Strategic Innovation and Entry *

RENJIE BAO — Princeton[†]

JAN EECKHOUT — UPF Barcelona[‡]

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Abstract

This paper proposes an endogenous growth theory with oligopolistic competition and innovations on quality ladder (with spillover) and contemporary productivity (without spillover). We highlight the mechanism of "killer innovation", where industrial leaders strategically make excessive innovation on productivity to deter entry and reduce competition. Consistent with the secular trends, our quantitative model predicts a negative correlation between profit margin and number of entrants for variation on both supply (firm heterogeneity) and demand (price elasticity) sides. Motive to kill competition incurs over-investment on contemporary productivity and excessive profits for the leaders, which is shown to be welfare-enhancing by correcting externalities in socially beneficial quality innovation. If there were no killer innovation, despite of higher static efficiency due to reduction in market power, social welfare will be 51.17% lower during 1980-1999 and 9.74% lower during 2000-2019.

Keywords. Killer Innovation. Entry Deterrence. Market Power. Superstar Firms. Firm Size Distribution. General Equilibrium. Intangibles.

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† renjie.bao@princeton.edu

‡ jan.eeckhout@upf.edu – ICREA-BSE-CREI

1 Introduction

Economists have documented a rise in market power (e.g., De Loecker, Eeckhout, and Unger, 2020) and decline of business dynamism (e.g., Decker, Haltiwanger, Jarmin, and Miranda, 2016) for the recent decades. In principal, an increase in profit margins may result from a less elastic demand function or, from the supply side, increased heterogeneity in productivity (e.g., De Loecker, Eeckhout, and Mongey, 2021). However, the connection between these factors and the observed decline in business dynamism, particularly the reduced startup rate, remains ambiguous. This paper aims to develop and quantitatively analyze a macroeconomic framework of strategic innovation, integrating these stylized facts through both demand and supply considerations.

Firms strategically innovate to become dominant and to gain market power. Upfront investments in intangibles that are *sunk* lead to higher productivity, which allows the innovating firm to gain a dominant position in the market. This is the essence of Sutton (1991, 2001)'s view of innovation to build endogenous firm productivity. We refer to *killer innovation* when dominant firms use strategic innovation to affect the market structure and deter entry by followers. On the supply side, this mechanism contributes to fewer entry and higher market power by endogenously making the productivity distribution more dispersed. More surprisingly, we find that killer innovation will alter the ECON 101 intuition of lower profit margins in markets with less differentiable goods. In particular, product homogeneity makes it easier for industrial leaders to deter entry by making strategic innovation on productivity, which feeds back to larger profitability for incumbent firms. Consistent with the secular trends, killer innovation simultaneously induces higher market power and fewer entry dynamism.

Our framework is built over the standard Schumpeterian growth model with infinitely many industries and finitely many firms within an industry (e.g., Grossman and Helpman, 1991; Aghion and Howitt, 1992). Each industry is associated with a quality level that can be improved period by period conditional upon quality ladder. The key is that we distinguish two types of innovation with different levels of spillover. The *quality* innovation is assumed to be with perfect spillover, meaning all firms in the same industry can benefit from a realized quality ladder. In contrast, the innovation on *productivity* is exclusive to each firm and exhibits no spillover, which creates opportunities for strategic behaviors à la Sutton (2001).[1] The two types of innovation interact with one another through the timing assumption, where the firm finding quality ladder becomes the industrial leader during that period and has the power to credibly make productivity innovation before any followers enter.[2] Firms maximize profits by optimally choosing investment in innovations and optimally making production decisions in the oligopolistic product market, where market structure is determined by the free entry equilibrium.

Our theoretical contribution is to add strategic innovation on productivity into the endogenous growth model. Innovation that increases productivity by the leading firms who can make investment before the entrants has an effect on the intensive as well as the extensive margin. On the intensive

[1] For example, in the telecom industry, a quality ladder could be the up-gradation from the fourth-generation technology standard (4G) for cellular networks to the fifth's (5G). Perfect spillover means all the telecom companies can freely access this new generation of idea. But they have to invest in building telecom towers and deploying base stations to establish connections and transmit signals, which is a productivity innovation exclusive for their own usages.

[2] In case there is no quality ladder in an industry for a certain period, there is no industrial leader.

margin, our model hosts the classic "escape-competition" effect where, holding market structure fixed, more innovation by the leader relative to followers leads to a larger gap in productivity (e.g., Aghion, Harris, Howitt, and Vickers, 2001; Aghion, Bloom, Blundell, Griffith, and Howitt, 2005; Liu, Mian, and Sufi, 2022). On the extensive margin, we highlight a novel mechanism in the macroeconomics literature of entry deterrence termed as killer innovation. Because larger innovation by the leader lowers profits by the followers, the potential entrants may be deterred from entering. Killer innovation occurs when dominant firms use strategic investment in innovation to affect the market structure and stymie entry and/or innovation by competitors.[3]

Social welfare is jointly determined by growth and static efficiency, where our theory embeds a rich set of externalities associated with both types of innovation. For productivity innovation, we identify externalities through aggregate demand, imperfect competition, and market structure. First, there is a positive aggregate demand externality on consumer surplus that is not internalized by self-interested firms.[4] Second, imperfect competition creates a negative externality from productivity innovation on the profits of other firms by changing the market price. Finally, the killer effect on the extensive margin will generate an externality on market structure, which is new to the literature and will be the main focus of this paper. The welfare implication of strategic innovation on productivity is therefore ambiguous ex ante and depends on the trade-off among these three externalities. Quality innovation, on the other hand, mainly suffers from the standard Pigouvian externality due to its nature of spillover to other firms in the same industry and to future quality improvement. When not fully internalized, this positive externality will result in an under-investment in quality innovation and thus a suboptimal growth rate. Strategic innovation on productivity that induces excessive leading profits will fix part of the distortion on quality innovation.

We then estimate the model for the periods of 1980-1999 and 2000-2019 by treating them as two independent balanced growth path (BGP). We acquire information on firms from the Compustat data and on growth from the Bureau of Economic Analysis (BEA). The estimation results make three main statements. First, ideas are getting harder to find, as is indicated by a lower entry cost but larger decreasing return to scale on quality innovation (Bloom, Jones, Van Reenen, and Webb, 2020). Second, the magnitude of killer innovation is increasing over time, which corresponds to lower curvature in the investment function and a larger premium in the leader's efficiency type. Finally, we find that products within the same industry becomes much more substitutable, which, through its interaction with killer innovation, deters entry in the product market and leads to higher market power.

Over time, our quantitative model reproduces the secular trends of the increasing markup, the declining entry, and the slow-down of growth. Moreover, we document a strong pattern of strategic innovation on productivity, especially on the extensive margin. In each period of time, we identify a significant fraction of industries with a "killer" leader who invests at the exact productivity level to deter the entry of a marginal follower (i.e., the corner solution). This pattern is getting stronger over time, as is accompanied by an increasingly concentrated product market structure. In total, we find a

[3] The notion of killer innovation where firms use innovation to block entry is similar to predatory pricing where firms use (dynamic) pricing to deter entry. Killer innovation should not be mistaken for predatory innovation, a concept in antitrust law that refers to the practice of altering product specifications (for example by limiting interoperability) to prevent competitors from entering, see for example Van Arsdale and Venzke (2015).

[4] In general equilibrium, this externality shows up as a higher household labor income when productivity increases.

large welfare loss from the period 1980-1999 to 2000-2019 when holding fixed the initial quality level.

Using our estimators, we decompose the secular changes and welfare effects over time through the lens of quality and productivity innovations by feeding in the fundamental changes sequentially. The increase in markup and the decline in entry can be largely explained by less curvature in productivity innovation and larger homogeneity among goods within an industry, but the welfare loss due to this static inefficiency is limited. Rather, our counterfactual results suggest that the lower growth rate due to changes in quality innovation is responsible for 89.1% of the welfare loss, highlighting the importance of the dynamic efficiency.

Furthermore, we study the effects of strategic productivity innovation in both partial equilibrium and general equilibrium through two counterfactual economies. First, we shut down the strategic innovation in a partial equilibrium setting by fixing follower's decision on entry and productivity exogenously at their equilibrium values. The counterfactual level of productivity innovation from the leaders is almost always lower than its baseline counterparts, meaning that the mechanism of strategic innovation, on both the intensive and extensive margin, will quantitatively result in an *over*-investment in productivity.[5] To study its welfare implication, we further solve the general equilibrium for a counterfactual world where all firms make productivity innovation simultaneously, which again shuts down the strategic advantages of the leaders. Under the new balanced growth path, the growth rate would be 1.28% and 0.40% lower for the periods of 1980-1999 and 2000-2019, respectively, while the static output increases by 6.38% and 7.14%. On aggregate, the channel of declining growth rate dominates and results in a decrease in social welfare by 51.17% and 9.74% for the two periods of time. Although the positive dynamic effect of strategic productivity innovation outweighs the negative static one, we document a trend where the static efficiency becomes more important most recently.

In summary, our analysis elucidates the *superstar* firm phenomenon, which highlights that a handful of firms have increasingly grown dominant (Autor, Dorn, Katz, Patterson, and Van Reenen, 2020). In this paper, we find that the distribution of superstar firms is tightly linked to strategic innovation on productivity at both the intensive and extensive margin. As a result, the observed productivity distribution and the emergence of superstar firms is the amalgam of over-investment by superstar firms who use their productivity and size to increase profitability, and under-investment or lack of entry at all of follower firms.

Related literature. This paper builds on vast literatures that study the macroeconomics of innovation. A starting point is the work on Schumpeterian growth model, which focuses on the spillover effect in innovation and centers around the process of creative destruction (Grossman and Helpman, 1991; Aghion and Howitt, 1992; Klette and Kortum, 2004; Lentz and Mortensen, 2008; Aghion, Akcigit, and Howitt, 2014; Acemoglu, Akcigit, Alp, Bloom, and Kerr, 2018; Akcigit and Kerr, 2018; Akcigit, Baslandze, and Lotti, 2018). We contribute to this strand of works by introducing non-spillover innovation on productivity and analyzing the strategic interaction between industrial leaders and followers on both intensive and extensive margin.

[5] With an exception from the monopolistic industries, where the leader's productivity innovation decision is identical for the baseline and counterfactual economies because there is no strategic interaction to begin with.

The discussion about the spillover of innovation is closely related to our work. Bloom, Schankerman, and Van Reenen (2013) quantify the magnitude of the positive knowledge spillover and the negative business stealing effects. They conclude that the positive one dominates and the social returns to innovation are at least twice as high as the private returns. Our structural estimators confirm with this finding that the distortion in quality innovation with knowledge spillover has a much larger implication on social welfare.

Our paper shares the same spirits of De Ridder (2019), who highlights the innovation in the intangibles that is specific to current producers, and the value-added we made is to study a differentiated product market within an industry, which allows to host a rich set of strategic interaction among firms in innovation and production. On the other hand, there are papers modeling the differentiated output markets with partial spillover (e.g., Aghion, Harris, Howitt, and Vickers, 2001) or no spillover (e.g., Cavenaile, Celik, and Tian, 2019) in innovation. We contribute by explicitly distinguishing the two types of innovation and highlight their different interactions with the stylized facts.

The literature pays much attention on the intensive margin of strategic innovation, i.e., the escape-competition effect, since the seminal work by Aghion, Harris, Howitt, and Vickers (2001). Following works use this mechanism to explain the inverted-U shape between innovation and competition (Aghion, Bloom, Blundell, Griffith, and Howitt, 2005; Cavenaile, Celik, and Tian, 2019). We differ from these works by also studying the strategic innovation on the extensive margin. On this topic, Fons-Rosen, Roldan-Blanco, and Schmitz (2021) study the effect of startup acquisition on business dynamism and incumbents' innovation incentives, and they conclude a positive net effects on growth and welfare. Without growth, Weiss (2019) analyzes the strategic innovation with entry deterrence in a dynamic oligopolistic framework and use it to explain the rise of concentration and markups. We differ from all these works by studying how does killer innovation interact with heterogeneity in product differentiability and demand elasticity.

Another strand of the literature focuses on the multi-product decisions. Aghion, Bergeaud, Boppart, Klenow, and Li (2023) study the decision of efficient firms spreading into new markets when the overhead cost is falling. They discuss the implication on quality innovation, but there is no strategic interaction in productivity innovation as it is assumed to be exogenous. On strategic innovation with imperfect spillover, Jo and Kim (2021) consider the trade-off between internal innovation that improves own products versus external innovation that enters others' markets. Argente, Baslandze, Hanley, and Moreira (2020), on the other hand, consider patenting as an instrument of market leaders to deter future product introduction by competitors. For simplicity, we abstract from multi-product firms, but our insights also apply to this more general case.

Our paper also adds value to the literature on superstar innovation. Aghion, Bergeaud, Boppart, Klenow, and Li (2022) studies R&D misallocation and suggests the policy maker to subsidize high-markup firms who make innovations that confer significant knowledge spillover ("good" rent). Focusing on political connections, Akcigit, Baslandze, and Lotti (2023) argues that market leaders are more likely to be politically connected but much less likely to innovate. Using patent data, Braguinsky, Choi, Ding, Jo, and Kim (2023) document a different fact that mega firms are generating more "novel patents", which are the new combinations of technology components for the first time. Cavenaile, Roldan-Blanco, and Schmitz (2023) explains the rise of superstars by the interaction between innovation and international trade. Studying the labor market consequences of innovation, Autor, Salomons, and Seegmiller (2023) concludes that superstar innovations are more labor-augmenting. We contribute to this discussion by endogenizing the market leading status, productivity innovation, and the relative firm size and exploring the interaction among these three elements.

Our insights build on the IO literature on entry deterrence, which can be mainly classified into three categories according to Wilson (1992). The first category of models focuses on preemption, where the key for a firm is to build commitment for claiming and preserving a monopoly position. Known mechanisms include capacity (e.g., Spence, 1977; Dixit, 1980), preemptive patenting (e.g., Dasgupta and Stiglitz, 1980; Gilbert and Newbery, 1982), advertisement (e.g., Salop and Scheffman, 1987), and first mover in durable-goods market (e.g., Hoppe and Lee, 2003). The second category of preemption models analyzes the role of signaling (e.g., Milgrom and Roberts, 1982a). The third category focuses on predation, lowering prices to drive out competitors or deter entrants (e.g., Milgrom and Roberts, 1982b). Our analysis complements this vast body of existing work by considering observable innovation as a commitment device, and by investigating and quantifying the consequences for the macro economy.

Our analysis of the economy-wide firm distribution provides new insights behind the causes of the rise of superstar firms. Superstar firms have shown to be behind the fall in the capital and labor shares (Hartman-Glaser, Lustig, and Zhang, 2016; Kehrig and Vincent, 2017; Barkai, 2019; Autor, Dorn, Katz, Patterson, and Van Reenen, 2020). Much of this literature highlights the role of market power that involves the reallocation of market share to high markup firms (Grassi, 2017; Edmond, Midrigan, and Xu, 2019; De Loecker, Eeckhout, and Mongey, 2021). Our analysis quantitatively captures these secular changes, and provides a novel mechanism based on endogenous innovation that leads to over-investment and hence excessive firm size.

The focus of our analysis is on effect of investment in innovation on market structure. Of course, other strategic decisions by firms affect market structure and innovation too. Motta and Tarantino (2021), Letina et al. (2021), and Morzenti (2023) focuses on the role of mergers for innovation and competition, with Letina et al. (2021) building on the insights from Cunningham, Ederer, and Ma (2021). In other work, Anton, Ederer, Giné, and Schmalz (2022) show that the welfare impact of innovation on market power is ambiguous – as it is in our setting – depending on the role of synergies in production and common ownership. And Vaziri (2022) studies the effect of antitrust law taking into account the strategic decision-making of firms to eliminate competition. More broadly, firms make investments in innovation that directly affects the ability for competitors to enter the market other than increases in productivity,[6] known as *predatory innovation*, as mentioned above with reference to Van Arsdale and Venzke (2015).

2 Model

[6] For another example, see Eeckhout and Veldkamp (2022) who analyze the role of data and how date can affect the market structure.

2.1 Setup

Our theory builds on the canonical growth model of quality ladder (Grossman and Helpman, 1991; Aghion and Howitt, 1992). To accommodate the idea of strategic investment, we apply the framework of oligopolistic competition (Aghion, Harris, Howitt, and Vickers, 2001; Atkeson and Burstein, 2008). We summarize all the model variables in Table 1. Our theoretical contribution is to disentangle two types of innovations on quality and productivity.

I. ENVIRONMENT

Time is discrete and denoted by subscript t. There is a continuum of industries indexed by subscript j with measure normalized to 1. Each industry j has an endogenous quality q_{jt} at time t, whose average is defined as the aggregate quality $\overline{q}_t$. We further define the relative quality as $x_{jt} \equiv q_{jt}/\overline{q}_t$, whose *distribution* is expected to be stationary along the BGP.

There is a representative household consumes outputs, supply a fixed amount of labor $\overline{L}$, and claim all the profits.[7] They consume hand-to-mouth with the following maximization problem:

$$\max_{\{C_t\}_{t=0}^{\infty}} U_0 = \sum_{t=0}^{\infty} \beta^t C_t, \quad \text{s.t.} \;\; C_t \leq \Pi_t + W_t \overline{L}_t, \;\forall t, \tag{1}$$

where β is the discounting factor and C_t is the household's consumption of final goods. The wage W_t and profit Π_t will be determined in the equilibrium. We normalize the price of aggregate consumption goods in every time period t.

On the output market, we assume the final goods C_t can be aggregated from industry-level quality-adjusted consumptions with the constant elasticity of substitution (CES) θ. Within an industry j, the market is oligopolistic, with the number of firms I_{jt} being determined by the game of free entry. Each firm i produces a differentiable good with constant elasticity of substitution η_j. The output system can therefore be summarized as:

$$C_t = \left[\int_0^1 \left(\overline{q}_t x_{jt} c_{jt}\right)^{\frac{\theta-1}{\theta}} \, \mathrm{d}j \right]^{\frac{\theta}{\theta-1}} \quad \text{and} \quad c_{jt} = \left[\sum_{i=1}^{I_{jt}} (c_{ijt})^{\frac{\eta_j - 1}{\eta_j}} \right]^{\frac{\eta_j}{\eta_j - 1}}. \tag{2}$$

We further assume that $\theta < \inf(\eta_j)$, meaning that goods are always more substitutable within an industry than across industries.

II. TWO TYPES OF INNOVATION

Our main contribution is to disentangle innovation into two types: *quality* and *productivity*. The key difference is that quality innovation has perfect spillover, meaning that all firms will have access to a quality ladder whenever it is created. On the contrary, there is no spillover on productivity innovation. For example, in the telecom industry, a successful quality innovation could be an up-

[7] We keep the labor supply inelastic to ensure the existence of a balanced growth path by eliminating the general equilibrium effects through labor supply. We also fix $\overline{L}$ over time because we want to focus on growth that is not mechanically driven by the increase in population.

gradation from the fourth generation to the fifth, which can be learned by all firms, while the exclusive productivity innovation could be that each telecom company builds their own telecom towers to transmit signals more efficiently.

We first introduce the process of quality innovation. There are N_{jt} research firms in every industry j making innovation on quality ladder at the beginning of each period t. They have access to the up-to-date quality $q_{j,t-1}$, which will then be updated into $q_{jt} = (1+\lambda)q_{j,t-1}$ upon drawing a quality ladder λ, or remain the same otherwise. We assume that at each time there could be *at most* one firm winning this quality ladder, and the likelihood is specified as:

$$h_{njt}(\boldsymbol{v}_{jt}) = \frac{v_{njt}}{x_{j,t-1}v_0 + \sum_{n'} v_{n'jt}}, \tag{3}$$

where v_{njt} is the research intensity chosen by research firm n that requires to hire $l^q_{njt} \equiv x^{\theta-1}_{j,t-1}v_{njt}$ unit of workers. To reach the same intensity level of research, firms in a higher-quality industry needs to hire more workers.[8] Parameter v_0, corresponding to the case with no successful quality improvement, controls the degree of decreasing return to scale in the research activity. According to (3), it is harder for an industry with relatively higher quality to improve, which becomes the contraction force that pins down the stationary distribution of relative qualities. In Appendix A.2, we show that this functional specification could be micro-founded by a standard discrete choice framework with an outside option v_0 and extreme value shocks.

Next comes the productivity innovation. The winner of quality innovation, if any, becomes the industry leader who can make productivity innovation prior to any other followers in current period t.[9] We denote leaders by subscript ℓ. Each leader is assigned with a type $z_{\ell jt} \geq 1$ from a Pareto distribution, which is a *structural residual* that accounts for other advantages for the leader that are not captured by this paper.[10] The leader can choose its productivity level $a_{\ell jt}$ by investing a deterministic amount of labor $l^a_{\ell jt} \equiv x^{\theta-1}_{jt}a^{\gamma}_{\ell jt}/(\gamma z_{\ell jt})$, where the parameter γ controls the curvature of the productivity investment function. The superscript a indicates for the productivity investment stage. Followers in each industry, upon entry, make innovation on productivity after seeing the productivity chosen by the leader (if any). To reduce the dimensionality of the problem, we focus on the industrial leaders by assuming followers have identical type that is normalized to 1, similar to Cavenaile, Celik, and Tian (2019).[11] Hence, the investment in terms of workers needed for them to get productivity a_{fjt} is $l^a_{fjt} \equiv x^{\theta-1}_{jt}a^{\gamma}_{fjt}/\gamma$. Again, we assume that it is more costly for productivity investment in an industry with a higher relative quality.

[8]This assumption can be interpreted as each worker has average knowledge $\bar{q}^{\theta-1}_{t-1}$, and the firm in market j needs to accumulate $q^{\theta-1}_{j,t-1}v_{njt}$ units of efficiency knowledge in order to generate v_{njt} unit of research outcomes.

[9]This timing assumption accommodates the reality observation that the firm who creates a new idea will be able to make investment on production first. Followers, upon seeing the leading product, can then learn this idea and make their own productivity investment.

[10]Other leader advantages could come from, for example, selection, where a successful leader has higher intrinsic type in productivity innovation. Our main mechanism, i.e., the first mover advantage, is more prominent when this structural residual $z_{\ell jt}$ is closer to 1, corresponding to a more concentrated Pareto distribution.

[11]This assumption for tractability means that we cannot speak about the distribution of small firms. Our main analysis will focus on the industry leaders, which is still meaningful as those superstar firms are shown to be the most relevant agents in economic activities (Autor, Dorn, Katz, Patterson, and Van Reenen, 2020).

III. TIMING

We have a dynamic system linked by quality process q_{jt}. The problem on the firm side is kept static for simplicity. That is, we assume all firms will die at the end of each time period. For quality innovation, the one-period leading premium corresponds to the temporary rents of innovation awarded by antitrust laws such as patents. Within a time t, however, there are four stages of decisions for firms to make.

1. **Innovation on quality ladder**. At the beginning of each period t, N_{jt} research firms in each industry j decides the research intensity v_{njt} for a quality ladder. The winner of this quality ladder will become the first mover in the productivity investment stage, which yields a leader premium $\pi_{\ell jt}$. The problem of a research firm is therefore:

$$\max_{v_{njt}\geq 0} \pi^q_{njt}(v_{njt}, \boldsymbol{v}_{-njt}; N_{jt}) = h_{njt}(v_{njt}, \boldsymbol{v}_{-njt}; N_{jt})\mathbb{E}_z\left[\pi^*_{\ell jt}(z)\right] - W_t\left(x^{\theta-1}_{j,t-1}v_{njt} + x^{\theta-1}_{j,t-1}\phi^q\right), \quad (4)$$

   where ϕ^q is the fixed cost of doing research. The number of research firms N^*_{jt} in equilibrium will be determined by the free entry condition.

2. **Innovation on productivity by industry leaders**. If a research firm manages to draw a quality ladder in the first stage, it will become the industry leader in period t and its type $z_{\ell jt}$ will be realized. The leader can make productivity investment prior to the entry of all the followers. The leader's problem can therefore be written as:

$$\pi^{a,*}_{\ell jt}(z_{\ell jt}) = \max_{a_{\ell jt}}\left\{\pi_{\ell jt}\left(a_{\ell jt}, a^*_{fjt}\left(a_{\ell jt}\right), I^*_{jt}\left(a_{\ell jt}\right)\right) - W_t l^a_{\ell jt}(a_{\ell jt}, z_{\ell jt})\right\}, \quad (5)$$

   where $a^*_{fjt}(\cdot)$ is the best response from the followers and $I^*_{jt}(\cdot)$ the resulting number of followers. The fact that a leader takes the reaction of followers into account highlights its first-mover advantage. With a slight abuse of notations, we refer $a_{\ell jt} = 0$ to those markets without a leader.

3. **Innovation on productivity by followers**. Given the (in)existence of an industry leader and its productivity $a_{\ell jt}$, identical followers enter the market by choosing a productivity level a_{fjt}. Conditional on the number of followers I_{jt}, the symmetric investment decision is given by the following fixed point problem:

$$a^*_{fjt}(a_{\ell jt}, I_{jt}) = \arg\max_{a_{djt}}\left\{\pi_{djt}\left(a_{djt}, a^*_{fjt}; a_{\ell jt}, I_{jt}\right) - W_t l^a_{fjt}(a_{djt})\right\}, \quad (6)$$

   where the subscript d denotes a "deviator" who should not want to deviate from the optimal choice $a^*_{fjt}(a_{\ell jt}, I_{jt})$. The number of followers $I^*_{jt}(a_{\ell jt})$ will then be determined by free entry, i.e., the biggest integer that sustains non-negative follower profits.

4. **Cournot competition on output market**. Given the productivity sequence $\left\{a^*_{\ell jt}, a^*_{fjt}, I^*_{jt}\right\}$ and

Table 1: Summary of the model variables

	Name	Meaning	Name	Meaning
ENVIRONMENT	t	Index for time	j	Index for industry
	n	Index for innovating firm	i	Index for production firm
	ℓ	Index for leader	f	Index for follower
	$\overline{L}$	Labor supply	β	Discount factor
	W_t	Wage	Π_t	Profit
	g_t	Growth rate	g_{jt}	Industrial growth rate
	$\mathcal{U}$	Social welfare		
QUALITY INNOV.	q_{jt}	Industrial quality	$\overline{q}_t$	Aggregate quality
	x_{jt}	Industrial relative quality	N_{jt}	Number of quality innovators
	λ	Quality ladder	v_{njt}	Research intensity
	v_0	DRS in research	l^q_{ijt}	Quality labor
	h_{njt}	Probability of quality ladder	H_{jt}	Probability of industrial growth
	ϕ^q	Fixed cost of quality research	π^q_{njt}	Profit of quality research firm
PRODUCTIVITY INNOV.	I_{jt}	Number of producing firms	l^a_{ijt}	Productivity labor
	z_{ijt}	Firm efficiency type	γ	Productivity innov. curvature
	a_{ijt}	Productivity	π^a	Profit of productivity innov. firm
PRODUCTION	C_t	Consumption on final goods	c_{jt}	Consumption on each industry
	c_{ijt}	Consumption on each good	l^p_{ijt}	Production labor
	θ	Elasticity of sub. across industry	η_j	Elasticity of sub. within industry
	p_{jt}	Price of industry good	p_{ijt}	Price of each good
	π_{ijt}	Profit of production firm	s_{ijt}	Market share
	μ_{ijt}	Markup		

quality $\{q_{jt}\}$, firms compete in each industry through output:

$$\pi_{ijt} = \max_{l_{ijt}} \left\{ p_{ijt} \left(a_{ijt} l^p_{ijt} \right) - W_t l^p_{ijt} \right\}, \ \forall i \in \{\ell, f, d\}, \tag{7}$$

subject to demand function from household optimality, where p_{ijt} and l^p_{ijt} denote prices and production employment, respectively. We implicitly assume a linear production technology with labor as the only input.

2.2 Balanced growth path

For our main analysis, we focus on the balanced growth path where all the aggregate outcomes $\{\overline{q}^*_t, W^*_t, C^*_t, \Pi^*_t\}$ grow at a constant rate g, which will be endogenously determined by the quality innovation process. We summarize the outcomes along the BGP and their rationales in Table 2.

Despite the constant growth of average quality, the distribution of relative qualities $\{x_{jt}\}$ remains stationary over time. Let $H_{jt} \equiv N_{jt} h_{njt}$ be the likelihood of industry j drawing a quality ladder at time t, which depends only on industry-level states $x_{j,t-1}$ and η_j along the BGP. We can write the law

Table 2: Definition: Balanced growth path

Variables	Rationales
Consumptions $\{c_{\ell jt}, c_{fjt}\}$	Households optimality (1) given prices and income
Research $\{v^*_{jt}\}$ and firms number $\{N^*_{jt}\}$	Research firm optimality (4) and free entry condition
Leader's productivity $\{a^*_{\ell jt}\}$	Leader optimality (5)
Followers' productivity $\{a^*_{fjt}\}$ and number $\{I^*_{jt}\}$	Follower optimality (6) and free entry
Production $\{y^*_{\ell jt}, y^*_{fjt}\}$	Production firm optimality (7) given productivities
Prices $\{p^*_{\ell jt}, p^*_{fjt}\}$	Goods market clearing $c^*_{ijt} = y^*_{ijt}$
Wage $\{W^*_t\}$	Labor market clearing $\overline{L} = L^{p,*} + L^{q,*} + L^{a,*}$
Relative quality $\{x^*_{jt}\}$	Stationary over time with law of motion (8)
Aggregate outcomes $\{\overline{q}^*_t, W^*_t, C^*_t, \Pi^*_t\}$	Grow at same speed g given by (9)

of motion for the relative quality as:

$$x_{j,t} = x_{j,t-1} \cdot \frac{1 + \mathbb{1}\{\text{get } \lambda\}\lambda}{1+g} \quad , \quad \text{where } \Pr\{\text{get } \lambda\} = H_{jt}. \tag{8}$$

The industry-level expected growth rate can therefore be defined as $g_{jt} \equiv H_{jt}\lambda$, which can further be aggregated into the overall growth rate g_t:

$$g_t = \frac{\overline{q}_t}{\overline{q}_{t-1}} = \int_0^1 \left(g_{jt} x_{j,t-1}\right) \, \mathrm{d}j, \tag{9}$$

where the relative qualities are the weights that measure how big each quality ladder is relative to the overall technology.

2.3 Solution

Although the model does not yield analytical solutions, we are still able to study its key features by characterizing optimality conditions at each stage of actions. Step-by-step derivations for the results in this section are documented in A.1. We also provide numerical algorithms for computing the balanced growth path and transition dynamics in Appendix A.3.

Household solution. We have a standard household problem (1) with nested-CES preference (2) that characterizes the demand system. The demand for goods produced by firm $i \in \{\ell, f\}$ in industry j at time t is:

$$c_{ijt} = x_{jt}^{\theta-1} \left(\frac{p_{ijt}}{p_{jt}}\right)^{-\eta_j} \left(\frac{p_{jt}}{P_t}\right)^{-\theta} \overline{q}_t^{\theta-1} C_t. \tag{10}$$

The usual CES price indexes are defined as:

$$p_{jt} = \left(\mathbb{1}\{a_{\ell jt} > 0\} p_{\ell j}^{1-\eta} + I_{jt} p_{fjt}^{1-\eta}\right)^{\frac{1}{1-\eta}} \quad \text{and} \quad P_t = \overline{q}_t \left[\int_0^1 \left(x_{jt}^{\theta-1} p_{jt}^{1-\theta}\right) dj\right]^{\frac{1}{1-\theta}} = 1, \tag{11}$$

where $\mathbb{1}\{a_{\ell jt} > 0\}$ is an indicator for the existence of a leader.

Production optimality and the output market. We analyze the firm problem backwards and start with characterizing the output market given the distribution of market structure $\{I_{jt}\}$ and productivities $\{a_{\ell jt}, a_{fjt}\}$. The first order condition of problem (7) yields:

$$\frac{p_{ijt}}{\mu_{ijt}} = \frac{W_t}{a_{ijt}}, \quad \text{where } \mu_{ijt} = \left(1 + \frac{\mathrm{d}p_{ijt}}{\mathrm{d}y_{ijt}} \frac{y_{ijt}}{p_{ijt}}\right)^{-1} = \left[1 - \frac{1}{\theta} s_{ijt} - \frac{1}{\eta_j}(1 - s_{ijt})\right]^{-1}. \tag{12}$$

At optimality, the marginal revenue p_{ijt}/μ_{ijt} equates the marginal cost W_t/a_{ijt} of producing one unit of goods. The markup μ_{ijt} is the inverse of demand elasticity that has a one-to-one mapping to the within-industry sales shares s_{ijt} under the nested-CES structure. It is determined by the elasticity of substitution within and between markets weighted by sales shares. For example, only the cross-market elasticity matters for a monopolist because it has no competitors in its market. In contrast, a small business has to face strong competition within its market, hence the within-market elasticity η determines its markup. Therefore, markup is an informative statistic that captures how intense the competition is faced by firms.

Furthermore, the output market clearing condition, the demand function (10), and the FOC (12) jointly yield:

$$s_{ijt} = \frac{\mathbb{1}\left\{a_{ijt} > 0\right\} \left(\mu_{ijt}/a_{ijt}\right)^{1-\eta_j}}{\mathbb{1}\left\{a_{\ell jt} > 0\right\} \left(\mu_{\ell jt}/a_{\ell jt}\right)^{1-\eta_j} + I_{jt} \left(\mu_{fjt}/a_{fjt}\right)^{1-\eta_j}}. \tag{13}$$

Firms with higher productivities can produce at lower costs and hence take a higher share, which enables them to exert larger markups. Equation (13), joint with the FOC (12), shows that the equilibrium market shares and markups are only determined by the industry-level states $\{a_{\ell jt}, a_{fjt}, I_{jt}\}$. As is mentioned in De Loecker, Eeckhout, and Mongey (2021), the homotheticity of preferences implies that this system of equations is *block recursive* in that it is independent of all aggregate variables and markups can be recovered independently of aggregates.

Using the demand function (10) and the FOC (12), we can characterize profits by the following expression:

$$\frac{\pi_{ijt}}{x_{jt}^{\theta-1} W_t} = \left(\mu_{ijt} - 1\right) \left[\frac{\mathbb{1}\left\{a_{ijt} > 0\right\}}{a_{ijt}} \left(\frac{\mu_{ijt}}{a_{ijt}}\right)^{-\eta_j} \left(\frac{p_{jt}}{W_t}\right)^{\eta_j - \theta}\right] \underbrace{\left[\bar{q}_t^{\theta-1} Y_t \left(\frac{W_t}{P_t}\right)^{-\theta}\right]}_{\psi_t}, \tag{14}$$

where, from equation (11) and (12), we can write p_{jt}/W_t in terms of firm-level markups and productivities:

$$\frac{p_{jt}}{W_t} = \left[\mathbb{1}\left\{a_{ijt} > 0\right\} \left(\frac{\mu_{\ell jt}}{a_{\ell jt}}\right)^{1-\eta_j} + I_j \left(\frac{\mu_{fjt}}{a_{fjt}}\right)^{1-\eta_j}\right]^{\frac{1}{1-\eta_j}}.$$

We express the quality-adjusted production profits in terms of workers, where both x_{jt} and W_t are exogenous for firms. The variable ψ_t defined in equation (14) is the one-dimension sufficient statistic that summarize everything that firms need to know on the aggregate level.

Finally, aggregate variables can be pinned down using market clearing conditions.[12] We highlight

[12]Details and more interpretations on this stage of the game are provided in Appendix A.1.

the solution for wage and output, which are measures of the flow utility. The equilibrium wage is given by:

$$\frac{W_t}{P_t} = \left[\int_0^1 \left(\frac{1}{x_{jt}} \frac{p_{jt}}{W_t} \right)^{\theta-1} dj \right]^{-\frac{1}{\theta-1}} \overline{q}_t, \tag{15}$$

whose level only depends on aggregate quality $\overline{q}_t$ and, moreover, is linear in $\overline{q}_t$. This linearity ensures that real wage grows at the same speed as the quality along the BGP. Given the wage expression, we can write the aggregate output as:

$$Y_t = \left[\int_0^1 x_{jt}^{\theta-1} \left[\frac{\mathbb{1}\left\{a_{\ell jt} > 0\right\}}{\mu_{\ell jt}} \left(\frac{\mu_{\ell jt}}{a_{\ell jt}} \right)^{1-\eta_j} + \frac{I_j}{\mu_{fjt}} \left(\frac{\mu_{fjt}}{a_{fjt}} \right)^{1-\eta_j} \right] \left(\frac{p_{jt}}{W_t} \right)^{\eta_j - \theta} \mathrm{d}j \right]^{-1} \overline{q}_t^{1-\theta} L_t^p \left(\frac{W_t}{P_t} \right)^{\theta}, \tag{16}$$

where $L_t^p := \overline{L} - L_t^q - L_t^a$ is the aggregate employment for the production process. One limitation of our current framework is that there is no aggregate loss directly associated with markups. To see this, think about a mind experiment with $\mu_{\ell jt} = \mu_{fjt} = \mu$ and one can easily validate that aggregate output does not depend on μ. Most literatures find the efficiency loss due to market power is through the general equilibrium effect by reducing aggregate employment (e.g. De Loecker, Eeckhout, and Mongey, 2021), which is absent in our model for constructing a BGP. Therefore, our analysis will likely underestimate the welfare loss due to market power.

Follower entry and productivity investment. We now discuss the entry and the productivity investment problem (6) of industry followers, given the leader's productivity $a_{\ell jt} \geq 0$. Recall that $a_{\ell jt}$ means no leader. First assuming I_{jt} followers enter the industry j at time t, we aim to find a symmetric equilibrium where all the followers choose the same productivity $a^*_{fjt}(I_{jt})$. Consider a deviating firm d who instead chooses a_{dfj} and earns payoff:

$$\pi^a_{djt} = \left(\frac{\pi_{djt}}{x_{jt}^{\theta-1} W_t} - \frac{a_{djt}^{\gamma}}{\gamma} \right) x_{jt}^{\theta-1} W_t.$$

The first order condition for this deviator is therefore:

$$\frac{\partial}{\partial a_{djt}} \left[\frac{\pi_{djt}}{x_{jt}^{\theta-1} W_t} \right] = a_{djt}^{\gamma-1}, \tag{17}$$

where the LHS is the marginal benefit from investment on production profits (14) and the RHS is its marginal cost. The investment at symmetric equilibrium will be the fixed point of this problem, where no firm wants to deviate from the equilibrium choice $a^*_{fjt}(I_{jt})$. We further denote the equilibrium profit as $\pi^{a,*}_{fjt}(I_{jt})$.

Given the subgame outcomes $\pi^{a,*}_{fjt}(I_{jt})$, the equilibrium market structure I^*_{jt} is determined by the free entry condition:

$$I^*_{jt} = \arg\max_{I_{jt}} \left\{ \pi^{a,*}_{fjt}(I_{jt}) > 0 \right\}. \tag{18}$$

In our model, the investment input l^a_{fjt} can be interpreted as the variable entry cost. In an extension,

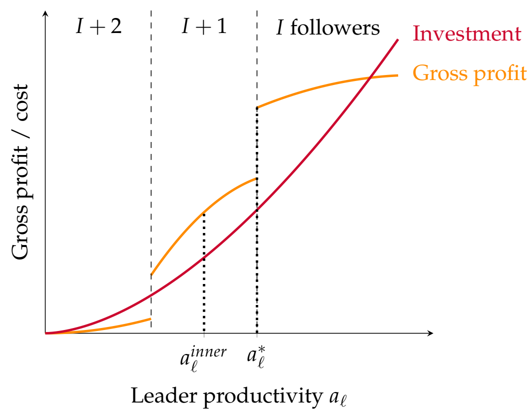

Figure 1: The killer effect in leader's productivity innovation

Notes: We plot the gross profit $\pi_{\ell jt}/x_{jt}^{\theta-1}W_t$ and investment cost $l_{\ell jt}^a$ as function of leader productivity a_ℓ. The gross profit function is discontinuous due to the discrete change in market structure in response to increases in leading productivity. The gap between the two curves indicates the net profit for the leader.

one can introduce a fixed entry cost, which will enter the free entry condition (18) and make entry more restrictive.

Productivity investment by leaders. We then consider the leader's problem (5) with residual type $z_{\ell jt} > 1$. Given the reaction $\{I_{jt}^*(a_{\ell jt}), a_{fjt}^*(a_{\ell jt})\}$, an *interior* solution will be captured by the FOC:

$$\frac{\partial}{\partial a_{\ell jt}}\left[\frac{\pi_{\ell jt}}{x_{jt}^{\theta-1}W_t}\right] + \underbrace{\frac{\mathrm{d}a_{fjt}^*}{\mathrm{d}a_{\ell jt}}\frac{\partial}{\partial a_{fjt}^*}\left[\frac{\pi_{\ell jt}}{x_{jt}^{\theta-1}W_t}\right]}_{\text{Escape-competition effect}} = \frac{1}{z_{\ell jt}}a_{\ell jt}^{\gamma-1}, \tag{19}$$

where the additional term compared to (17) captures the ability of the leader to influence its follower's productivity level. This component is known in the literature as the *escape-competition* effect, where industry leaders invest more to disincentivize the investment made by followers (e.g., Aghion, Harris, Howitt, and Vickers, 2001; Aghion, Bloom, Blundell, Griffith, and Howitt, 2005; Liu, Mian, and Sufi, 2022).

Our contribution is to extend this trade-off to the *extensive* margin, where we introduce a *killer* effect. The idea is that leaders, by investing more on productivity, can manage to deter entry and make larger profits. Because $I_{jt}^*(a_{\ell jt})$ is a step function, this motive will not explicitly show up in the FOC (19), but rather take in charge of the selection of I_{jt} in the background. Leader optimality will therefore be determined by the best choice among all the potential interior solutions and corner outcomes. In Figure 1, we plot the function of both gross profit and investment cost on leader productivity. The gross profit is increasing in the leader's productivity, which is further amplified by the discrete jumps due to successful exclusion of a marginal entrant. The FOC (19) yields an interior solution a_ℓ^{inner}, while the global optimality points to a higher investment level a_ℓ^* that kills one more follower. This particular discrepancy demonstrates the killer effects on the extensive margin.

Research on quality ladder. Finally, we study the decision on quality ladder innovation. The payoff of a successful research is the premium of becoming the industry leader $\pi^*_{\ell jt}$, which is independent from the intensity of research on quality ladder. Given the number of research firm N_{jt}, this separability makes it easy to characterize the optimality of a research firm (4) by the following FOC:

$$\left[\frac{\partial}{\partial v_{njt}} h_{njt}(v_{njt}, v^*_{njt}, N_{jt})\right] \mathbb{E}_{z_\ell}\left[\frac{\pi^a_{\ell jt}}{W_t x^{\theta-1}_{jt}}\right] = \left(\frac{g_t}{\lambda}\right)^{\theta-1}, \tag{20}$$

where the LHS is the expected marginal profit of increasing research and the RHS is the quality-adjusted marginal cost. Since the return of innovation $\partial h/\partial v$ is decreasing, firms will innovate more on quality ladder when the leader premium increases. The symmetric equilibrium is given by the fixed point $v^*_{njt}(N_{jt})$.

The number of research firms will be determined by the free entry condition. Recall that a research firm faces both variable research costs l^q_{njt} and fixed costs ϕ^q. Denoting $\pi^{q,*}_{njt}(N_{jt})$ the net profits of research firms, the equilibrium N^*_{jt} will be the largest number that yields non-negative profits:

$$N^*_{jt} = \arg\max_{N_{jt}} \left\{\pi^{q,*}_{njt}(N_{jt}) > 0\right\}. \tag{21}$$

2.4 Entry and profitability

Motivated by the stylized facts presented in Section **??**, we examine the model prediction about profitability and the number of entrants. Our framework integrates a rich set of cross-industry heterogeneity, which provides an ideal context to study the relationship between entry and profitability. On the demand side, we have different within-industry elasticities of substitution, η_j, which provides an exogenous variation for demand elasticities and therefore markups. On the supply end, different industries have different types of leaders, which induces variations in the leading productivity across different industries.

Holding the leader's productivity fixed, heterogeneity in demand elasticities predicts a positive correlation between profitability and entry rates. When products are less substitutable within an industry (smaller η), firms, particularly the smaller ones like the followers, can in general exert higher markups à la the FOC (12). Higher profit margin will create larger profits and thus attracts more entrants, as is shown in Figure 2a.[13] This mechanism is consistent with the conventional wisdom from Schumpeterian growth theory that higher profits generate more entry.

However, this prediction will be altered when we allow the leader to strategically choose its productivity level according to (5). With higher elasticity of substitution, followers will have lower profit margins according to markup determination (12), which makes it easier for the leaders to strategically kill competition. Hence, the killer innovation effect will generate fewer entry and higher market power when endogenizing the market structure. Our estimation results in Figure 5 confirm with this intuition by showing the market structure is indeed much more concentrated in the markets with

[13] The average markup for incumbents changes discontinuously on the substitution elasticity η because of the discrete change in market structure.

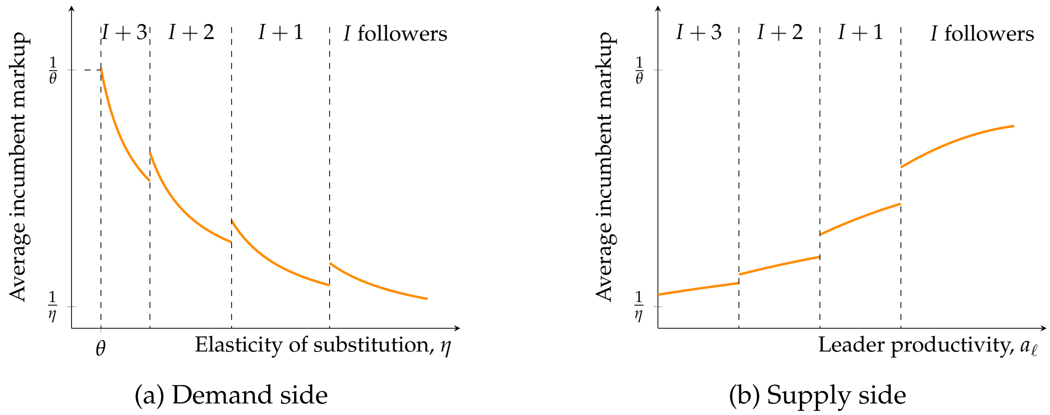

Figure 2: Profit margin and entry

Notes: In panel (a), we show that in general both the number of entrants and the average markup (profit margin) move towards the same direction as the within-industry elasticity of substitution η. In panel (b), we show that the average markup and the number of entrants move with negative correlation when the leader productivity changes. The jumps in markups for both figures are due to the discrete change in market structure. In the extreme of both cases when η or a_ℓ is large enough, there would be no entry and the market ends up being monopoly, which mechanically gives rise to the monopolistic markup $1/\theta$. We omit these extreme cases in our plots.

higher product homogeneity.

On the supply side, fixing the elasticity of substitution η, an increase in leader's productivity will in general raise the average profit margin yet lead to fewer entrants. In this scenario, higher productivity of the leader is a credible threat that deters entry from the followers, which creates higher markups for industry incumbents. We illustrate this point in Figure 2b, where the profit margin of incumbents is increasing in a_ℓ for two reasons. On the intensive margin, higher leading productivity allocates larger market share to higher-markup leaders, which increases incumbent markup through the direct and reallocation effects (De Loecker, Eeckhout, and Unger, 2020; De Loecker, Eeckhout, and Mongey, 2021). On the extensive margin, markups for all incumbent firms will jump discretely when the market structure becomes more concentrated. Both channels connect profitability negatively with the entry of followers.

In summary, our model incorporates both positive and negative correlation between profitability and entry rate, where the causality is reverse. On the demand side, a higher demand elasticity increases profitability and thus motivates entry of followers, which creates a positive correlation. When interact with killer innovation, however, the demand-side model prediction could be altered. On the supply side, a higher type of the industry leader will deter entry and thus increase markups for the incumbents, resulting in the negative correlation between the two components. We therefore conclude that our theory is rich enough to capture the empirical patterns.

2.5 Welfare: dynamic growth vs. static efficiency

Along the balanced growth path, the social welfare can be written as:

$$\mathcal{U}_0^* = \underbrace{\frac{1}{1-\beta g^*}}_{\text{growth}} \underbrace{Y_0^*}_{\text{flow utility}}, \tag{22}$$

where the output level follows equation (16). We can view the total welfare as the product of a dynamic discounting component of growth and a static component of flow utility. As we discussed earlier, one caveat of this framework is that it understates the efficiency loss due to market power. Therefore, we will focus on the welfare effects from quality and productivity innovation.

We first consider the static component of flow utility, through which productivity innovation affects welfare. The static output Y_0^* can be expressed as the sum of profits and labor income:

$$Y_0^* = \int_0^1 \underbrace{\left[\mathbb{1}\{a_{\ell j0>0}\}\pi^a_{\ell j0} + I_{jt}\pi^a_{fj0}\right]}_{\text{Industrial profit, }\Pi^a_{j0}} \mathrm{d}j + \underbrace{W_0\left(L_0^p + L_0^a\right)}_{\text{Labor income}}. \tag{23}$$

Given market structure, the planner solution for productivity innovation satisfies the following first order condition:

$$\underbrace{0 = \frac{\partial}{\partial a_{ij0}}\left[\pi^a_{ij0}\right]}_{\text{Firm opt.}} + \underbrace{\frac{\partial}{\partial a_{ij0}}\left[\Pi^a_{j0} - \pi^a_{ij0}\right]}_{\text{Strategic interaction, }(-)} + \underbrace{\frac{\partial}{\partial a_{ij0}}\left[W_0\left(L_0^p + L_0^a\right)\right]}_{\text{Externality on workers, }(+)}, \quad \forall i \in \{\ell, f\}. \tag{24}$$

However, in a decentralized economy firms only care about their profits when making innovation on productivity, resulting inefficiency due to the externality on other firms and on households. In particular, there are two types of inefficiencies. First, the productivity choice of one firm has direct negative impact on profits of other firms in the same industry through oligopolistic competition, as is termed by "strategic interaction" in Equation (24). Ignoring this negative externality will lead to a prisoner's dilemma with *over*-investment. The second one is a positive externality of productivity innovation on household's labor income, which will increase competitive wage as it is determined by the marginal product of workers. Neglecting this externality will thus result in *under*-investment. Therefore, the competitive level of productivity innovation could be either too high or too low, depending on the trade-off between these two competing mechanisms. The static efficiency of strategic innovation also remains ambiguous, which we study quantitatively in Section 4.

Quality innovation matters for welfare through the growth component, where higher intensity in quality research will contribute to larger growth rate and thus create more outputs in the future. In a decentralized economy, such innovation is incentivized by the expected leader's profit $\mathbb{E}_{z_\ell}[\pi^a_{\ell j0}]$, so the previously discussed channels of static inefficiency in productivity innovation also preserve in quality research. More importantly, potential leaders fail to internalize the *intertemporal* externality on future outputs when they no longer have the leading status. In fact, quality ladder has a long-lasting positive effect on welfare because it becomes the foundation for the next generation of quality improvement, which, when ignored, will cause significant under-investment among quality-innovating firms. In Section 4, we show that the under-investment in quality innovation and the consequent low growth rate will lead to a quantitatively significant welfare cost.

Finally, the welfare specification (22) highlights another trade-off between the two types of innovation. Given the fixed amount of labor, it is qualitatively ambiguous how to best allocate workers workers among the roles of quality innovation, productivity innovation, and production.

In summary, our model incorporates a rich set of mechanisms in welfare determination. In this complex system, we are particularly interested in studying the welfare implications of strategic innovation. Through a series of counterfactual exercises in Section 4, our quantitative analysis aims at understanding whether strategic innovation enhances welfare by correcting part of externalities or harms the economy by creating further distortions.

3 Quantification

3.1 Data

In this section, we describe our data and how we map it to the model. We consider two pre-Covid periods of time, 1980 to 1999 and 2000 to 2019, and assume they are on two different balanced growth paths. We will utilize data variation on growth rates, labor productivity, and markups, which helps in identifying parameters on model stages of quality research, productivity innovation, and imperfect competition, respectively.

We first construct the growth data on both aggregate and industry level. The annual growth rate for the US economy is calculated from annual US GDP from Federal Reserve Economic Data (FRED). We also obtain the growth rate for nearly a hundred industries from year 1987 to 2019 using the value added accounting data from the Bureau of Economic Analysis (BEA).

We exploit micro data on publicly traded firms from Compustat, from which we observe firm-level financial statements including revenues, employment, input expenditure, and industry classifications. We drop the finance, insurance, and real estate sectors (SIC between 6000 and 6799). Labor productivity can be directly computed from observations on revenues and employment. We further estimate markups, which is a commonly used measure for profit margin, using the production approach from De Loecker and Warzynski (2012) and De Loecker, Eeckhout, and Unger (2020). We refer readers to Appendix B.1 for complete data cleaning process.

3.2 Model primitives

We detail the quantitative strategy and results in this section, which combines the approach of calibration and estimation. For model primitives that are not crucial for our main story, we will calibrate those parameters from data or external literature. We will then estimate the key parameters for the two periods of time independently using the Simulated Method of Moments.

Table 3: Externally calibrated parameters

	Meaning	Value	Source
θ	Cross-industry elasticity	1.20	De Loecker, Eeckhout, and Mongey (2021)
η_L	Within-industry elasticity (low)	5.00	Anderson and Van Wincoop (2004)
η_H	Within-industry elasticity (high)	10.00	Anderson and Van Wincoop (2004)
β	Discounting factor	0.96	Real interest rate 4% per annum
λ	Quality ladder (%)	6.63	Average growth rate of growing industries (BEA)

Calibration. Table 3 summarizes the calibrated parameters, most of which is on the demand side as we mainly focus on the strategic interaction on the supply side. We first take the cross-industry elasticity of substitutes θ from De Loecker, Eeckhout, and Mongey (2021), who quantify the oligopolistic model within the same nested-CES utility framework. We also simplify the distribution of the within-industry elasticity η_j using a Bernoulli distribution, where we calibrate the two values, η_H and η_L, from a survey carried by Anderson and Van Wincoop (2004), and will endogenously estimate the probability of taking the high value, ρ, to track the change on the demand elasticity over time. The discount factor β is calibrated to 0.96 by the real interest rate.

On the supply side, we calibrate the quality ladder λ by the average growth rate of the growing industries in BEA sample from 1987 to 2019. As growth is driven by quality progress on the industry level, the industrial growth rate becomes a direct measure of quality ladder. Moreover, the aggregate model outcomes are isomorphic between a larger λ and a higher probability of drawing λ, so calibrating this quality ladder allows us to identify the process of quality research from the data moments on aggregate growth.

Estimation. We estimate five parameters, $\boldsymbol{\vartheta} = \{\phi^q, v_0, \gamma, \alpha_z, \rho\}$, by the Simulated Method of Moments. For each time period, we identify the endogenous parameters by minimizing the following objective function:

$$\widehat{\boldsymbol{\vartheta}} = \min_{\boldsymbol{\vartheta}} \left\{ \left(\widehat{\boldsymbol{M}} - \boldsymbol{M}(\boldsymbol{\vartheta})\right)' \boldsymbol{W}^{-1} \left(\widehat{\boldsymbol{M}} - \boldsymbol{M}(\boldsymbol{\vartheta})\right) \right\},$$

where $\boldsymbol{M}$ is the vector of targeted moments in the model and $\widehat{\boldsymbol{M}}$ is the corresponding vector of moments in the data.[14] The results are reported in Table 4. We classify the set of endogenous parameters $\boldsymbol{\vartheta}$ into three categories and discuss the identification strategy and results accordingly. In Appendix C.1, we provide further details rationalizing our identification.

Parameters $\{\phi^q, v_0\}$ are in charge of the innovation process on quality ladder. Fixed cost ϕ^q can be identified from the aggregate growth rate because it directly controls the number of research firms on quality ladder. The parameter v_0 captures the level of decreasing return to scale of research outcome, which will affect the stationary distribution of quality across industries. We therefore utilize the standard deviation of revenue per worker (LPR) by industry to identify it, where the industry in data is defined as three-digit NAICS code. Our estimation shows a big decline in fixed cost of doing research from 0.27 to 0.01, while the degree of decreasing return to scale v_0 has been increasing

[14] We will have equal number of targeted moments and parameters, so the choice of weighing matrix $\boldsymbol{W}$ is not crucial for our estimation strategy.

Table 4: Endogenously estimated parameters

	Meaning	Moment	1980-1999			2000-2019		
			Value	Moment		Value	Moment	
				Data	Model		Data	Model
ϕ^q	Fixed cost of research	GDP growth rate (%)	0.27	3.16	3.06	0.01	1.93	2.06
v_0	DRS in research outcome	St.D. log lpr by industry	0.05	0.54	0.51	0.30	0.63	0.59
γ	Investment curvature	Diff. log lpr, p90 - p75	3.00	0.47	0.45	2.69	0.57	0.58
α_z	Shape for Pareto residual z_ℓ	Markup p90	0.20	2.45	2.51	0.33	3.07	2.96
ρ	Fraction of high-η industry	Average markup, < p75	0.41	1.35	1.40	0.81	1.44	1.48

drastically from 0.05 to 0.30. We conclude that it is easier to start a research on quality ladder, but in the meantime ideas are getting harder to find (Bloom, Jones, Van Reenen, and Webb, 2020).

Endogenous parameters $\{\gamma, \alpha_z\}$ capture the stage of productivity innovation. First, the curvature of investment function γ influences the intensity of competition. In particular, the smaller γ is, the easier it would be for industrial leaders to build up first mover advantage, based on which we identify γ by targeting the difference between 90th and 75th percentile of LPR distribution. Next, recall that leader type z_ℓ is introduced as a structural residual to capture the whole advantage leaders have in the data, which by assumption follows a Pareto distribution with scale parameter normalized to 1. We estimate the shape parameter α_z by the 90th percentile of markup distribution. We find that the investment cost function becomes less convex, marked by a decline in γ from 3.00 to 2.69, which leads to a greater competitive advantage for the leaders. Meanwhile, α_z is estimated to increase from 0.20 to 0.33, meaning z_ℓ gets much more concentrated to 1 during year 2000-2019. This result indicates that our mechanism of strategic innovation plays a major role in determining the premium of industrial leader most recently.

Finally, we use the fraction of high-η industries, ρ, to capture the changes in the substitutability of goods in the same industry. As is shown in the first order condition (12), the within-industry elasticity η has a larger impact on the markup of the smaller firms, i.e., the industry followers. We therefore use the average markup among small firms, which are defined as the ones with markups below the third quartile, to identify parameter ρ. Our results document a sharp increase from 0.41 to 0.81, meaning that products are becoming more homogenous within each industry over time.

3.3 Profit margin and entry

We analyze the relationship between profitability and entry in our estimated economies. We will study the entry on both stages of quality and productivity innovation. The discussion in this section highlights the importance of distinguishing these two types of innovation.

Leader profitability and entry into quality innovation. On quality ladder, the incentive for candidates to innovate comes from the excessive profits guaranteed by becoming the leader. Therefore, consistent with the standard Schumpeterian growth theory, higher leader profitability will attract

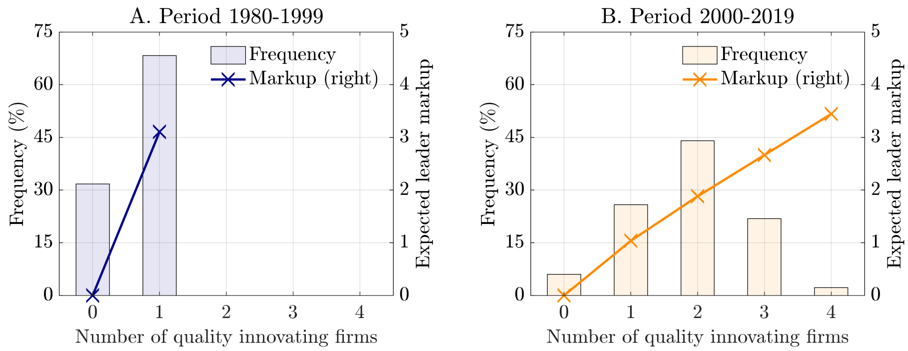

Figure 3: Entry into quality innovation and the expected leader's markup

Notes: This figure consists of two panels, which correspond to the two periods of time in our study. For a given integer from the x-axis, the barplot, corresponding to the left y-axis, represents for the percentage frequency of industries that has this number of firms making quality ladder innovation. The line with cross mark indicates the average realized markup of leaders in each type of the industry, which corresponds to the right y-axis. The expected leader markup is set to zero for industries with no quality innovation because no firm becomes the leader.

more entrants making quality innovation.

In Figure 3, we plot the estimated distribution by markets for the number of firms innovating on quality ladder as well as the corresponding expected markup of being a leader. For both periods of time, the results suggest a perfectly positive correlation between leader's expected markup and the number of entrants making innovation on quality. Furthermore, by comparing the two panels, we document a trend where more firms are working on quality improvement in 2000-2019 than 1980-1999. There are two reasons accounting for this change. First, the fixed cost of starting a quality research firm, ϕ^q, is estimated to be declining. Second, higher markup of becoming a leader further incentivize more firms to make quality ladder innovation. Nevertheless, due to the larger decreasing to scale in quality innovation, v_0, the probability of successfully reaching a quality ladder becomes smaller, which corresponds to a lower growth rate since 2000s.

Incumbent profitability and entry in product market. The relationship between profit margin and entry on the product market is much more complicated. As we discussed earlier, depending on whether the profitability comes from the demand or supply side, higher profit margin for incumbents can either result *in* more entry or result *from* fewer entry. In this part, we only study the superficial patterns of correlation from our estimated models. We will investigate deeper into each channel through the lens of counterfactuals in Section 4.

Figure 4 shows the correlation between market structure and average markup in product markets for both time periods. In general, markup is declining over the number of firms per market (with one exception when a market has four firms during 2000 to 2019), which suggests that the mechanism on the supply side dominates the demand one. That is, higher profit margin is an outcome of strategic productivity innovation made by the leaders that deter follower entry. This argument is further supported by the observation that fringe markets are the ones with the lowest markups. On the other hand, as a sanity check, our estimation results yield an increase in product market concentration despite of a larger fraction of fringe markets, which is consistent with the findings from the litera-

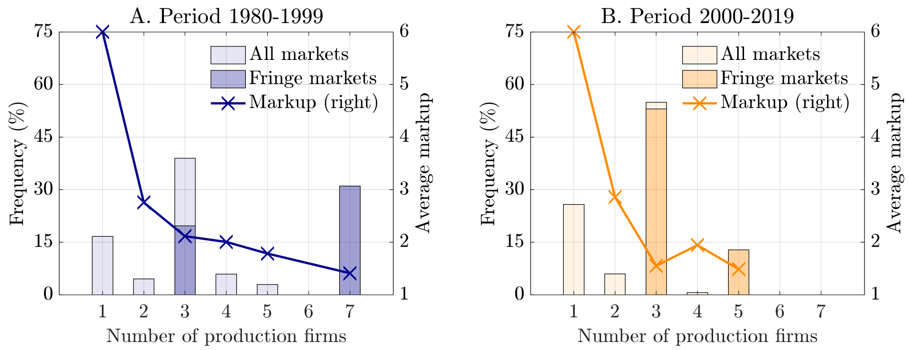

Figure 4: Entry into product competition and the incumbent markup

Notes: This figure consists of two panels, which correspond to the two periods of time in our study. For a given integer from the x-axis, the barplot, corresponding to the left y-axis, represents for the percentage frequency of product markets that has this number of firms making innovation on productivity. The fraction of fringe markets, i.e., markets without a leader, is represented by deeper color in the bars. On the right y-axis, the line with cross mark indicates the average markup in each type of the market.

ture on increasing market concentration (e.g., Autor, Dorn, Katz, Patterson, and Van Reenen, 2020; De Loecker, Eeckhout, and Unger, 2020).

We further examine the strategic innovation on the extensive margin. In Figure 5, we plot the leader's decision rule on productivity innovation and the resulting product market structure conditional on within-market elasticity of substitution η. The most prominent feature of the decision rule is its discontinuity, which corresponds to the corner solution and is followed by a plateau (the shaded areas) where the productivity decision remains constant. We further term these corner solutions as *killer innovation*, where the productivity level is chosen to exclude the marginal follower from the product market, as is suggested by the discrete jump in the number of followers. The prevalence of this killer innovation that leads to fewer entrants and larger market power further rationalizes the negative correlation between markup and the number of firms in the product market.

Finally, by cross-sectional comparison, we find that a market with more substitutable products (higher η) is more likely to have a concentrated market structure and provides convenience for the leader to kill competition. This observation highlights the importance of interaction between preferences and strategic innovation, where the leader's first-mover advantage is amplified by higher substitutability among goods in the same market. In an extreme case with homogenous goods, entry becomes least profitable for followers as they will find it hard to gain market share by distinguishing their products from the leader's. Therefore, through this interaction the mechanism on the demand side also gives rise to the negative correlation between profitability and entry.

4 Counterfactuals

In this section, we study the strategic innovation, especially on the extensive margin, and its welfare implications through a sequence of counterfactuals. We first decompose the change of markups and market structure by sequentially feeding in changes in parameters in Section 4.1. In Section 4.2, we study the partial equilibrium effects of strategic innovation by exogenously fixing the product

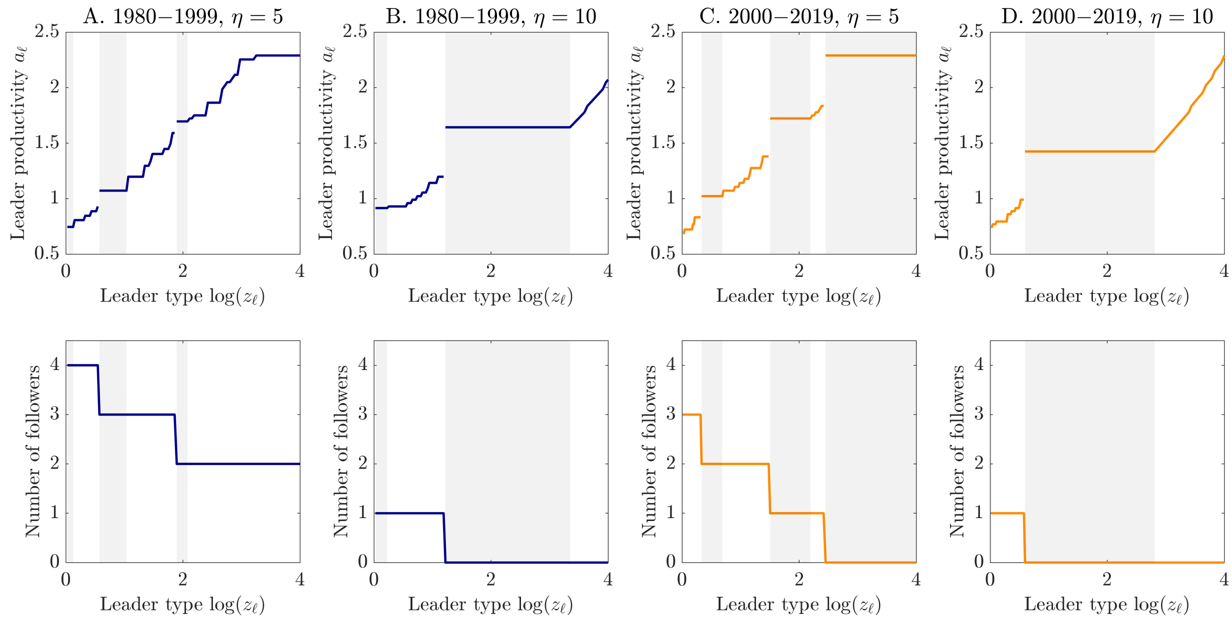

Figure 5: Strategic innovation from leaders to deter entry

Notes: Each column of the figure shows the leader's decision rule on productivity (first row) and the resulting number of followers in product market (second row) conditional on estimators and the within-market elasticity of substitution η. The decision rule is a step function because we took grids over the productivity space in the numerical solution. The shaded areas correspond to the corner solution of the leader's problem where the productivity is chosen to the point which just excludes a marginal follower. The upper bound we set for the productivity space is 2.29, which will be reached when the leader type is big enough.

market structure. We further study in Section 4.3 the welfare effect of strategic innovation in a general equilibrium setup where firms make productivity innovation simultaneously.

4.1 Decompose changes over time

We first study our motivation facts, i.e., higher profit margin and fewer entry in the goods market, by a decomposition exercise which sequentially feeds estimated parameters for the period 2000-2019 into the initial economy for 1980-1999. We aim at understanding the primary reasons for this secular trend and studying the consequent welfare effects.

The counterfactual results are reported in Table 5. Starting from the baseline economy in 1980-1999, we first feed in the changes in quality innovation $\{\phi^q, v_0\}$, which corresponds to a decline in fixed cost ϕ^q and a higher level of decreasing return to scale v_0. In general, ideas are getting harder to find after this change, as is suggested by the decline in growth rate from 3.06% to 1.89%. A direct consequence is an increase in the fraction of fringe markets without a leader, which further leads to lower average markup (decline by 8.30%) and more entry from followers (increase by 19.26%). On efficiency, we observe an increase in static output by 6.97% due to smaller market power, but the overall welfare declines sharply by 47.97%, indicating a dominating status of dynamic growth in the welfare trade-off (22).

We then feed in the decline in the curvature of productivity innovation γ. Recall that a less convex cost function amplifies the leader's first-mover advantage, which simultaneously deter entry and

Table 5: Decomposition of changes over time

Fed-in parameters	Outcomes				
	Markup	# Entrants	Growth (%)	Output*	Welfare*
Baseline economy: 1980-1999	**1.78**	**3.49**	**3.06**	**0.47**	**44.46**
+ quality innovation $\{\phi^q, v_0\}$	1.63	4.16	1.89	0.51	23.13
	[-8.30%]	[19.26%]	[-38.29%]	[6.97%]	[-47.97%]
+ productivity innovation $\{\phi^q, v_0, \gamma\}$	1.97	2.68	2.47	0.44	26.88
	[10.93%]	[-23.00%]	[-19.26%]	[-7.42%]	[-39.54%]
+ substitutability $\{\phi^q, v_0, \gamma, \rho\}$	2.24	1.98	2.74	0.40	29.47
	[25.92%]	[-43.28%]	[-10.25%]	[-14.97%]	[-33.71%]
New economy: 2000-2019 $\{\phi^q, v_0, \gamma, \rho, \alpha_z\}$	**1.98**	**2.35**	**2.06**	**0.42**	**20.53**
	[11.24%]	**[-32.72%]**	**[-32.72%]**	**[-12.22%]**	**[-53.82%]**

Notes: In this exercise, we start from the estimated baseline economy during the period 1980-1999 and sequentially feed in the changes in parameters for quality innovation $\{\phi^q, v_0\}$, productivity innovation $\{\gamma\}$, and product substitutability $\{\rho\}$. We compute the outcomes including average markup, average number of followers, growth rate, aggregate output, and welfare. We also report their percentage changes from the baseline moments in the bracket. The output and welfare are computed by normalizing the time zero aggregate quality $\bar{q}_0 = 1$ for each counterfactual economy.

create a larger profit margin. Aligned with the theory, our counterfactual table shows a 10.93% increase in the average markup and a 23.00% decline in the number of entrants, altering the opposite effects due to greater difficulty in quality innovation. As a result, the static output declines by 7.42%, while the growth rate is still 19.26% lower than the baseline economy, which jointly causes a 39.54% decline in total welfare.

Next, we introduce the change in substitutability parameter ρ, generating more markets with high elasticity of substitution η. This change, through the interaction with strategic innovation as is previously shown in Figure 5, makes it easier for leaders to kill competition, which results in even larger market power (25.92% higher than the baseline) and fewer number of entrants (43.28% fewer than the baseline). Compared to the previous counterfactual case, growth rate is higher while the static output is lower, which contributes to slightly larger welfare but is still 33.71% lower than the baseline economy.

Finally, the ended-up counterfactual economy has too high markups and growth rate compared to the real data, so we adapt the change in structural residual, or the leader type, α_z, which leads to the estimated economy for period 2000-2019. Overall, average markup has increased by 11.24% while the entry decreased by 32.72%, consistent with our empirical findings. According to the decomposition exercise, we conclude that this pattern can be explained by less curvature in productivity innovation and larger homogeneity among goods within a market. On the other hand, the lower growth rate due to changes in quality innovation is responsible for most of the welfare loss.

4.2 Strategic productivity innovation in partial equilibrium

We now study the consequences of strategic innovation on productivity by two counterfactual worlds. First, we consider the leader's policy rule on productivity innovation when facing exogenous entry

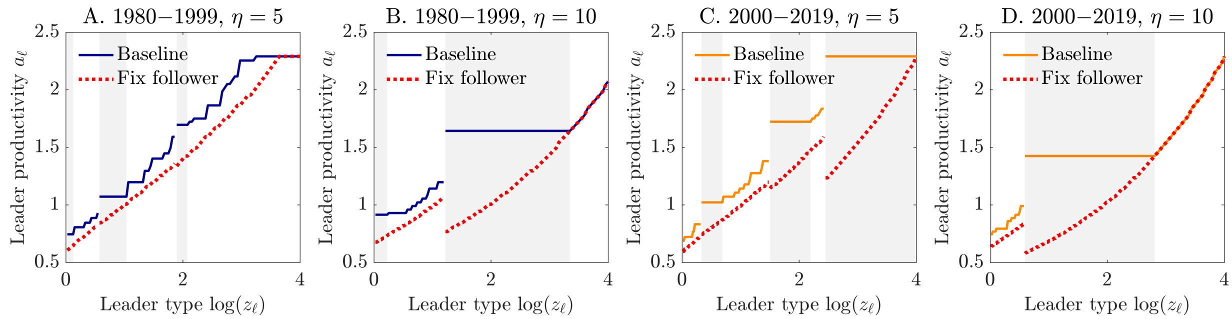

Figure 6: Leader's productivity decision given exogenous followers

Notes: The figure is constructed over the first row of Figure 5, where we take the baseline productivity schedule and add its counterpart from the counterfactual economies, marked as the red and dotted line. The shaded areas indicate the corner productivity solution in the baseline economy, which we term as "killer innovation". The discrete jumps in both curves correspond to the discrete changes in market structure.

and productivity decisions from followers in a partial equilibrium setup, which allows to speak to the distributional effects of strategic innovation. We manage to shut down the strategic innovation by exogenously fixing follower decisions on entry and productivity at their equilibrium value $I^*(\eta, z)$ and $a_f^*(\eta, z)$, conditional on market states (η, z). We study the leader's productivity decision in a *partial equilibrium* holding constant the economy-wide aggregator ψ^*, which is reported as the red, dotted curve in Figure 6.

We find that leaders are incentivized to *over*-invest in productivity to escape competition, through both the intensive and extensive margin, which shows in the counterfactual level of productivity that is lower than its baseline value. On the intensive margin (non-shaded areas in Figure 6), both baseline and counterfactual productivities increase with leader type, but there is always a sizable gap in between, illuminating the incentive for the leaders to crowd out productivity innovation made by the followers.[15] On the extensive margin (the shaded area), the baseline productivity is at a flat corner solution, while leaders in the counterfactual economy without the killer motive will increase their productivity when innovation gets more efficient.[16]

Nevertheless, the welfare effect of this over-investment is ambiguous. First, we need a general equilibrium framework to study its influence on quality innovation, and thus, growth. And second, even for the static efficiency, the sign of welfare implication will depend on the trade-off between the relative scale of externalities on the supply and demand side, as is previously discussed in Section 2.5. We will therefore study the aggregate effects with the second counterfactual featuring the general equilibrium effect.

4.3 Strategic productivity innovation in general equilibrium

To study the aggregate impact of strategic innovation on productivity, we consider a second counterfactual economy where leaders make innovation on productivity simultaneously with the followers.

[15]One exception is under monopolistic competition, where the interior productivity solutions for baseline and counterfactual economies are identical. This is, however, a trivial result because there is no strategic interaction in productivity innovation when no follower enters.

[16]The counterfactual productivity schedule is discontinuous because of the discrete jump in the market structure.

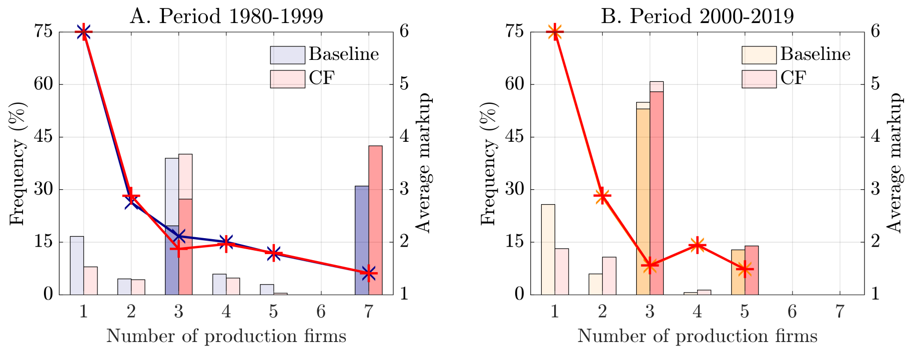

Figure 7: Product market entry and market power with simultaneous productivity innovation

Notes: We took the baseline plot for the two periods of time from Figure 4 and add the counterfactual results that are represented in red. The bars refer to the left y-axis, meaning the frequency of markets with each number of firms, while the darker ones refer to the fringe markets without leaders. Corresponding to the right y-axis, the curves with cross and plus marker represent the average markup for the baseline and counterfactual cases, respectively.

Without being able to commit to a high level of productivity, leaders lose their ability to manipulate followers' entry and innovation decisions. We will therefore compare the aggregate outcomes in this counterfactual world with the baseline economy to study how strategic innovation influences the welfare trade-off between dynamic growth and static efficiency.

In such a counterfactual, the leader's excessive profit margin comes from its potentially higher type, which is smaller than the baseline case with an extra first mover advantage from strategic innovation. This intuition can be seen from Figure 7, where we plot the product market structure and the corresponding average markups for both baseline and counterfactual economies. Even though the markups conditional on market structure are similar in both cases, a more competitive market structure arises on the extensive margin because leaders can no longer commit to deter entry. As is further reported in Table 6, more competitive product markets lead to more entry (increase by 12%-22%), lower market power (decline by 10%) and higher static efficiency (increase by 7%) in the counterfactual economy, whose scales are consistent over time.

However, the decline in market power due to the exclusion of strategic innovation may backfire on growth through the general equilibrium channel. When the reward from being a leader declines, quality-innovating firms are less willing to make investment, resulting in a lower growth rate. Our counterfactual study shows that, if productivity were made simultaneously, the level of growth rate will drop by 1.28% and 0.40% for the periods 1980-1999 and 2000-2019, respectively. This pushback in growth turns out to be big enough to alter the welfare gains from static efficiency, as the aggregate welfare will respectively decline by 51.17% and 9.74% for the two periods.

Notably, the trends suggest that strategic innovation plays a more positive role during the period of 1980-1999 than 2000-2019. While its negative effects on higher market power have a similar level, strategic innovation contributes to 41.83% of growth in earlier years but only 19.42% most recently. This change highlights the increasingly important welfare effects from the rise of market power. Note that our framework will likely underestimate the static inefficiency due to market power since we have to fix labor supply to keep a balanced growth, while a sizable loss due to market power has been shown through the general equilibrium effect on labor market when labor supply is instead

Table 6: Aggregate effect of strategic innovation: comparison with simultaneous move

Period of time	Outcomes				
	Markup	# Entrants	Growth (%)	Output*	Welfare*
1980-1999					
Baseline	1.78	3.49	3.06	0.47	44.46
Simultaneous productivity innovation	1.60	4.25	1.78	0.50	21.71
	[-10.11%]	[21.78%]	[-41.83%]	[6.38%]	[-51.17%]
2000-2019					
Baseline	1.98	2.35	2.06	0.42	20.53
Simultaneous productivity innovation	1.77	2.64	1.66	0.45	18.53
	[-10.61%]	[12.34%]	[-19.42%]	[7.14%]	[-9.74%]

Notes: For the baseline and counterfactual economies at both periods of time, we compute the outcomes including average markup, average number of followers, growth rate, aggregate output, and welfare. We also report their percentage changes from the baseline moments in the bracket. The output and welfare are computed by normalizing the time zero aggregate quality $\bar{q}_0 = 1$ for each counterfactual economy.

elastic (De Loecker, Eeckhout, and Mongey, 2021; Deb, Eeckhout, Patel, and Warren, 2022, 2023).

5 Conclusion

The rise of superstar firms and the dominant position of a handful of firms has enormous implications economy-wide. In this paper, we build on Sutton (1991, 2001)'s view that a firm's productivity and hence its dominant position is endogenous and the result of investment in innovation. Most importantly, when firms operate in oligopolistic markets, they invest strategically to affect other firms' behaviors and the market structure. The ex ante ambiguous, we find that dominant firms over-invest in innovation in order to keep competitors out, and to increase the productivity gap with followers. Both lead to dominant firms having higher market shares, higher profits and larger sizes. In other words, the firm size distribution is excessively skewed towards large dominant firms.

This strategic innovation on productivity has far-reaching macroeconomic implications. The resulting market concentration will lead to static inefficiency, but in the meantime it creates extra incentive for quality innovation and thus drives growth. Our quantitative analysis shows that strategic productivity innovation has a positive effects on social welfare.

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