q_{Ait} > q_{Bit} \\ 0, & \text{if } q_{Ait} < q_{Bit} \end{cases} \tag{6}$$

When $q_{Ait} = q_{Bit}$ it is assumed that either firm A or B take over the entire market. The share of gap zero product lines where firm B produces helps to match the Chinese participation in the U.S./Europe market.

Equations 5 and 6 together imply that the operating profits (excluding research costs) can be written as a function of the gap between the leader and the follower:

$$\pi_{Ait} = \left(p_{Ait} - \frac{w_t}{q_{Ait}}\right) y_{Ait} = (1 - \lambda^{-m_{Ait}}) Y_t \tag{7}$$

Note that profits are zero whenever $m_{Ait} = 0$, that is, in a neck-and-neck intermediate product line, or whenever the firm is a follower. Also, this rich environment provides incentives both for the leaders and followers to pursue innovation. Climbing up the productivity rungs allows leaders to increase prices and markups. At the same time, follower innovation increases the chance of making positive profits.

Innovation decision

For the sake of brevity, we describe here the value of the firms and their innovation decisions in product lines in which firm A is the leader. Those are the same product lines where the competitive shock takes places and will be the focus of our analysis. We leave the discussion of the remaining value functions to the Appendix.

The present discounted value of a firm A that leads by m steps, where $0 < m < \bar{m}$, can be written in the form of the HJB equation as follows[5]:

$$\begin{aligned} r_t V_{Amt} - \dot{V}_{Amt} = \underset{x_{Amt}|x_{B(-m)t}}{\text{Max}} \Bigg\{ & (1 - \lambda^{-m}) Y_t - w_t \theta_A \frac{x_{Amt}^{\eta_A}}{\eta_A} + x_{Amt}(V_{A(m+1)t} - V_{Amt}) \\ & + (x_{B(-m)t} + \kappa)(V_{A0t} - V_{Amt}) + \delta \left(V_{A(m-1)t} - V_{Amt}\right) \Bigg\} \end{aligned} \tag{8}$$

It follows from this equation that the market yield net of the instantaneous change in the value, the left hand side, must equal the return on innovation. The first term in the right hand side describes the operational profits of the leader that is m-steps ahead. Next, the second term is the innovation cost in terms of wages paid. The main difference lie in the remaining terms that reflect the innovation decisions and their respective benefits. The last term in the first line shows that innovation by the leader improves its position by one step. Then the first term in the second line shows that if the follower innovates, firm A ends up in a neck-and-neck product line. Finally, the last term reflects the new innovation incentive generated by the followers replacement. If the replacement shock takes place, the leader goes one step down in the gap position. Therefore, the competitive fringe shock affects the innovation decision indirectly through its effect on the value of

[5] We drop the variety index and the time subscript of m_{it} based on the observation that the profit function only depends on the number of gaps. Hence, the gap is the only payoff relevant variable for innovation decision.

the firm in each gap. Also, it makes harder for the leader to improve its productivity distance from the follower thus closing the overall distribution of gaps in the economy.

Analogously, the present discounted value of a firm B that lags by m steps is given by

$$\begin{aligned} r_t V_{B(-m)t} - \dot{V}_{B(-m)t} = \underset{x_{B(-m)t}|x_{Amt}}{\text{Max}} \Bigg\{ & -w_t \theta_B \frac{x_{B(-m)t}^{\eta_B}}{\eta_B} + (x_{B(-m)t} + \kappa)(V_{B0t} - V_{B(-m)t}) \\ & + x_{Amt}(V_{B(-m-1)t} - V_{B(-m)t}) - \delta V_{B(-m)t} \Big\} \end{aligned} \tag{9}$$

Different from the leader's value function, there is no instantaneous operational profits for the follower since there is no production. However, there are still incentives to innovate. The second term in the right hand side, for instance, captures the productivity catch-up that follows the laggard innovation or the exogenous knowledge spillover arrival. Then the first term in the second line reflects the change in the position of the follower when the leader successfully innovate. Finally, the last term is the loss in the value of the firm B when it is replaced by a new competitor.

Next, we present the value of both firms in the neck-and-neck position. The firm A value is given by

$$r_t V_{A0t} - \dot{V}_{A0t} = \underset{x_{A0t}|x_{B0t}}{\text{Max}} \left\{ -w_t \theta_A \frac{x_{A0t}^{\eta_A}}{\eta_A} + x_{A0t}(V_{A1t} - V_{A0t}) + x_{B0t}(V_{A(-1)t} - V_{A0t}) \right\} \tag{10}$$

and, similarly, for firm B we have

$$\begin{aligned} r_t V_{B0t} - \dot{V}_{B0t} = \underset{x_{B0t}|x_{A0t}}{\text{Max}} \Bigg\{ & -w_t \theta_B \frac{x_{B0t}^{\eta_B}}{\eta_B} + x_{B0t}(V_{B1t} - V_{B0t}) \\ & + x_{A0t}(V_{B(-1)t} - V_{B0t}) - \delta V_{B0t} \Big\} \end{aligned} \tag{11}$$

The main difference in the zero gap value function is twofold. First, since there is no concept of leadership in this state we assume that only firm B is subject to the competitive fringe shock. Second, we assume that the competitive fringe shock only replaces the incumbent firm B in gap zero product line without changing firm A's position. The idea is to be consistent with the notion of the entrants in the market being small firms that grow through time, instead of entrants jumping ahead of the incumbents as in the first generation of Schumpeterian models. However, the competitive fringe shock still affects negatively the value of the firm B, as a competition shock.

In order to render the problem stationary we normalize the value function by the total output. For brevity, we present only the normalized value function for the firm A that leads by m-steps ahead. Substituting the euler equation 3, one can derive the normalized value function as

$$\begin{aligned}\rho v_{Amt} - \dot{v}_{Amt} = \underset{x_{Amt}|x_{B(-m)t}}{\text{Max}} & \Bigg\{(1-\lambda^{-m}) - \omega_t \theta_A \frac{x_{Amt}^{\eta_A}}{\eta_A} + x_{Amt}(v_{A(m+1)t} - v_{Amt}) \\ & + (x_{B(-m)t} + \kappa)(v_{A0t} - v_{Amt}) \\ & + \delta\left(v_{A(m-1)t} - v_{Amt}\right)\Bigg\}\end{aligned} \tag{12}$$

where $v_{Amt} \equiv V_{Amt}/Y_t$ is the normalized value function of a firm A that is m-steps ahead in time t; and $\omega_t \equiv w_t/Y_t$ is the labor share at time t.

Solving the optimization problem in the value function we obtain the following optimal innovation decisions:

$$x_{Amt} = \max\left\{\left(\frac{v_{A(m+1)t} - v_{Amt}}{\theta_A \omega_t}\right)^{\frac{1}{\eta_A - 1}}, 0\right\} \tag{13}$$

$$x_{B(-m)t} = \max\left\{\left(\frac{v_{B0t} - v_{B(-m)t}}{\theta_B \omega_t}\right)^{\frac{1}{\eta_B - 1}}, 0\right\} \tag{14}$$

The optimal innovation decision captures the key economic force of the model. The innovation decision depends directly on the increase in the value of the firm in the gap m and inversely on the cost of hiring researchers. The effect of a change in the competition environment measured by the replacement shock works indirectly through its effect on the shape of the value function. On one hand, an increase in the competitive fringe shock would decrease the value of the innovation since it would be more likely for the leader to face a new better competitor and go down one step, facing lower profits. On the other hand, since lower gaps tend to have higher innovation incentives (due to the concavity of the profit function), the competitive shock might induce an increase in the innovation by closing the gap[6]. From the followers standpoint, more competition dissuade innovation by driving the future profits to zero if the shock takes place. Additionally, since only one innovation is required for the follower to catch up with the leader's productivity the laggard's innovation decision is the same across gaps.

It is worth noting that, the competitive fringe shock here adds the Schumpeterian effect to the model that would otherwise only feature the escape competition effect, that is, the only incentive would be to climb up the productivity ladder. Therefore, as it

[6]This point will be clear in the results section that shows the inverted-U shape of the leader's innovation decisions.

becomes clear from the previous equations, the escape competition incentives directly determine the innovation decision whereas the the Schumpeterian effect acts indirectly through the shape of the value function. In the end, the total effect in the economy will depend on both effects along with the distribution of gaps. Moreover, with this formulation we are able to analyze the within sector innovation response found in the empirical literature resulting from a combination of the disincentive Schumpeterian effect and the composition effect and do not need to rely on aggregate responses to generate both positive and negative effects as in previous models.

Let us now use the endogenous production and innovation decisions to describe the labor market clearing condition and the law of motion for the distribution of gaps.

The linear production function of intermediates along with the optimal quantity decision, equation 6, imply

$$\ell_{Ait} = \frac{q_{Bit}}{q_{Ait}} \frac{Y_t}{w_t} = \frac{\lambda^{-m}}{\omega_t} \tag{15}$$

In turn, the labor market clearing can be written as

$$\int_0^1 \ell_{Ait} + \ell_{Bit} + \ell^R_{Ait} + \ell^R_{Bit} di = 1$$

Now, let us define μ_{jmt} as the fraction of product lines in which firm j leads by m steps[7]. Then, substitute equations 15 and 2 into the previous equation to obtain

$$\omega_t^{-1} \left(\sum_{s=0}^{\bar{m}} \mu_{st} \lambda^{-s} \right) + \sum_{s=0}^{\bar{m}} \left[\left(\theta_A \frac{x_{Ast}^{\eta_A}}{\eta_A} + \theta_B \frac{x_{B(-s)t}^{\eta_B}}{\eta_B} \right) \mu_{Ast} + \left(\theta_A \frac{x_{A(-s)t}^{\eta_A}}{\eta_A} + \theta_B \frac{x_{Bst}^{\eta_B}}{\eta_B} \right) \mu_{Bst} \right] = 1$$

where $\mu_{mt} \equiv \mu_{Amt} + \mu_{Bmt}$.

As a consequence of the firm's innovation efforts the distribution of gaps evolves endogenously. The law of motion for the measure of product lines in which firm A and firm B lead ($0 < m < \bar{m}$) is given by the following two equations, respectively,

$$\dot{\mu}_{Amt} = x_{A(m-1)t}\mu_{A(m-1)t} + \delta\mu_{A(m+1)t} - (x_{Amt} + x_{B(-m)t} + \kappa + \delta)\mu_{Amt} \tag{16}$$

$$\dot{\mu}_{Bmt} = x_{B(m-1)t}\mu_{B(m-1)t} - (x_{Bmt} + x_{A(-m)t} + \kappa)\mu_{Bmt} \tag{17}$$

Basically, both measures evolve based on the difference between entry and exit in the state m. In equation 16, for instance, the first two terms are the measure of entrants in

[7]In the gap zero the interpretation is the fraction of product lines in which firm j has positive production. Recall that in the gap zero both firms have the same productivity in each product line. Thus, we implicitly assume that only one firm produces in each product line in this case.

gap m state, either by successful innovation of gap $m-1$ leaders (first term) or by the leaders in state $m+1$ that face a new one step ahead competitor (second term). The last term, in turn, measures the exit from state m that happens when leaders as well as followers in product lines with gap m innovate or when the replacement takes place.

The law of motion for product lines with firm B leadership, equation 17, takes this simpler form because of our assumption that the shock only hits those product lines where firm A has a lead. Thus, the measure of entry in this state reflects innovation by leaders in gap $m-1$ (the first term) and the correspondent exit measure comes from successful innovation by gap m firms. Additionally, equation 17 shows what the law of motion for firm A and B would be the same in the case without the competitive fringe shock. The remaining law of motions, as well as the value functions, are described in the Appendix6.

We conclude this section deriving the aggregate variables of interest for our analysis, that is, the output growth rate and the average innovation intensity. Let us begin with the output growth rate. Substituting equation 15 in 1 we obtain the equilibrium output of the economy

$$Y_t = \frac{Q_t \lambda^{-\sum_{s=0}^{\bar{m}} m\mu_{st}}}{\omega_t}$$

where $Q_t \equiv \int_0^1 \ln q_{jit} di$ and $j =$ leader.

One implication of the above equation is that the evolution of the quality index is crucial for output growth. In particular, in the balanced growth path equilibrium the growth of the quality index is the sole determinant of the output growth rate (since the labor share is constant and the distribution of gaps stationary by definition). Hence, the evolution of the quality index is given by

$$\frac{\dot{Q}_t}{Q_t} = \ln \lambda \left((x_{A0t} + x_{B0t})\mu_{0t} + \sum_{s=1}^{\bar{m}} x_{Ast}\mu_{Ast} + \sum_{s=1}^{\bar{m}} x_{Bst}\mu_{Bst} \right) \tag{18}$$

Intuitively, there is an improvement in the quality index whenever leaders successfully innovate both in product lines where firm A and firm B are the technological frontier and when they are neck-and-neck. In each case the productivity increases by the step size λ.

Finally, define the average innovation intensity as the weighted sum of the innovation efforts in each gap m, where the weights are given by the gap distribution. Therefore,

$$\mathcal{II}_t = \sum_{s=0}^{\bar{m}} \left((x_{Ast} + x_{B(-s)t})\mu_{Ast} + (x_{Bst} + x_{A(-s)t})\mu_{Bst} \right) \tag{19}$$

Since the empirical literature investigated the effect of the increased Chinese competition on the firm-level innovation within developed countries, it is reasonable to focus our attention in the average innovation intensity among U.S. or European firms. In this sense, define the average innovation intensity in the developed economies as:

$$\mathcal{II}_{At} = \sum_{s=0}^{\bar{m}} \left(x_{Ast}\mu_{Ast} + x_{A(-s)t}\mu_{Bst} \right) \tag{20}$$

Our main goal is to evaluate how the average innovation intensity respond to a change in the competitive fringe shock. In doing so I calibrate the balanced growth path of the model to the U.S. in 2000, a period before China joined WTO. Next, I calibrate the competitive fringe shock parameter to fit the European import exposure to Chinese products in 2000 and the ex-post exposure in 2006 for both regions. Consequently, we are able to quantify the average innovation intensity response to increased competition, the innovation response within each gap m and, finally, the effects on long-run growth.

4 Data and Calibration

As already mentioned we are interested in evaluate the effect of increased exposure to Chinese imports on firm-level innovation in the U.S. and Europe, before and after China joins the WTO. In terms of the model, the exercise can be mapped as how the average innovation intensity respond to changes in the competitive fringe shock. In order to achieve that we pursue some steps in the calibration procedure. First, we calibrate the balanced growth path of the model for the U.S. economy in 2000, the year before China joined the WTO. Following the empirical literature we use this year as the starting point for the important change in the exposure to imports from China that followed the long term agreement, as pointed out in Bloom et al. (2015). As explained in more detail below, the parameters used to calibrate the model help to replicate the Chinese import competition. In particular, the competitive fringe shock parameter is disciplined by the import share from China, our measure of exposure to foreign competition. Therefore, holding all the parameters constant we calibrate the competitive fringe shock to replicate the European exposure to China imports in 2000, as a second step. This exercise allows us to isolate the importance of the initial level of the competitive shock from other differences in characteristics between the U.S. and European economy captured by the remaining parameters. Finally, we use the import share from China in 2006 to calibrate the terminal values of the shock parameter both for U.S. and Europe. This moment informs the model about the change in the competition environment in the subsequent period. With the calibrated balanced growth path we are able to analyse the effect of the change in import exposure from China - as measured by the change in the competitive fringe shock - on the average innovation intensity, the effects on the innovation intensity by gap and leadership and, finally, its effect on the growth rate.

The model has nine parameters to be calibrated in the balanced growth path equilibrium $\Theta = \{\lambda, \delta, \kappa, \theta_A, \theta_B, \eta_A, \eta_B, \rho, \bar{m}\}$. The last four parameters are set exogenously and they are, respectively, the curvature parameters of the R&D cost function for firm A and B, the intertemporal discount rate and the maximum gap. In the lack of micro estimates for the curvature parameter for Chinese firms, we set $\eta_A = \eta_B$, and use the literature estimate for the U.S. value of $\eta_A = 1/0.35$ (Acemoglu and Akcigit (2012); Akcigit and Ates (2019b)). Additionally, the intertemporal discount rate is set to be $\rho = 0.05$ and the maximum gap $\bar{m} = 15$.

The remaining first five parameters, in turn, are disciplined by the moments in the data. Before going through the parameters and the matched data moments, is important to briefly discuss how the moments for Europe are constructed. We use data on twelve European countries (the same as in Bloom et al. (2015)), and calculate the weighted average of each data moment of interest using the country's participation in the total output of the country's set[8]. In order to get a better measure of each country share in total output we use the output-side real GDP at chained PPPs from the Penn World Table 9.0 (Feenstra et al. (2015)) which is a measure that accounts for price differences between countries.

Our calibration strategy exploits five data moments to discipline the five calibrated parameter. An inspection of equation 18 suggests that the step-size λ is directly related to the output growth rate and, in the balanced growth path, it is the sole driver. Therefore, we use the annual growth of the multifactor productivity measure from the OECD database (OECD, 2014) averaged between 1985-2000 to capture the long-run trend in productivity growth prior to China's WTO accession[9]. In order to discipline the replacement parameter δ – the only parameter calibrated for the set of European countries, as previously mentioned – we calculate the import share from China pre and post WTO accession in 2000 and 2006, using data on imports and GDP reported in the Eurostat database for European countries, data on imports from the U.S. Census and data on GDP from BEA data for the U.S. The knowledge spillover parameter κ,

[8] The twelve countries used in the analysis are as follows: Austria, Denmark, Finland, France, Germany, Ireland, Italy, Norway, Spain, Sweden, Switzerland, and the UK.

[9] We use the period 1985-2006 to calculate the average TFP growth and the average markup in the new balanced growth path in 2006.

Table 1: Structural parameters calibrated values

Internally Calibrated			Externally Calibrated		
Definition	Parameter	Value	Definition	Parameter	Value
Step-size	λ	1.035	R&D curvature firm a	η_a	1/0.35
Fringe shock	δ	0.320	R&D curvature firm b	η_b	1/0.35
Spillover/IPR policy	κ	3.47e-07	Rate of time preference	ρ	0.05
R&D scale firm a	θ_a	3.189	Maximum gap	$\bar{m}$	15
R&D scale firm b	θ_b	154.289			

Notes: The R&D curvatures parameters are taken from Acemoglu and Akcigit (2012), Akcigit and Ates (2019b); the intertemporal discount rate and the maximum gap are set exogenously.

in turn, reflects the within product line flow of knowledge between the frontier firms and the followers. In this sense, a product line with high spillovers prevent the leaders to gain further distance and to charge higher markups as a result. In the model, the average markup is defined as the weighted average of step-sizes (to the power of gap) where the weights are given by the gap distribution. Conditional on the step-size the markups inform about the gap distribution. Hence, the average markup as estimated in De Loecker and Eeckhout (2017) for the U.S. discipline the spillover parameter. Finally, the R&D scale parameters θ_A and θ_B are disciplined by the share of R&D expenditure in total GDP averaged over the most recent period 1996-2000 in the World Development Indicators database. Since the model considered here is a closed economy model, the use of China's overall R&D to GDP ratio would imply a much higher Chinese participation in total GDP in both U.S. and Europe relative to the import share observed in the data. In order to deal with this issue, we weight the R&D share in China in each country with its respective import share so that the moment in the data could reflect the fact that the R&D content of imports comes from only a small fraction of Chinese firms that actually exports to these markets.

The calibrated values for the structural parameters in the model are summarized in Table 1. Additionally, the value for the competitive fringe shock for the U.S. in initial year is presented in Table 1 and the remaining calibrated values are left to the results section where we discuss the impact of changes in the competitive fringe shock on aggregate outcomes.

Table 2 shows how the model is able to replicate the aggregate features of both U.S. economy and the set of European countries. In the benchmark calibration, all the moments for the U.S. in 2000 were targeted. However, the import share from China –

the share of producing Chinese firms in the model – is the only targeted moment used to calibrate the competitive fringe shock parameter for the U.S. in 2006 and for Europe in both years. Thus, the remaining moments can be viewed as the non-targeted moments, consequently, reflecting the quality of the model fit.

As can be seen in Panel A the model replicates nearly all targeted moments for the U.S. economy in 2000 with the exception of the average markup calibrated to a lower level relative to the observed in data. The calibration also fit closely the import share from China for the U.S. in 2006 and for Europe in both years. Regarding the non-targeted moments, the model implies a decrease in the TFP growth rate in the U.S., though the TFP growth rate slightly increases between 2000 and 2006. Accordingly, there is a decrease in the average markups and R&D share in total GDP. Although in the data both markups and R&D to GDP remain constant. One potential explanation is that there are other important contemporaneous mechanisms changing such as the decrease in the knowledge spillover in this period. As suggested by Akcigit and Ates (2019b), there appear to be some evidence of less spillovers from the "best" to the "rest" of the economy in recent years. In the calibration we keep the knowledge spillover parameter fixed between steady states.

The model implied decrease in markup is as one would expect given the increase in the competitive fringe shock that shifts firms to lower gaps. Since markups are an increasing function of the technological gap within product line, the implied shift decreases markup in the economy. In contrast, the data shows a fairly stable markup's long-run average between 1985-2006. Although the markup has been increasing since the 80's, it has been fairly stable during the 2000-06 period, if not decreasing (De Loecker and Eeckhout (2017)). Therefore, the model implied decrease in markup somewhat reflects the change in the observed markup trend in the short run. In addition, the model replicates the observed increase in the R&D to GDP ratio in China though overshooting.

The bottom panel shows the model fit for Europe in both years. As mentioned earlier the model fits closely the import share in each year. The model reproduces the decrease in the long run TFP growth rate in the period although they are smaller than the observed values. Also, the model replicates the qualitative increase in the R&D share in China over the period but implies a higher value. In contrast, the model implies a decrease in R&D to GDP ratio in Europe while the data shows an increase if anything. This is somewhat expected since a higher competitive fringe shock could in principle decrease the within gap innovation incentives. Finally, the average markup shows a mild decrease for the reasons analogous to the U.S. case.

In the next section we go forward to discuss the main results of the calibrated bal-

Table 2: Model fit by country-year

Panel A: U.S.				
	2000		**2006**	
Moments	Model	Data	Model	Data
TFP growth	0.91%	0.93%	0.59%	1.06%
Import share China	1.01%	0.98%	2.08%	2.08%
Markup	1.298	1.383	1.122	1.404
R&D/GDP	2.42%	2.51%	1.04%	2.53%
R&D/GDP in CHN	0.0069%	0.0068%	0.1317%	0.0199%
Panel B: Europe				
	2000		**2006**	
Moments	Model	Data	Model	Data
TFP growth	0.71%	1.24%	0.66%	1.10%
Import share China	0.67%	0.67%	1.31%	1.29%
Markup	1.143	n.a.	1.134	n.a.
R&D/GDP	1.58%	1.77%	1.34%	1.82%
R&D/GDP in CHN	0.0802%	0.0047%	0.0995%	0.0123%

Notes: The annual TFP growth is obtained from the multifactor productivity measure in the OECD database. The import share is calculated from the data on imports and GDP reported in the Eurostat database for European countries and for U.S., imports are from U.S. Census whereas GDP data is obtained from the BEA data. The markup series is obtained from De Loecker and Eeckhout (2017). The data on R&D expenditure to GDP is obtained directly from the World Development Indicators database. Finally, the R&D over GDP in China is weighted by the imports from China to account for the fact that part of the R&D is made by Chinese firms that do not exports to either U.S. or Europe. “n.a.” stands for “not available”.

anced growth path of the model in 2000 compared to the new balanced growth path in 2006, pre and post Chinese accession to the WTO. First, we present the main results regarding the effect of increased competition on aggregate outcomes such as the aggregate innovation intensity and long run growth. Next, we discuss the heterogeneous firm-level innovation responses to increased competition within each gap and its effect on the distribution of gaps.

5 Quantifying the effects of increased competition

This section investigates the effects of increased exposure to import competition from China on innovation incentives both in the U.S. and in a combination of European countries, pre and post China's accession to the WTO in 2001. In the model economy the increased exposure is captured by the competitive fringe shock parameter that ultimately reflects the rate at which the follower is replaced in each product line, and which changes the innovation incentives and the aggregate gap distribution in the economy. We analyze the effect of the change in the competitive fringe shock on firm level innovation effort within each gap, the effect on the average economy-wide innovation intensity and the effect on long run output growth.

Table 3 summarizes the main aggregate results. Panel A shows the effect of the increase in the competitive fringe parameter in a set of moments for the U.S whereas the Panel B shows the same moments for Europe. As can be seen in Table 3, the increase in the competitive fringe shock parameter in the U.S. during the analyzed period is considerably higher than the shock increase for the set of European countries, a six-fold percentage points increase in the U.S. relative to Europe (33.44 p.p. and 5.20 p.p., respectively), although it starts at a higher level in Europe (51.72% compared to 32.01% in the U.S.). The resulting impact on the import share from China is somewhat similar in the U.S. (105.83%) and in Europe (94.92%), which implies an U-shaped relationship between the shock and the import share.

Regarding the effect of the replacement shock on the overall innovation, the stronger increase in the competitive fringe shock in the U.S. translates into a higher decrease in the overall innovation, around -8.45%, relative to Europe, around -1.40%. All the decline in innovation is due to less innovation effort of the U.S./European firms, as can be seen in the innovation intensity disaggregated by country. The reason, as it will become clearer when we discuss the effect by gap, is that the increase in the competitive fringe shock drives down the optimal innovation decision for lower gap product lines leaders and strongly so for the U.S. relative to Europe. At the same time, the competition shock shifts most industries to lower gaps resulting in a stronger decrease in the innovation intensity among U.S. firms relative to Europe.

As discussed in the calibration section, the model implies a decrease in the growth rate of the economy of 0.33 p.p. in the U.S. - whereas there was an increase in the observed growth rate - and a decrease of 0.05 p.p. in Europe, in the model, and a decline in the observed growth rate, although the growth rates are considerably smaller than the observed TFP growth rates. Also, the average markup decreases 13.56% in the U.S. and are lower than the observed markups whereas remaining fairly stable for the U.S. in the data. In Europe the average markup decreases 0.85% and are lower than the implied average markup for the U.S. but there is no available markup data for the set of European countries. Overall, the model implies a stronger import competition shock from China in the U.S., as measured by the increase in the competitive fringe shock parameter, and a more negative response of the innovation intensity for U.S. firms relative to European firms, in line with the empirical literature. Autor et al. (2016) suggest that the effects of increased exposure to Chinese competition were more severe in the U.S. relative to Europe.

Now we turn to investigate the effect of fiercer competition in a more disaggregated analysis focusing on the within gap response of leaders and followers to the increase in the measure of competition as well as the effect on the endogenous distribution of gaps.

Figure 2 depicts the optimal innovation rate along with the gap distribution pre and post China accession to the WTO. The optimal innovation rate drawn is simply the sum of the innovation by leaders and followers in each gap including both the product lines in which U.S./Europe has a lead or those with Chinese leadership. The contrast between the left Panel (a) for the U.S. and the right Panel (b) for Europe highlights some of the important innovation responses to the increase in the import exposure: First, the optimal innovation effort by gap decreases between 2000 (the red circles) and 2006 (the blue crosses) both in U.S. and in Europe but the decrease is more pronounced in the former. Second, the decrease in the within gap innovation effort is more pronounced for lower gap product lines, specially in the U.S. economy. This feature sharply contrasts with the Aghion et al. (2005)'s model that first highlighted the importance of the escape-competition and the Schumpeterian effects, in which more competition would increase innovation effort in the gap zero. Third, according to the model there is, initially, a greater mass of high gap product lines in the U.S relative to the European economy. Finally, the increase in the measure of lower gaps between years is much more pronounced in the U.S. than in Europe. Since the total within gap innovation response to the increased competition is mostly negative the shift in the distribution towards lower

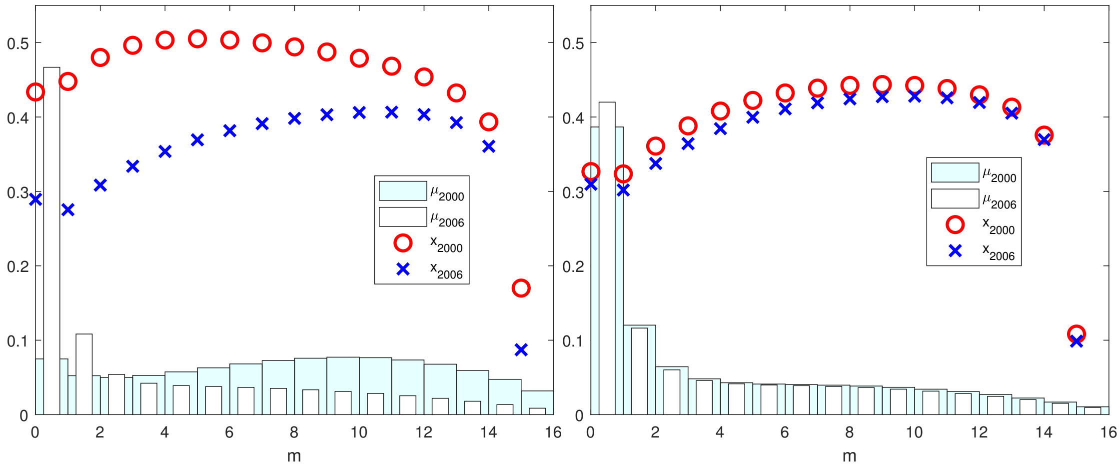
Table 3: Endogenous response to the Competitive Fringe shock

Panel A: U.S.				
Variables (%)	**2000**	**2006**	**p.p.(Δ)**	**%(Δ)**
Fringe shock	32.01	65.45	33.44	104.46
TFP growth	0.91	0.59	-0.33	-36.05
Innov intensity	27.62	19.17	-8.45	-30.58
Innov intensity US	27.13	17.37	-9.76	-35.97
Innov intensity CHN	0.49	1.80	1.31	268.10
Import share CHN	1.01	2.08	1.07	105.83
Avg Markup	1.298	1.122	-0.1759	-13.56
R&D/GDP US	2.42	1.04	-1.38	-57.05
R&D/GDP CHN	0.0069	0.1317	0.1249	1815.74
Labor share	81.17	92.11	10.93	13.47

Panel B: Europe				
Variables (%)	**2000**	**2006**	**p.p.(Δ)**	**%(Δ)**
Fringe shock	51.72	56.92	5.20	10.06
TFP growth	0.71	0.66	-0.05	-7.62
Innov intensity	22.41	21.01	-1.40	-6.25
Innov intensity Eu	21.00	19.44	-1.56	-7.41
Innov intensity CHN	1.41	1.57	0.16	11.12
Import share CHN	0.67	1.31	0.64	94.92
Avg Markup	1.143	1.134	-0.0098	-0.85
R&D/GDP Eu	1.58	1.34	-0.24	-15.42
R&D/GDP CHN	0.08	0.10	0.02	24.03
Labor share	91.04	91.51	0.47	0.52

Figure 2: Innovation rate sum and Gap distribution

(a) U.S. (b) Europe



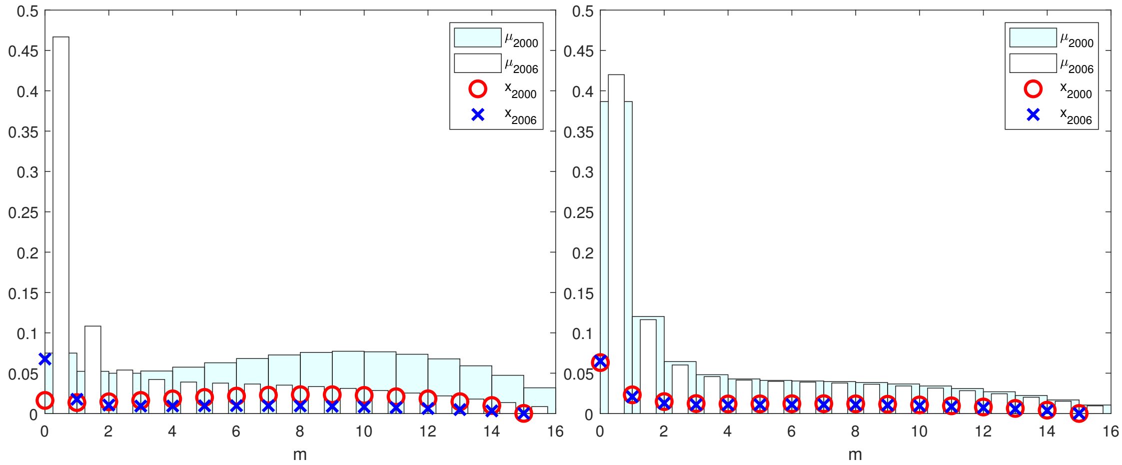
gaps ends up decreasing the average innovation intensity of the economy, as previously mentioned. It is worth noting that an increase in the competitive fringe shock has a direct effect on the gap distribution, increasing the rate at which the leader in the gap $m+1$ go down one step, that is, increasing entry whereas increasing the rate at which the leader in gap m also go down one step which increases exit. Also, there is an indirect effect through the endogenous innovation rate of leaders and followers. Therefore, both effects combined shape the final gap distribution.

The previous figure showed the within gap innovation response to an increase in the competition environment. However, the impact on the aggregate economy depend on the size of each gap. Thus, Figure 3 presents the innovation rate weighted by the mass of product lines in each gap along with the gap distribution again. Note that when the distribution of gaps is taken into account the innovation rate (weighted) decreases for almost all gaps in the U.S due to a combination of the within gap negative effect and a composition effect. Among a few exceptions are the gap zero and one that faced a major increase in their measures that more than compensate the decrease in the optimal innovation effort. In contrast, there are nearly any changes in the weighted innovation rate for Europe (Panel 3b), since both the optimal innovation decisions and the measure of product lines decreased less in each gap relative to the U.S. Again, only the gap zero showed a greater increase in its measure. Overall, the composition effect shifted the product lines towards lower gaps where the innovation rates are smaller, contributing to the negative within gap net effect (escape-competition and Schumpeterian effect).

Within each gap leaders and followers might have different responses to the same

Figure 3: Innovation rate (weighted) and Gap distribution

(a) U.S. (b) Europe



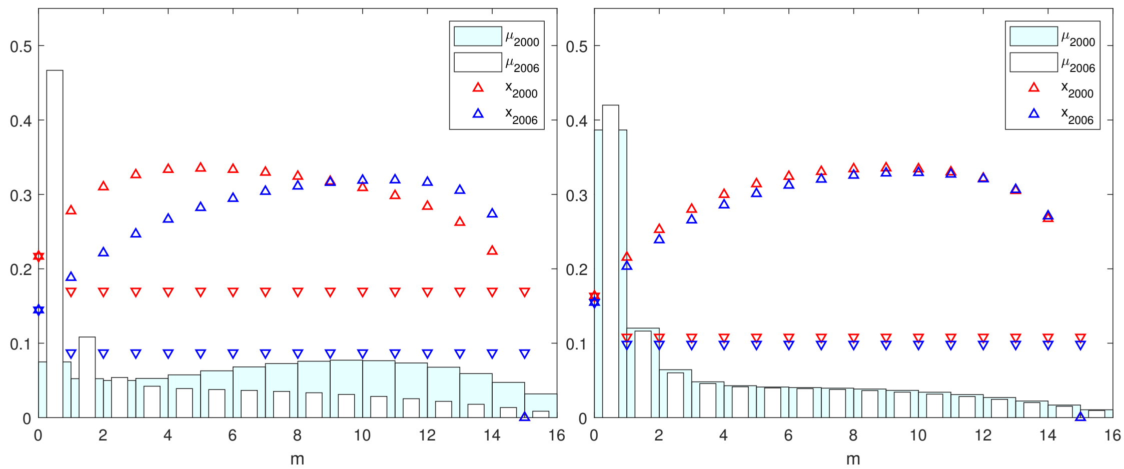
competitive fringe shock. In fact, equations 13 and 14 show that the leader incentives depend on the marginal increase in value which, in turn, depends on the shape of the value function in positive gaps, whereas the follower incentives depends on the value of catching-up. As Figure 4 shows there is a substantial heterogeneity in the responses across gaps. In the figure, the red upward (downward) triangles depicts the innovation effort of the leaders (followers) - the sum of the optimal innovation rates for U.S./Europe firms and the Chinese firms - by gap in 2000 while the blue triangles show the innovation decisions in 2006.

The results for the U.S. highlight the theoretical possibility of an ambiguous effect. For product lines in lower gaps, the leaders respond to increased competition by lowering the innovation efforts, that is, the Schumpeterian effect dominates, whereas for higher gaps the opposite holds and the escape-competition dominates. Again, these results reflect a departure from the Aghion et al. (2005)'s stylized model, where the Schumpeterian effect dominates in higher gaps. However, recall that in their model the maximum gap is one, in which case the leader is not allowed to innovate. Thus, in this case they only take into account the followers response. In the model presented here, on the other hand, both mechanisms play a role in the leader's innovative decision.

In contrast, since the followers in each gap have the same innovation incentives (due to the assumption that one successful innovation is enough to catch up with the leader), the increase in competition implies a lower innovation effort for the followers. Alternatively, in this case only the Schumpeterian effect takes place. In sum, the within gap change in the innovation effort is the result of the heterogeneous response in the leader's innovation

Figure 4: Innovation rate breakdown by leadership

(a) U.S. (b) Europe



effort and the decrease in the followers innovation effort. Consequently, the within gap innovation effort decreases for all gaps due to the fact that the increase in the leader's innovation effort in high gaps is not enough to compensate the decrease in the follower's innovation rate. Panel 4b shows a similar pattern of innovation responses for European firms.

Finally, Figures 5 and 6 depict the optimal innovation rate for leaders and followers by firm leadership - either U.S./Europe or China - along with the respective gap distribution. Panels 5a and 6a show the innovation rate for leaders in product lines where the U.S./Europe has a lead in 2000 (red upward triangle) and in 2006 (blue upward triangle), and the innovation rate for the Chinese followers (the downward triangles).

Most of the innovation effort behaviour described before for leaders and followers in the U.S./Europe in the previous figures reflects almost completely the patterns in the product lines with U.S./Europe leadership, since the Chinese leadership accounts for just a small share of the overall distribution of gaps. Nonetheless, it is important to highlight that the increase in the competitive fringe shock parameter decreases the innovation effort for the U.S./European followers (Panels 5b and 6b) even though the replacement shock only takes place in product lines where the Chinese firm is the follower. This happens due to the indirect effect of the increased competition in the firm value of the U.S./European leader. A tougher competition increases the chances of facing a new one-step-ahead competitive fringe, thus decreasing the value of catching up with the Chinese leader.

The last exercise is described in Table 4. We calculate the contribution of the

Figure 5: Innovation rate breakdown by firm leadership for the US

(a) U.S. leader (b) China leader

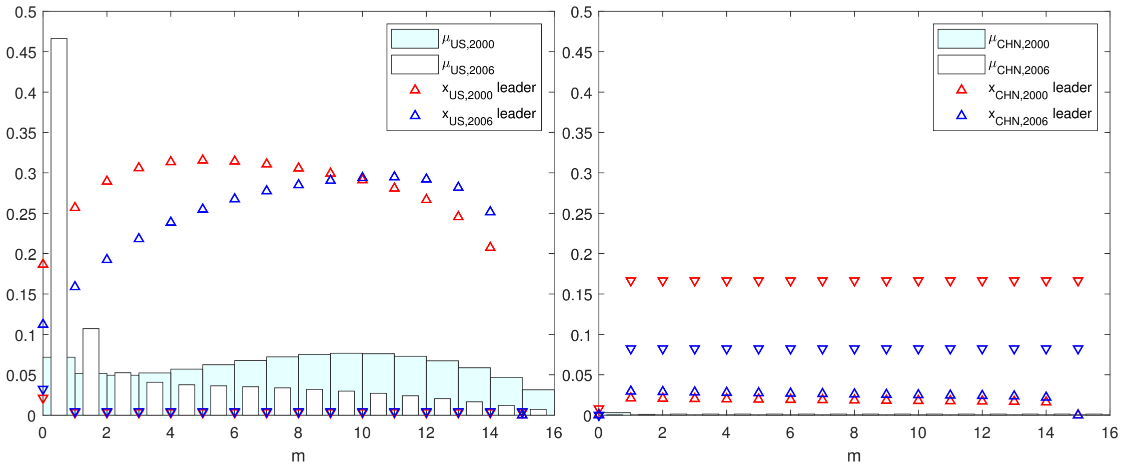


Figure 6: Innovation rate breakdown by firm leadership for Europe

(a) Europe leader (b) China leader

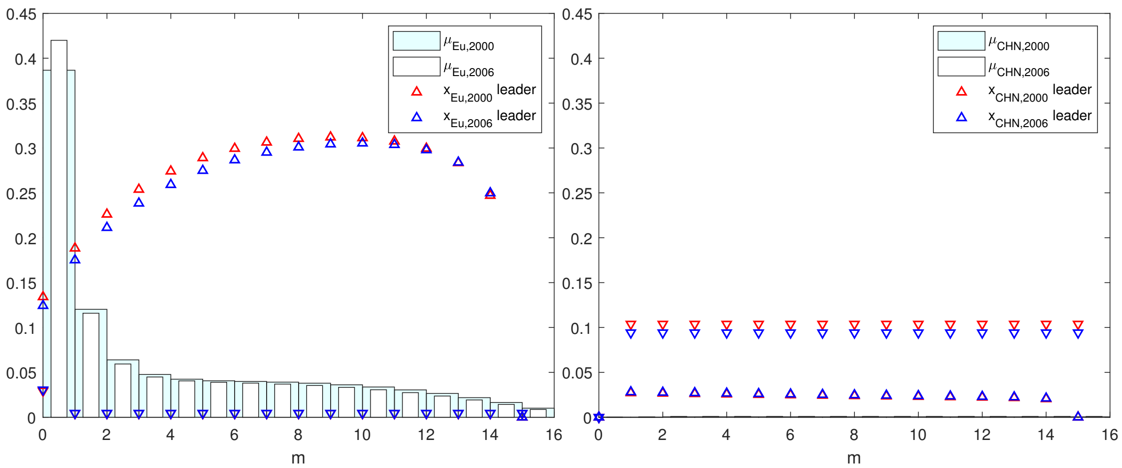


Table 4: Contribution of each mechanism for the change in output growth

	Constant variable	
(%)	**Innovation intensities (x_{jm})**	**Gap distribution(μ_{jm})**
US	34.11	29.84
Europe	36.58	63.56

within gap innovation response, which encompasses the escape-competition as well as the Schumpeterian effect, and the between gap innovation response, which reflects the composition effect, in the total change of the TFP growth rate within the period. The first column measures the change in the TFP growth rate due to changes in the gap distribution between years while maintaining the innovation intensities for leaders and followers constant at the initial level. In turn, the second column shows the same exercise except that, now, the gap distribution remains constant at the initial year.

The first line shows that the composition effect have a higher contribution, around 34.11%, in the model implied decrease in the growth rate between 2000 and 2006 for the U.S. economy. However, the contribution of the within gap innovation response and the composition effect are relatively similar, roughly 30%. In contrast the contribution of the within gap innovation response is much stronger for the set of European countries - in fact, 63.56% -, accounting for roughly 1.7 times the composition effect's contribution.

In conclusion, the results suggest that the increased Chinese import competition captured by the increase in the competitive fringe shock affected negatively both economies with a stronger effect in the U.S. The overall negative effect hides the heterogeneous responses across product lines with different technological gaps between followers and leaders as well as differential within gap responses. Additionally, in the model presented here the preponderance of the within gap mechanisms, the escape-competition and Schumpeterian effect, presents a different pattern relative to the previous literature by which the former tend to dominate in high gap industries instead of neck-and-neck industries. Lastly, the composition effect might strengthen or weaken the within gap mechanisms depending on the shape of the optimal innovation decisions.

6 Conclusion

In this paper we revisit the competition-innovation debate in light of the recent empirical evidence on the effects of the increased import competition from low-wage countries, such as China, on firm-level innovation in developed countries. The empirical evidence is mixed. Faced with increased competition from Chinese products, European firms respond filling more patents, increasing IT usage and productivity. On the other hand, U.S. manufacturing firms within sectors more exposed to Chinese import competition experienced a decrease in the number of patents relative to the trend.

Guided by the insights from the theory we extend the standard Schumpeterian growth model with step-by-step innovation to allow for a shock that replaces the follower in each product line - which in these models acts as a competitive fringe limiting the leader's ability to charge higher markups. The competitive fringe shock discourages the follower innovation (the Schumpeterian effect) by introducing a rate of replacement. The shock also adds the Schumpeterian disincentive effect for leaders to the escape-competition effect already in place. Therefore, for the leader, the Schumpeterian effect is balanced by the new escape-competition effect which may generate positive or negative effects on innovation depending on the shape of the firm's value.

In this setting, we calibrate the quantitative model to the U.S. and Europe pre and post China accession to the WTO. The results suggest that differences in the initial level of the competitive fringe shock as well as the magnitude of its increase can explain part of the differences in the innovation responses between the U.S. and Europe. In fact, the increase in competition is much stronger for the U.S. implying a higher decrease in the aggregate innovation intensity. Both the within gap and composition effect contribute roughly the same for the decline in productivity growth. For Europe, although the initial level of competition is higher the increase in the exposure to low-wage competition is smaller which implies a smaller decrease in aggregate innovation. Nevertheless, the within gap effect contributes significantly more to the smaller decline in productivity growth. Moreover, in contrast to previous literature, we show that the escape-competition effect tend to dominate in high gap industries instead of "neck-and-neck" industries.

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Appendix

A Model equilibrium equations

A.1 Value functions

In this section we describe the remaining value functions not defined in the main text. The value of the firm A when it lags by m steps is analogous to the firm B except for the absence of the competitive shock:

$$r_t V_{A(-m)t} - \dot{V}_{A(-m)t} = \underset{x_{A(-m)t}|x_{Bmt}}{\text{Max}} \Big\{ -w_t \theta_A \frac{x_{A(-m)t}^{\eta_A}}{\eta_A} + (x_{A(-m)t} + \kappa)(V_{A0t} - V_{A(-m)t}) + x_{Bmt}(V_{A(-m-1)t} - V_{A(-m)t}) \Big\} \tag{21}$$

In the maximum gap, $\bar{m}$, the leader cannot improve further its position. Thus, the value function for firm A when leader and follower reflects that restriction:

$$r_t V_{A\bar{m}t} - \dot{V}_{A\bar{m}t} = \underset{x_{A\bar{m}t}|x_{B(-\bar{m})t}}{\text{Max}} \Big\{ (1-\lambda^{-\bar{m}})Y_t - w_t \theta_A \frac{x_{A\bar{m}t}^{\eta_A}}{\eta_A} + (x_{B(-\bar{m})t} + \kappa)(V_{A0t} - V_{A\bar{m}t}) + \delta \left(V_{A(\bar{m}-1)t} - V_{A\bar{m}t} \right) \Big\} \tag{22}$$

$$r_t V_{A(-\bar{m})t} - \dot{V}_{A(-\bar{m})t} = \underset{x_{A(-\bar{m})t}|x_{B\bar{m}t}}{\text{Max}} \left\{ -w_t \theta_A \frac{x_{A(-\bar{m})t}^{\eta_A}}{\eta_A} + (x_{A(-\bar{m})t} + \kappa)(V_{A0t} - V_{A(-\bar{m})t}) \right\} \tag{23}$$

Analogously, the value of a firm B that leads by m steps is similar to the value of a firm A when leader except for the absence of the competitive fringe shock, as reflected in the equation below:

$$r_t V_{Bmt} - \dot{V}_{Bmt} = \underset{x_{Bmt}|x_{A(-m)t}}{\text{Max}} \Big\{ (1-\lambda^{-m})Y_t - w_t \theta_B \frac{x_{Bmt}^{\eta_B}}{\eta_B} + x_{Bmt}(V_{B(m+1)t} - V_{Bmt}) + (x_{A(-m)t} + \kappa)(V_{B0t} - V_{Bmt}) \Big\} \tag{24}$$

In the maximum gap, the value of the firm B reflects the presence of the shock (when follower) and the lack of additional steps for the leaders:

$$r_t V_{B\bar{m}t} - \dot{V}_{B\bar{m}t} = \underset{x_{B\bar{m}t}|x_{A(-\bar{m})t}}{\text{Max}} \left\{ (1-\lambda^{-\bar{m}})Y_t - w_t \theta_B \frac{x_{B\bar{m}t}^{\eta_B}}{\eta_B} + (x_{A(-\bar{m})t} + \kappa)(V_{B0t} - V_{B\bar{m}t}) \right\} \tag{25}$$

$$r_t V_{B(-\bar{m})t} - \dot{V}_{B(-\bar{m})t} = \underset{x_{B(-\bar{m})t}|x_{A\bar{m}t}}{\text{Max}} \left\{ -w_t \theta_B \frac{x_{B(-\bar{m})t}^{\eta_B}}{\eta_B} + (x_{B(-\bar{m})t} + \kappa)(V_{B0t} - V_{B(-\bar{m})t}) \right.$$
$$\left. -\delta V_{B(-\bar{m})t} \right\} \tag{26}$$

The optimal innovation decision for firm B when it is the leader is symmetric to the equation 13, and the optimal innovation for firm A that lags by m steps is analogous to equation 14. The gap zero innovation decision for both firms are obtained setting $m = 0$ in equation 13. The maximum gap when the firm is the follower is obtained accordingly setting $m = -\bar{m}$ in equation 14. Since the maximum gap is $\bar{m}$, we have that $x_{A\bar{m}t} = x_{B\bar{m}t} = 0$.

A.2 Law of motion for $m = 0$ and $m = \bar{m}$

The law of motion for the measure of product lines with gap $m = 0$ for firm A and firm B are given by, respectively,

$$\dot{\mu}_{A0t} = \sum_{s=1}^{\bar{m}} (x_{B(-s)t} + \kappa)\mu_{Ast} + \delta\mu_{A1t} - (x_{A0t} + x_{B0t})\mu_{A0t} \tag{27}$$

$$\dot{\mu}_{B0t} = \sum_{s=1}^{\bar{m}} (x_{A(-s)t} + \kappa)\mu_{Bst} - (x_{B0t} + x_{A0t})\mu_{B0t} \tag{28}$$

Again, both measures evolve based on the difference between entry and exit in the state m. In equation 27, for instance, the first two terms are the measure of entrants in gap $m = 0$ state, either by successful innovation of followers in each gap m where firm A is the leader (first term) or by the leaders in state $m = 1$ that face a new one step ahead competitor (second term). The last term, in turn, measures the exit from state $m = 0$ that happens when one of the firms innovate. The law of motion for the gap $m = 0$, equation 28, where firm B produces is analogous except that there is no replacement in gap $m = 1$ so that there is no analogous expression for the second term in the previous equation.

For the limiting gap $m = \bar{m}$ the law of motion can be written as

$$\dot{\mu}_{A\bar{m}t} = x_{A(\bar{m}-1)t}\mu_{A(\bar{m}-1)t} - (x_{B(-\bar{m})t} + \kappa + \delta)\mu_{A\bar{m}t} \tag{29}$$

$$\dot{\mu}_{B\bar{m}t} = x_{B(\bar{m}-1)t}\mu_{B(\bar{m}-1)t} - (x_{A(-\bar{m})t} + \kappa)\mu_{B\bar{m}t} \tag{30}$$

The previous equations take into account that in the limiting gap it is optimal to not innovate, since there is no improvement in the gap position by assumption.

A.3 Equation 18

For a given interval Δt, the aggregate quality index evolves through innovation by leaders in gap $m > 0$, at rates $x_{Amt} + o(\Delta t)$ and $x_{Bmt} + o(\Delta t)$ in industries with firm A and firm B leadership, respectively. Also, the quality index improves through innovation of both firms in gap $m = 0$ at rates $x_{A0t} + o(\Delta t)$ and $x_{B0t} + o(\Delta t)$. Since the productivity increases by one step λ whenever there is innovation we have that the evolution of the quality index is given by:

$$\ln Q_{t+\Delta t} = \ln Q_t + \ln \lambda \left((x_{A0t} + x_{B0t})\mu_{0t} + \sum_{s=1}^{\bar{m}} x_{Ast}\mu_{Ast} + \sum_{s=1}^{\bar{m}} x_{Bst}\mu_{Bst} \right) \Delta t + o(\Delta t) \tag{31}$$

where $o(\Delta t)$ captures second-order terms such as the probability of more than one innovation within the time interval Δt and satisfies $\lim_{\Delta t \to 0} o(\Delta t)/\Delta t = 0$. Subtracting $\ln Q_t$ from both sides, dividing by Δt and taking the limit we obtain 18.