Killer Innovation:

The Macroeconomic Implications of Strategic Investment that affects Market Structure*

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– PRELIMINARY AND INCOMPLETE –

Abstract

We propose a theory of innovation where incumbent firms strategically invest excessively in innovation to deter entry and reduce competition. In our quantitative exercise we find that the phenomenon of killer innovation becomes pervasive during the 2000s and remains at a high level until now. We also identify a large efficiency loss from the resulting market power due to killer innovation, in excess of 15% of aggregate output in 2019. Large firms over-invest and small firms under-invest or do not enter the market. Finally, we investigate a set of counterfactual policies and find that a 10% profit tax on incumbents can enhance social welfare by 5.3% in 2019, while a 10% entry subsidy leads to inefficient innovation entrants that harms the economy.

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

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1 Introduction

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 this as *Killer innovation*, which occurs when dominant firms use strategic investment in innovation to affect the market structure and stymie entry and/or innovation by competitors. In this paper we investigate the macroeconomic implications of such strategic innovation. Since the 1980s, there has been a decline in business dynamism with fewer startups and declining labor reallocation which has implications for innovation and welfare (e.g., Decker, Haltiwanger, Jarmin, and Miranda, 2016). Our objective is to model strategic firm innovation and quantify the economy-wide impact and welfare implications between 1980 and today. We find that killer innovation has become prevalent during the 2000s and has remained so until today. Large firms over-invest and small firms under-invest or do not enter the market at all. Superstar firms are inefficiently large. Our quantitative results attribute a large welfare cost to killer innovations, that are increasing over time with a welfare cost in excess of 15% of GDP today.

We introduce strategic interaction – both in innovation and in production – between dominant firms and potential entrants in a Suttonian setting where investment increases firm productivity. Like in Schumpeterian models of creative destruction, innovation increases productivity, but the main difference here is strategic interaction in production.[1] Innovation that increases productivity by the incumbent firms who have the power to credibly innovate before the entrants enter has an effect on the intensive as well as on the extensive margin: 1. On the intensive margin, more innovation by the leader relative to followers leads to a larger gap in productivity. Under oligopolistic competition this leads to an increase in market power as the dominant firm obtains a higher market share, higher profits and a higher markup, thus increasing the average markup. 2. On the extensive margin, more innovation by the leader may lead to a decline in the number of entering firms. Because more investment 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.[2]

[1] In the benchmark model of Schumpeterian innovation (e.g., Grossman and Helpman, 1991; Aghion and Howitt, 1992), there is monopolistic competition without strategic interaction in production between firms within a market. Our model of oligopolistic competition subsumes the case of monopolistic competition. On the other hand, the literature on Schumpeterian innovation typically analyzes dynamic investment and long run growth. Because with strategic interaction, the dimensionality of the state space in a dynamic game grows unbounded, in this paper we abstract from long term growth.

[2] 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

Our economy has the main ingredients of the economy posited by Sutton (2001). The economy is large with many independent markets with few competitors (Sutton's 'independence' principle). There is free entry and firms only enter when profits are non-negative ('survivor' principle). Firms need to invest in innovation, which are sunk costs, and innovation endogenously determines the productivity of the firm. Firms maximize profits ('arbitrage' principle) by optimally choosing investment in innovation and optimally making production decisions in the oligopolistic product market. Key for our analysis is the strategic interaction between firms in the oligopolistic goods market. Incumbents have the power to credibly invest in innovation before entrants enter. This first-mover advantage in innovation allows them to manipulate the entry equilibrium, and hence the market structure. Innovation affects productivity and hence profits of competitors, which in turn determines entry.

The welfare implication of killer innovation is ambiguous ex ante, and the trade-off involves three components. First, incumbents care about profits instead of total surplus. Overlooking the effects on consumer surplus will lead to underinvestment on innovation. Second, incumbents fail to internalize the negative externality on other firms' surplus and will hence over-invest. The innovation made by incumbents vitiates surplus of other entering firms due to the nature of competition. The third component, which is new to the literature, is the killer effect on the extensive margin. While the socially desirable market structure may incur more entrants due to more variety and lower market power, incumbents over-invest in innovation so as to deter entry and gain larger profits.

We derive these insights from a general equilibrium model with oligopolistic competition based on Atkeson and Burstein (2008). The key feature we add is that productivities are endogenously determined by heterogenous firm types through investment in innovation. To capture the idea of killer innovation, we assume that there is an incumbent leader in each market who can credibly make innovation prior to the entry game. After realization of leaders' productivities from investment,[3] the market structure is pinned down by a free-entry game where ex ante identical entrants enter each market by making investment in innovation. After entering, entrant types are independently drawn, which, joint with innovation, determine their productivities. Once entry and innovation decisions are realized, firms Cournot compete in each of the many product markets. The main contribution of our model is to capture the notion of killer innovation, that is, how can leaders manipulate the market structure via their innovation decisions.

We then estimate the model using Compustat data, which shows two different patterns of innovation from 1980 to 2019. Before the year 2000, around 70% of markets in the economy are fringe markets

from entering, see for example Van Arsdale and Venzke (2015).

[3]Note that leaders whose type is low may choose to exit if operating is not profitable. As a result, there exists a mass of fringe markets without incumbents.

without leaders, suggesting a low level of strategic investment to affect the market structure during this period. However, the proportion of dominant markets increases drastically afterwards, from 30.1% in 2000 to 78.6% in 2005, and stabilizes around 80% in the run up to 2019. The phenomenon of killer innovation that starts around 2000s, demonstrates the importance of the strategic manipulation of market structure in understanding the recent trends in innovation and business dynamism.

Furthermore, we quantify the welfare effect of killer innovation by examining two counterfactual economies. The first is the social planner solution where the planner is able to choose investment for all incumbent leaders. This counterfactual result informs us of a lower bound of the efficiency change due to killer innovation, because the planner takes not only this killer effect but also externalities on other firms and consumer surplus into account when making innovation decisions for the leaders. The second exercise sets the number of entering firms exogenously equal to the equilibrium level, which directly eliminates the incentive for leaders to kill competition via innovation. However, this counterfactual comparison does not include the welfare gain from more variety and lower market power due to changes in market structure, and thus specifies an upper bound of the welfare effect of killer innovation. The results show that the efficiency loss due to killer innovation is initially minuscule around 2.08% in 1980, which ranges from 5.77% to 9.39% in the early 2000s and eventually increases to the interval between 15.42% and 29.60% in 2019.

Finally, we evaluate the effect of counterfactual policies of incumbent taxes and entry subsidies. The results show that a 10% profit tax on incumbents can enhance social welfare by 0.4% in 1980, 2.8% in 2000, and 5.3% in 2019, which means the welfare gain due to mediation of the problem of killer innovation outweighs the costs of less innovation due to the incumbent taxes, and increasingly so over time. To the contrary, we find that a 10% subsidy on entrants does not enhance welfare. Although the subsidy fosters entry, the subsidy reduces investment by entrants and hence lead to a decline in total welfare.

Our analysis elucidates the *superstar* firm phenomenon (Autor et al., 2020), which highlights that a handful of firms have increasingly grown dominant. An open question remains regarding the origins of their dominant position. Standard in economics, we attribute firm size to productivity. Though we often assume productivity is an unexplained primitive, in reality productivity is endogenous and the result of investment in innovation. In this paper, we find that the distribution of productivity and of superstar firms is tightly linked to strategic innovation and to the incentives of innovation to endogenously shape the market structure. 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.

As a result, the upper tail of the firm size is too far out.

Related literature. This paper builds on vast literatures that study innovation, market structure and the macroeconomic implications. A starting point is the work on Schumpeterian innovation, which centers around the process of creative destruction (e.g., 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; De Ridder, 2019). We contribute to this work by exploring the effect of strategic interaction in the goods market, as a result of which, incumbent leaders innovate strategically to deter potential entrants. To the best of our knowledge, we know of only one study (Weiss, 2019) who incorporates strategic interaction through the lens of intangibles. His work focuses on endogenous growth, while our paper focuses on the endogenous market structure and on the macroeconomic implications.

Our insights also 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), Morzenti (2023) and Letina et al. (2021) 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,[4] known as *predatory innovation*, as mentioned above with reference to Van Arsdale and Venzke (2015).

The paper is organized as follows. We first use a motivating model to demonstrate key insights of killer innovation in section 2, based on which we build the full general equilibrium model in section 3. We then quantify the general equilibrium model in section 4. We derive the main results and perform the counterfactual exercises in section 5. Section 6 offers concluding remarks.

2 Motivating model

We first motivate the role of killer innovation in the simplest model in a partial equilibrium. The spirit is well-known as entry deterrence. Economists have discussed different approaches such as predatory pricing (e.g., Milgrom and Roberts, 1982a,b) and investment in capacity (e.g., Spence, 1977; Dixit, 1980). In this paper, we propose strategic innovation as a new tool that incumbents use to kill competition.

Setup. Consider a market with an incumbent 'leader' of type z_ℓ and many potential entrants ('followers') with the same type z_f. We index firms by subscript ι. Given firm type z_ι, the productivity a_i is endogenously determined by innovation, incurring investment $\phi^q(a_\iota, z_\iota)$. On the other hand, the production cost for the firm to produce y units of goods is $C(y, a_\iota)$. We assume goods are identical and the inverse demand function is $P(Y)$, where $Y = \sum_\iota y_\iota$ is the aggregate outputs. The timing of the game is as follows:

1. The incumbent leader chooses productivity a_ℓ;
2. Identical potential entrants enter the market by choosing productivity a_f with some fixed cost ϕ^F;
3. Firms compete à la Cournot.

We further make the following regularity assumptions: $(\phi^q)_a > 0$, $(\phi^q)_{aa} > 0$, $C_y > 0$, $C_q < 0$ and $P'(Y) < 0$. To address our key mechanism, we abstract from the rich heterogeneity and stochasticity that will be included in the full, general equilibrium model in section 3.

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

Solution. The model can be easily solved by backward induction. In stage 3, each firm observes the productivity sequence **a** and makes production choice to maximize its own profit:

$$\widetilde{\pi}_\iota(\mathbf{a}) = \max_{y_\iota} \Big[P\,(Y)\, y_\iota - C(y_\iota, a_\iota) \Big], \quad \forall \iota \in \{\ell, f\}.$$

The output **y** given productivity **a** is hence pinned down by the standard first order condition:

$$\frac{P}{C_y(y_\iota, a_\iota)} = \left[\left(\frac{\mathrm{d}P}{\mathrm{d}Y} \frac{Y}{P} \right) \frac{y_\iota}{Y} + 1 \right]^{-1}, \quad \forall \iota \in \{\ell, f\} \tag{1}$$

where the LHS is the markup while the RHS is the inverse of the demand elasticity. The equilibrium output **y** further gives the gross profit function $\widetilde{\pi}_\iota(\mathbf{a})$, which is the objective function of firms in making innovation decisions in previous periods.

In stage 2, observing the leader's productivity a_ℓ, an infinity number of potential entrants make entry decision by choosing a productivity level. We consider a symmetric equilibrium where identical entrants have the same level of innovation a_f. To derive the free entry equilibrium, we first solve the optimal innovation $\widehat{a}_f(a_\ell; I)$ conditional on the number of entrants I:

$$\widehat{\pi}_i(a_\ell, I; \widehat{a}_f) = \max_{a_\iota} \left[\widetilde{\pi}_i(\underbrace{a_\ell, a_\iota, \overbrace{\widehat{a}_f, ..., \widehat{a}_f}^{I-1}}_{\mathbf{a}}) - \phi^q(a_\iota, z_f) - \phi^F \right],$$

with FOC:

$$\frac{\partial}{\partial a_\iota} \widetilde{\pi}_\iota = \frac{\partial}{\partial a_\iota} \phi^q(a_\iota, z_f),$$

setting the marginal return of innovation in productivity equal to the marginal cost. Given the conditional profit function $\widehat{\pi}_f(a_\ell, I)$, the equilibrium market structure I^* for this subgame is pinned down by the maximum number of entrants that can support positive profits when entering, i.e.,

$$\widehat{\pi}_f(a_\ell, I^*) \geq 0 \quad \text{and} \quad \widehat{\pi}_f(a_\ell, I) < 0, \quad \forall I > I^*.$$

Hence, the equilibrium productivity of followers is $a_f^*(a_\ell) := \widehat{a}_f(a_\ell, I^*)$.

Finally, anticipating the reactions from potential entrants, the leader chooses productivity a_ℓ in period 1 to maximize its net profit:

$$\pi_\ell(a_\ell) = \max_{a_\ell} \left[\widetilde{\pi}_\ell(a_\ell, \overbrace{a_f^*(a_\ell), ..., a_f^*(a_\ell)}^{I^*(a_\ell) \text{ entrants}}) - \phi^q(a_\ell, z_\ell) \right].$$

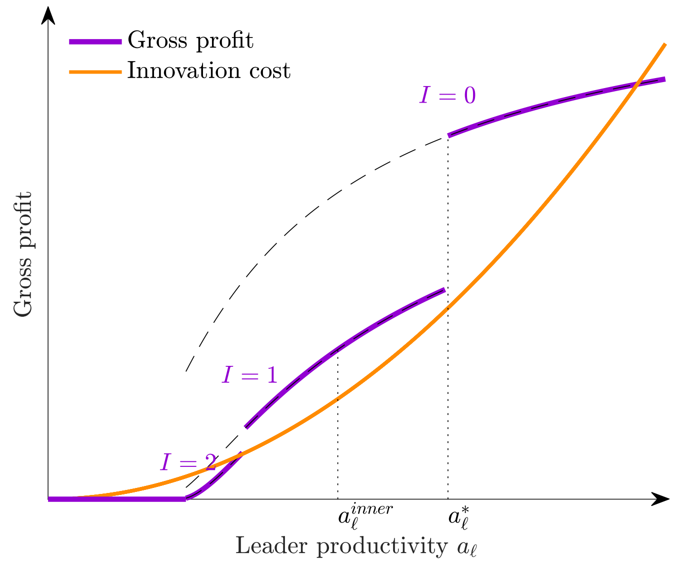

Figure 1: Trade-off: gross profits and innovation cost

Notes: The gross profit and innovation cost function is derived from the example with $P(Y) = 3.5 - Y$, $\phi^q(a,z) = a^2/(2z)$, $C(y,a) = y/a$, $\phi^F = 0$, $z_\ell = 1.2$ and $z_f = 1$. The inner solution a_ℓ^{inner} is the choice where the incumbent leader equates marginal benefit and cost of increasing productivity, while the global optimizer a_ℓ^* is the corner solution that takes the extensive margin of market structure into account.

To solve this problem, we first treat the number of entrants I as exogenous, and the first order condition will give the optimal solution $a_\ell(I)$:

$$\underbrace{\frac{\partial \widetilde{\pi}_\ell}{\partial a_\ell} + I \times \frac{\partial \widetilde{\pi}_\ell}{\partial a_f}\frac{\mathrm{d}a_f}{\mathrm{d}a_\ell}}_{\mathrm{d}\widetilde{\pi}_\ell/\mathrm{d}a_\ell} = \frac{\partial}{\partial a_\ell}\phi^q. \tag{2}$$

Note that the LHS of the condition (2) is the marginal return of innovating in productivity that consists of a direct effect and an indirect effect through the reaction of followers. This incentive is therefore the *intensive* margin in leader's decision. However, since the leader's innovation also determines the market structure I, the optimization problem involves an *extensive* margin decision as the leader can choose a productivity that is just high enough to deter the marginal entrant. This is "killer innovation" as a metaphor for the leader who innovates strategically to stymie competition.

Killer innovation. Our motivating model, though simple, conveys the key insights of killer innovation. We further provide a concrete example of a profit function to illustrate the intuition of the killer innovation mechanism in Figure 1. The lines in purple show the leader's gross profit $\widetilde{\pi}_\ell$ as a discontinuous function of its productivity a_ℓ. The market structure changes at each jump as the number of entrants changes, resulting in less competition (fewer entrants) and discretely higher gross profit as the investment in innovation of the leader increases. Given the type z_ℓ, the orange line indicates the innovation cost to reach each level of productivity a_ℓ.

The objective of the leader is to maximize the net profit, which is graphically the gap between the purple and the orange curves. The node a_ℓ^{inner} indicates the inner solution where the marginal benefit of increasing productivity equals the marginal cost. However, due to the feasibility of killer innovation, the optimal innovation is a corner solution indicated by a_ℓ^*, under which the innovation of the leader is high enough to keep all the entrants out and hence monopolize the market. The excessive profits motivate the leader to innovate at a high level to kill competition, which is inefficient due to the high market power.

3 Full model

To map the insights of killer innovation to the reality, we build a model of the macroeconomy with endogenous innovation decision and oligopolistic competition. We set the model up in section 3.1 and present the solution in section 3.2.

3.1 Setup

Environment. The economy is populated by representative households who consume goods and supply labor. There is a continuum of markets indexed by j with measure being normalized to 1. Each market has an incumbent leader, indexed by ℓ, facing competition from a large number of potential entrants indexed by i. There are three stages. In stage 1, leaders in each market make investment decision simultaneously, which determines their productivity. In stage 2, observing leader's productivity, potential followers enter each market by making an investment until entry becomes no longer profitable. Finally, all firms in stage 3 produce differentiable goods simultaneously under Cournot competition.

Household preference and budget constraint. Following Atkeson and Burstein (2008), we assume households have preferences for consumption of all goods, within and between markets. The utility of consumption is represented by a double-nested Constant Elasticity of Substitution (CES) aggregator:

$$C = \left(\int_0^1 c_j^{\frac{\theta-1}{\theta}} \, \mathrm{d}j \right)^{\frac{\theta}{\theta-1}}, \quad \text{where} \quad c_j = \left(c_{\ell j}^{\frac{\eta-1}{\eta}} + \sum_{i=1}^{I_j} c_{ij}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}.$$

We use capital C for the economy-wide aggregator of consumption, which aggregates market-level consumptions c_j, while the latter ones are also CES aggregators of all varieties in each market j. The $I_j \in \mathbb{N}$ stands for the equilibrium number of entrants, where we assume firms produce single product.

Furthermore, the finite number of $I_j + 1$ goods are substitutes with elasticity η, and the elasticity of substitution between markets is θ. We assume $\eta > \theta > 1$, indicating that households are more willing to substitute goods within a market (say Pepsi vs. Coke) than across markets (soft drinks vs. cars). Finally, we represent the household's preferences with the following utility function over the consumption bundle, $\{c_{\iota j}\}$ for any $\iota \in \{\ell, 1, ..., I_j\}$, that aggregates to C, and the supply of labor L:

$$U(C,L) = C - \overline{\varphi}^{-\frac{1}{\varphi}} \frac{L^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}, \tag{3}$$

where utility is linear over aggregate consumption, and there is a constant elasticity disutility of labor with elasticity φ and a constant shifter $\overline{\varphi}$. We exclude the income effect on labor decision in this preference specification.[5]

Prices of the final consumption goods are denoted by $p_{\iota j}$, wages for production labor by W, and profits by $\pi_{\iota j}$. Profits aggregate economy-wide to Π, of which each household receives an equal share. Households face a budget constraints, where their spending on goods cannot exceed the income consisting of wage bill WL and dividends Π. We can thus summarize the household problem as:

$$\max_{\{c_{\iota j}\},L} U(C,L) \quad , \quad \text{s.t.} \quad \int_0^1 \left(p_{\ell j} c_{\ell j} + \sum_{i=1}^{I_j} p_{ij} c_{ij} \right) \mathrm{d}j \leq WL + \Pi. \tag{4}$$

An important feature here is that all output produced is equal to the total income of the households. Therefore, all the value general by the allocation of this economy stays in the economy.

Market Structure. We assume that there is a market-specific type $a_j \sim G(\cdot)$ that scales the productivities of all firms in this market in the same way. In each market j, there is one incumbent leader with a revealed type $z_{\ell j}$ drawn from some distribution F_ℓ. Also, there is a large number of *ex ante* identical potential entrants in the economy being able to enter every market. Once entering, the follower has its own type z_{ij} drawn from the distribution F_f, which will, however, remain unobservable until it has made its investment decision.

Innovation and production. For firm $\iota \in \{\ell, 1, ..., I_j\}$ in market j, the productivity $a_{\iota j}$ is determined by:

$$a_{\iota j} = a_j \widetilde{a}_{\iota j} \quad , \quad \text{where} \quad \widetilde{a}_{\iota j} = \left(q_{\iota j}^{\gamma} + z_{\iota j}^{\gamma} \right)^{\frac{1}{\gamma}}, \tag{5}$$

[5] We focus on the imperfect competition on the goods market, and having income effect in labor supply will not alter any of our insights. We exclude this effect for the sake of tractability.

with $q_{\iota j}$ being the level of innovation. We further assume the elasticity $\gamma < 0$, which implies a strong complementarity between firm type and innovation that will be empirically important to match the size-investment correlation in the data. The investment cost in labor, $\phi^q_{\iota j}$, to reach innovation $q_{\iota j}$ is assumed to be:

$$\phi^q_{\iota j}(q_{\iota j}) = \beta a_j^{\theta-1} q_{\iota j}, \tag{6}$$

where β is an exogenous parameter that captures how costly it is to make innovation. We introduce market type a_j here, meaning that it is harder to get the same level of innovation in a high-type market.[6] Finally, we assume a linear production function:

$$y_{\iota j} = a_{\iota j} n_{\iota j}, \tag{7}$$

where $y_{\iota j}$ and $n_{\iota j}$ are output and employment of firm ι in market j.

Timing. The game on the firm side consists of three stages.

1. THE INCUMBENT LEADERS MAKE INNOVATION DECISIONS. The leader ℓ in market j, knowing its own type $z_{\ell j}$, chooses innovation level $q_{\ell j}$ to maximize its expected profit:

$$\mathbb{E}\left[\pi_{\ell j} | z_{\ell j}\right] = \max_{q_{\ell j}} \left\{ \mathbb{E}\left[\widetilde{\pi}_{\ell j} | a_{\ell j}\right] - \phi^q_{\ell j} W \right\}, \tag{8}$$

   where $\widetilde{\pi}_{\ell j}$ is the *gross* profit that comes from the product market competition.

2. POTENTIAL ENTRANTS MAKE ENTRY AND INNOVATION DECISIONS. Entry happens simultaneously. Observing the leader's productivity $a_{\ell j}$, follower i will enter market j if and only if the expected profit from entry is positive.[7] Once entering, the firm chooses an innovation level q_{ij} to maximize its expected profit:

$$\mathbb{E}\left[\pi_{ij} | a_{\ell j}\right] = \max_{q_{ij}} \left\{ \mathbb{E}\left[\widetilde{\pi}_{ij} | q_{ij}, a_{\ell j}\right] - \phi^q_{ij} W \right\}. \tag{9}$$

   Followers' type z_{ij} will be drawn after the innovation is made, which determines the productivity a_{ij}. The productivity of each firm then becomes a common knowledge.

[6] We make this assumption to simplify the model solution by making a_j irrelevant from firms' innovation decisions. The intuition is that the profits of firms are homogenous of degree $\theta - 1$ regarding a_j, which will therefore be canceled out in profit-maximization problem.

[7] We assume there is no fixed cost of entry. Including fixed costs will not influence our main results.

3. COURNOT COMPETITION ON THE GOODS MARKET. Finally, firms make production decision simultaneously to maximize their gross profits:

$$\widetilde{\pi}_{\iota j} = \max_{n_{\iota j}} \{ p_{\iota j} y_{\iota j} - n_{\iota j} W \} \tag{10}$$

subject to the production function (7). The investment $\phi^q_{\iota j}$ does not enter this problem because it has become the sunk cost.

Equilibrium. We formally define an equilibrium as a collection of market structure $\{I_j, a_j\}$, realized firm type $\{z_{\iota j}\}$ and productivity $\{a_{\iota j}\}$, employment $\{n_{\iota j}\}$, output $\{y_{\iota j}\}$, innovation $\{q_{\iota j}, \phi^q_{\iota j}\}$, consumption $\{c_{\iota j}\}$, prices $\{p_{\iota j}\}$, wage W, and labor supply L, such that

- HOUSEHOLDS OPTIMIZE. Given prices $\{p_{\iota j}\}$ and wage W, the consumption bundle $\{c_{\iota j}\}$ and labor supply L solve households' optimization problem (4).
- FREE ENTRY. Given leaders' productivity $\{a_{\ell j}\}$, market type $\{a_j\}$, and wage W, the market structure $\{I_j\}$ is the largest number of firms that ensure positive expected profits for all entrants in each market.
- FIRMS OPTIMIZE. Given wage W, firm's optimization contains two parts:
  - ⋆ *Innovation.* Given own type $\{z_{\ell j}\}$, the innovation bundle of leaders, $\{q_{\ell j}\}$, solves leaders' problem (8). Given leaders' productivity $\{a_{\ell j}\}$ and market structure $\{I_j\}$, the innovation bundle $\{q_{ij}\}$ solves followers' problem (9).
  - ⋆ *Production.* Given productivities $\{a_{\iota j}\}$, the employment bundle $\{n_{\iota j}\}$ solves the production problem (10).
- MARKETS CLEAR. Both the output and the labor markets are cleared:
  - ⋆ *Goods market*: $y_{\iota j} = c_{\iota j}$, where $y_{\iota j}$ is supply and $c_{\iota j}$ is demand for each good ι in market j.
  - ⋆ *Labor market*: $L = N + \Phi$, where $N = \int_0^1 \sum_\iota n_{\iota j} \mathrm{d}j$ is the aggregate production labor demand and $\Phi = \int_0^1 \sum_\iota \phi^q_{\iota j} \mathrm{d}j$ is the aggregate innovation labor demand.

3.2 Solution

The model does not have an analytical solution. Nevertheless, in this section we document the key equations based on which we solve the equilibrium numerically. The key insights echo with the ones in the motivating model.

Household solution. We have a standard household problem as in Atkeson and Burstein (2008), which gives the demand function and the aggregate labor supply function. Demand for the goods of firm ιj is given by:

$$c(p_{\iota j}, \mathbf{p}_{-\iota j}, P, C) = \left[\frac{p_{\iota j}}{p_j(p_{\iota j}, \mathbf{p}_{-\iota j})}\right]^{-\eta} \left[\frac{p_j(p_{\iota j}, \mathbf{p}_{-\iota j})}{P}\right]^{-\theta} C, \tag{11}$$

where the CES price indexes are defined as:

$$p_j(p_{\iota j}, \mathbf{p}_{-\iota j}) = \left(p_{\ell j}^{1-\eta} + \sum_{i=1}^{I_j} p_{ij}^{1-\eta}\right)^{\frac{1}{1-\eta}} \quad \text{and} \quad P = \left(\int_0^1 p_j^{1-\theta} \mathrm{d}j\right)^{\frac{1}{1-\theta}} = 1.$$

We normalize the aggregate price index to 1. The labor supply curve is obtained by equating the marginal cost of working an extra hour and the marginal benefit W: $L = \overline{\varphi} W^{\varphi}$.

Output market equilibrium. We solve the firm problem backwards and first deal with the output market equilibrium given market structure $\{I_j\}$, innovation $\{q_{\iota j}\}$, and productivity $\{a_{\iota j}\}$. The first order condition of firms problem (10) yields:

$$p_{\iota j}(y_{\iota j}, \mathbf{y}_{-\iota j}) \underbrace{\left(1 + \frac{\mathrm{d}p_{\iota j}}{\mathrm{d}y_{\iota j}} \frac{y_{\iota j}}{p_{\iota j}}\right)}_{\mu_{\iota j}^{-1}} \frac{\mathrm{d}y_{\iota j}}{\mathrm{d}n_{\iota j}} = W, \tag{12}$$

where the LHS is the marginal product of employment while the RHS is its marginal cost. The markup, $\mu_{\iota j}$, is defined as the price $p_{\iota j}$ over marginal cost $W/a_{\iota j}$, which takes form of the inverse of the price elasticity of demand as is shown in equation (12). Under this nested CES structure, this elasticity, and hence the markup, can be further expressed by the elasticity of substitution θ and η:

$$\mu_{\iota j} = \left[1 - \frac{1}{\theta} s_{\iota j} - \frac{1}{\eta}(1 - s_{\iota j})\right]^{-1}, \tag{13}$$

where $s_{\iota j} := p_{\iota j} y_{\iota j} / (\sum_{\iota'} p_{\iota' j} y_{\iota' j})$ is the sales share of firm ι in market j. Equation (13) suggests that the markups are determined by the elasticity of substitution within and between markets weighted by sales shares. For example, only the across-market elasticity matter 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.

Furthermore, the output market clearing condition and the demand function (11) ensure that:

$$s_{\iota j} := \frac{p_{\iota j} y_{\iota j}}{\sum_{\iota'} p_{\iota' j} y_{\iota' j}} = \left(\frac{p_{\iota j}}{p_j}\right)^{1-\eta} = \frac{\left(\mu_{\iota j}/a_{\iota j}\right)^{1-\eta}}{\sum_{\iota'} \left(\mu_{\iota' j}/a_{\iota' j}\right)^{1-\eta}}. \tag{14}$$

Equation (14), joint with the first order condition (13), shows that the equilibrium market shares and markups are only determined by market j vector of firm productivities $\mathbf{a}_j = (a_{\ell j}, a_{1j}, ..., a_{I_j j})$. Firms with higher productivities can produce at lower costs and hence take a higher share. Meanwhile, their prices relative to cost, i.e., markups, are high, which means they are able to exert larger market power. As is pointed out in De Loecker et al. (2021), the homotheticitiy of preferences implies that this system of equations (13) and (14), is *block recursive* in that it is independent of all aggregate variables, that is, markups can be recovered independently of aggregates.

Moreover, when making production decision, each firm will take the aggregates P, W and Y as given because they are determined by the actions of a continuum of markets and firms. Goods market clearing conditions, demand function (11), and the first order condition (12) together deliver the equilibrium employment $n_{\iota j}$ as a function of primitive productivities $\mathbf{a}_j$, endogenous markups $\{\mu_{\iota j}\}$, and aggregates W and Y:

$$n_{\iota j} = a_j^{\theta-1} \left(\frac{1}{\widetilde{a}_{\iota j}}\right) \left(\frac{\mu_{\iota j}}{\widetilde{a}_{\iota j}}\right)^{-\eta} \left[\sum_{\iota'} \left(\frac{\mu_{\iota' j}}{\widetilde{a}_{\iota' j}}\right)^{1-\eta}\right]^{\frac{\eta-\theta}{1-\eta}} Y W^{-\theta}. \tag{15}$$

Furthermore, from the first order condition (12), we can write the gross profit $\widetilde{\pi}_{\iota j}$ from Cournot competition as:

$$\widetilde{\pi}_{\iota j} = \left(\mu_{\iota j} - 1\right) W n_{\iota j}, \tag{16}$$

where the markups can be solved solely by productivities and employment is given by the equation (15). Hence, we manage to express the gross profit with the aggregate $YW^{1-\theta}$ being the only unknown.

In this subgame, aggregates W and Y are standard and easy to solve. Since we have a competitive labor market, the equilibrium wage will be the marginal product of workers, which directly comes from the FOC (12):

$$\frac{W}{P} = \left[\int_0^1 \left[\sum_{\iota} \left(\frac{\mu_{\iota j}}{a_{\iota j}}\right)^{1-\eta}\right]^{\frac{1-\theta}{1-\eta}} dj\right]^{\frac{1}{\theta-1}}. \tag{17}$$

Then, labor market clearing condition incurs:

$$Y = \left\{\int_0^1 \left[\sum_i \left(\frac{1}{a_{ij}}\right) \left(\frac{\mu_{ij}}{a_{ij}}\right)^{-\eta} \left(\left[\sum_i \left(\frac{\mu_{ij}}{a_{ij}}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}\right)^{\eta-\theta}\right] \mathrm{d}j\right\}^{-1} \left(\frac{W}{P}\right)^{\theta} (L - \Phi). \tag{18}$$

Free entry and innovation from the entrants. We now discuss the entry problem and the associated innovation problem (9). Since there are a large number of markets, the action in a single market will not influence the equilibrium aggregates. Hence, we will take aggregates W and Y as given and focus on the entry and innovation decision in each market j.

First assume that I_j followers enter the market j. The innovation problem (9) induces first order condition:

$$\beta a_j^{\theta-1} W = \frac{\partial \mathbb{E}\left[\widetilde{\pi}_{ij}\right]}{\partial q_{ij}}, \tag{19}$$

where the LHS is the marginal cost of innovation while the RHS is the marginal expected gross profit. A direct implication of this FOC is:

$$q_{ij} = \frac{1}{\beta}\mathbb{E}\left[\left(\frac{\partial \widetilde{\pi}_{ij}}{\partial a_{ij}}\frac{a_{ij}}{\widetilde{\pi}_{ij}}\right)\left(\frac{\partial a_{ij}}{\partial q_{ij}}\frac{q_{ij}}{a_{ij}}\right)\frac{\widetilde{\pi}_{ij}}{a_j^{\theta-1}W}\right], \tag{20}$$

which is, given aggregates W and Y, a fixed point problem on innovation q_{ij}. The key component here is the elasticity of productivity on gross profits, which consists of two channels: markup and firm size. We further refer readers to Bao et al. (2022) for more discussion on this margin.

Let $\widehat{q}_{ij}(I_j; W, Y)$ be the solution of equation (20), i.e., the optimal innovation level given aggregates and market structure I_j. This result further gives the expected profit of entry, $\mathbb{E}[\widetilde{\pi}_{ij}] - \phi_{ij}^q W$. Finally, the free entry condition pins down the equilibrium market structure as the largest I_j that ensures the expected profit of entry to be non-negative.

Innovation from the leaders. We close the model solution by analyzing the optimal innovation of the leaders. Again, the decision of each single leader will not affect equilibrium aggregates, so we can discuss the leader's problem market by market taking aggregates W and Y as given. The difference of the leader's problem from the entrant's is that the leader, as a first-mover in a market, can commit to any innovation level and hence take the reaction of entrants into its account. Hence, the leader ℓj will choose the innovation $q_{\ell j}$ subject to problem (8), knowing that this decision will influence the innovation (intensive margin) and market structure (extensive margin) from the entry game. While this problem can only be solved numerically, the underlying trade-off is still between the marginal cost and benefit of innovation. Note that we do not exclude the possibility of a corner solution where the leader does not want to innovate, in which case we have $a_{\ell j} = 0$ and only entrants operate in this market. We use the term *fringe market* for this type of market where the leader quits in the first stage.

Aggregates. Finally, the only step remains for solving the equilibrium numerically is to pin down the aggregates W and Y, where we rely on the goods and labor market clearing conditions. Given any initial guess W^0 and Y^0, we can solve the induced equilibrium following discussions above and calculate the induced aggregates W^1 and Y^1 according to equation (17) and (18). Therefore, we get another fixed-point problem by solving which will give us the equilibrium wage W and output Y that clear the labor and goods market.

4 Quantification

We estimate the model using Compustat data from 1980 to 2019. In order to map to the data, we extend the model to include capital and intermediate inputs. We first describe the model extension in section 4.1, parametrize it in section 4.2, then estimate the model annually using Simulated Method of Moments (SMM) in section 4.3. Results are presented in section 4.4.

4.1 Extended model and the mapping to the data

We extend the labor-only model of section 3 to include capital and intermediates so that we can map cost measures from the data into the model.

We first specify the demand side of these new inputs. Specifically, we include capital and materials in production:

$$y_{\iota j} = a_{\iota j} \left(n_{\iota j} + m_{\iota j}\right)^{\zeta} k_{\iota j}^{1-\zeta}, \tag{21}$$

where $k_{\iota j}$ and $m_{\iota j}$ denote the capital and intermediate inputs of firm ι in market j. We assume that the production technology is constant return to scale, and that labor and materials are perfect substitutes. Given the extended production function (21), we have the expression for profits:

$$\pi_{\iota j} = \overbrace{\underbrace{p_{\iota j} a_{\iota j} \left(n_{\iota j} + m_{\iota j}\right)^{\zeta} k_{\iota j}^{1-\zeta}}_{\text{Sales}} - \underbrace{\left(P^m m_{\iota j} + W n_{\iota j}\right)}_{\text{COGS}} - \underbrace{R k_{\iota j}}_{\text{Capital cost}}}^{\text{Gross profit } \tilde{\pi}_{\iota j}} - \underbrace{W \phi_{\iota j}^{q}}_{\text{SG\&A}}, \tag{22}$$

where P^m and R are the prices for materials and capital and we assume firms are all price takers. Note that we will use SG&A as a measure of innovation cost due to data limitation.

Typically, by the cost minimization problem, we have

$$m_{\iota j} = \frac{1-\psi}{\psi} n_{\iota j} \quad \text{and} \quad k_{\iota j} = \frac{1}{\psi} \frac{W/\zeta}{R/(1-\zeta)} n_{\iota j}, \tag{23}$$

where $\psi := n_{\iota j}/(n_{\iota j} + m_{\iota j})$ is an exogenous parameter that assumed to be identical for all firms.[8] Equation (23) implies that the extended production function can be equivalently written into:

$$y_{\iota j} = \widehat{a}_{\iota j} n_{\iota j}, \quad \text{where} \quad \widehat{a}_{\iota j} := \frac{1}{\psi} \left[\frac{W/\zeta}{R/(1-\zeta)} \right]^{1-\zeta} a_{\iota j}.$$

Since each single firm is not able to affect the aggregate wage W, they will take this equivalent labor productivity $\widehat{a}_{\iota j}$ as given. Therefore, firms problem can be solved as before as we keep linearity in production technology and inputs markets are all competitive. This solution hence gives us the additional demand function for intermediates and capital.

On the supply side, we assume the supply for both intermediates and capital are inelastic. Due to perfect substitution, the equilibrium price for material P^m must be equal to the wage W. On the other hand, we will directly take the capital price R from the data in doing our quantitative exercise.

4.2 Parametrization

To quantify the model, we assume that distribution for leaders' types F_ℓ, potential entrants' types F_f, and market type G are lognormal with log mean and log standard deviation $\{m_\ell, \sigma_\ell\}$, $\{m_f, \sigma_f\}$, and $\{m_a, \sigma_a\}$. The market structure is endogenously determined by the free entry equilibrium, so there is no need to put any additional assumptions. Nevertheless, due to the restriction from computational power, the high-dimension problem with a large I_j is not tractable, so we restrict our discussion within the case where the number of entrants is smaller than or equal to five.[9]

Externally chosen parameters. Table 1 summarizes all the exogenously chosen parameters. All the action of our model is on the production side, so we take the preference parameters, the elasticities of substitutes η and θ, from De Loecker et al. (2021), who quantify the oligopolistic model within the same framework of Atkeson and Burstein (2008). The labor supply elasticity is set to 0.25, which is consistent with the micro-estimates from (Chetty et al., 2011). Regarding the model extension, we set the cost of capital R to 1.16 (from De Loecker et al. (2021)) who incorporates discounting, depreciation and corrects for inflation. The elasticity in production, ζ and ψ, are directly estimated in the Compustat data based on the first order condition of Cobb-Douglass production function. We first compute firm level input shares, then take the median value within each year across firms, and finally take the average across years to get a share of COGS of $\zeta = 0.88$ and a share of labor of $\psi = 0.33$. Finally, we take the estimates

[8] This assumption is not crucial for our analysis. We can allow ψ to vary by firms and all of our results are robust.

[9] It turns out that this assumption is not crucial to our quantitative exercise because the number of entrants in our estimated economy have never exceeded 4, i.e., the entry equilibrium has never touched the exogenous bound.

Table 1: Exogenous parameters

Parameter	Meaning	Value	Source
η	Within-sector elasticity of demand	5.75	De Loecker et al. (2021)
θ	Between-sector elasticity of demand	1.20	De Loecker et al. (2021)
φ	Labor supply elasticity	0.25	Chetty et al. (2011)
R	User cost of capital	1.16	De Loecker et al. (2021)
ζ	Factor share: labor + material in variable cost	0.88	Compustat data
ψ	Factor share: labor in labor + intermediates	0.33	Compustat data
m_a	Mean of $\log a_j$	9	Bao et al. (2022)
σ_a	Standard deviation of $\log a_j$	3	Bao et al. (2022)

regarding sector productivity, m_a and σ_a, from Bao et al. (2022), who have a similar production setup.

Internally estimated parameters. We will internally estimate five parameters: (1) the elasticity γ; (2) the labor cost of innovation β; (3) the mean of the leader's type m_ℓ; (4) the standard deviation of leader's type σ_ℓ and (5) the standard deviation of follower's type σ_f. The mean of follower's type, m_f, is normalized to 1 throughout the exercise, so m_l captures how good the leader is on average relative to the potential entrants.

4.3 Approach

We estimate the five model parameters $\boldsymbol{\vartheta} = \{\gamma, \beta, m_\ell, \sigma_\ell, \sigma_f\}$ annually by Simulated Method of Moments from 1980 to 2019, treating every year as a stationary economy. We identify the endogenous parameters by minimizing the following objective function:

$$\widehat{\boldsymbol{\vartheta}}_t = \min_{\boldsymbol{\vartheta}} \left\{ \left(\widehat{\boldsymbol{M}}_t - \boldsymbol{M}(\boldsymbol{\vartheta}) \right)' \boldsymbol{W}^{-1} \left(\widehat{\boldsymbol{M}}_t - \boldsymbol{M}(\boldsymbol{\vartheta}) \right) \right\}, \tag{24}$$

where the subscript t denotes for years and $\boldsymbol{M}$ is the vector of targeted moments we choose, which will be constructed and motivated in this section.

Table 2 lists the six moments that we target. We take the direct observations of revenues and SG&As from the Compustat data and estimate markups using the production approach based on De Loecker et al. (2020). While all parameters affect all moments in the general equilibrium, we also list the corresponding key parameter that affects each of the moments most directly in the table. We will motivate our choice of the targeted moments next.

Table 2: Targeted Moments

Categories	Moment	Key Parameter
I. Innovation Technology	Correlation between log SGA share and log sales	γ
	Mean of log SGA share	β
II. Types	Markup at 90th percentile	m_ℓ
	Markup at 75th percentile	m_ℓ
	Variance of log markup (sales weighted) between markets	σ_ℓ
	Variance of log markup (sales weighted) within markets	σ_f

Notes: The SG&A share is defined as SG&A/sales. The market in the data is defined at four-digit NAICS code level.

I. Innovation Technology. The first category of parameters concerns the innovation technology, which includes the elasticity of substitution, γ, and labor costs of innovation, β. First, because we assume the innovation is complementary to the firm type, we use the correlation coefficient between log SGA share and log sales to identify γ. Intuitively, the more negative γ gets, the stronger this complementarity will be. Consequently, more surplus is generated by this complementarity for the firm and the correlation between innovation share and sales will therefore become more negative. For the innovation cost β, it is straightforward that the share of innovation cost will be higher if the innovation becomes more costly. We thus use the log share of SG&A to identify this parameter.

II. Types. We mainly use the distribution of markups to identify the distributions of firms' types. For the log average type of the leaders, since the leader is generally the largest firm in a market due to the first-mover advantage, we use the right tail of markup distribution, i.e., the 75th and 90th percentiles, to identify m_ℓ. Meanwhile, the between-market variance of markups is most informative on the standard deviation of leader's type σ_ℓ because the difference in leader's type $z_{\ell j}$ is the only source of heterogeneity in markups across markets.[10] Following the same argument, we will use the within-market variance of markups to identify the standard deviation of the potential entrants' types σ_f. The higher σ_f is, the larger heterogeneity of productivities among followers will be, and hence the variance of markups within each market will be higher.

4.4 Estimation

The model fit of targeted moments is reported in Figure 2. Since our model is overidentified with the number of moments greater than the number of parameters, we do not expect the match to be perfect.

[10] The market type a_j will not affect markups because, as is shown in equation (13) and (14), only the relative size of productivity $\widetilde{a}_{\ell j}$ matters for the markups.

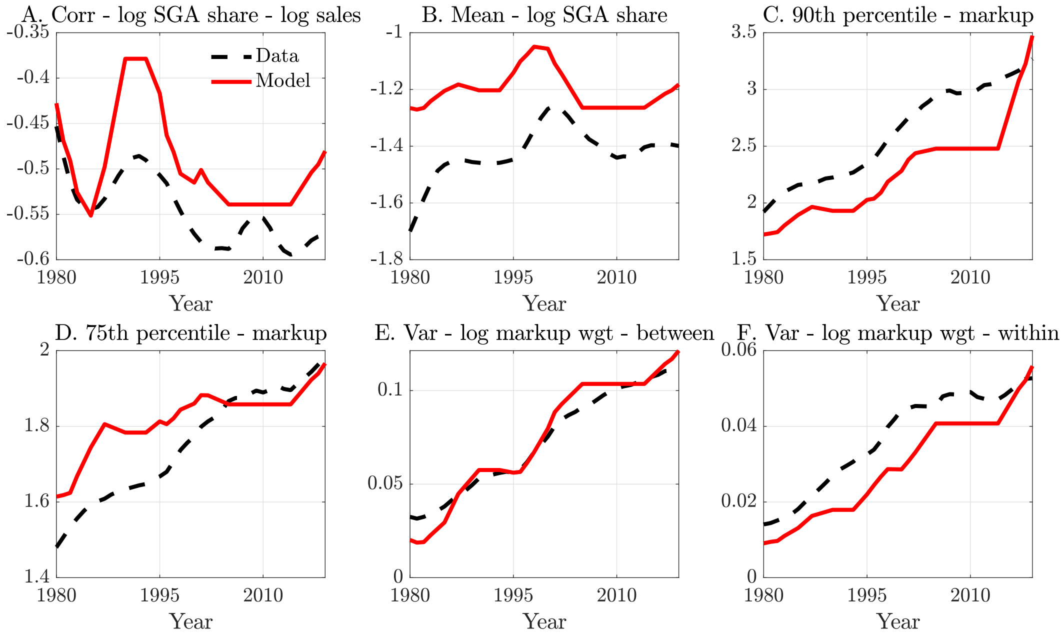

Figure 2: Estimation: targeted moments

Notes: The series of data and model are both plotted with five-year centered moving average.

Yet, the result still demonstrates that our model can capture the important patterns in data quite well, especially the trend over time.

We report the estimated parameters $\widehat{\boldsymbol{\vartheta}}_t$ in Figure 3. First, regarding innovation, we find that the estimated γ is in general increasing over time with a spike around 2000, implying that the complementarity between innovation and firm type is getting weaker over time. The cost of innovation does not change too much between 1980 and 2019, but has a peak in early 1990s. These hump shapes may relate to the internet bubble around that time, which, according to our estimates, is mainly driven by the decreasing complementarity and skyrocketing cost of innovation.

Interestingly, we document that the type of leading firms becomes overall worse (declining m_ℓ) but meanwhile more heterogenous (increasing σ_ℓ) from 1980 to 2000. This result pictures that before the technology bubble, it is more likely for superstar leaders to arise, but the overall type of leaders are declining. Afterwards, we see a clear turnaround — the average type (in log) of leaders is increasing while the variance is declining, which suggests a different mode of development after the dot com bubble. We observe the rise of superstar firms in both periods: before 2000, the type of a superstar can be very high, while afterwards there appear to have more superstars. This phenomenon corresponds to the findings of Autor, Dorn, Katz, Patterson, and Van Reenen (2020), which explains the increase in the right tail of markups in the data. Finally, the constant rise in σ_f suggests that the heterogeneity among firms is enlarging, which mainly occurs among entrants. This results corresponds to the findings of an

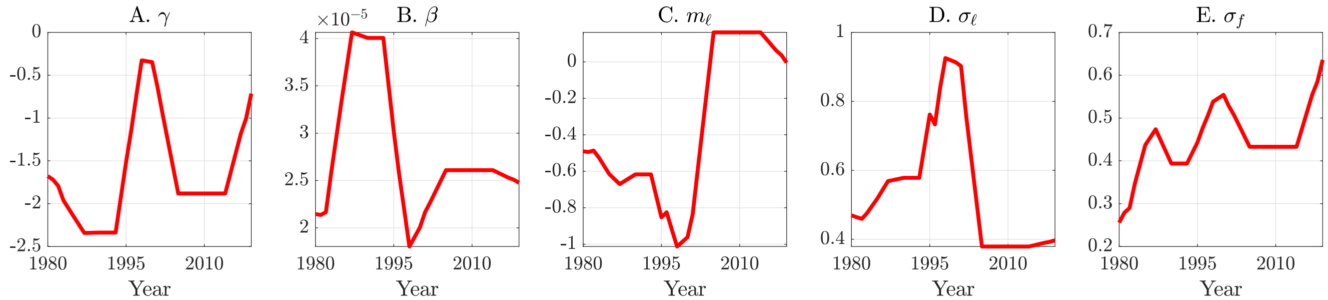

Figure 3: Estimation: parameters

Notes: The estimated parameters are both plotted with five-year centered moving average.

increasing dispersion in firm type by other literature (see for example, De Loecker et al., 2021).

5 Results

Using the time series of estimates derived in section 4, we are able to discuss quantitatively the effect of killer innovation and its welfare consequences. In section 5.1, we document the evolution of market structure in the US economy, which indicates the change of killer innovation over time. We then quantify its efficiency effect in section 5.2 by specifying upper and lower bounds through counterfactual analysis. Finally in section 5.3, we discuss the effect of policies about taxes and subsidies that may help address the issue of killer innovation.

5.1 The evolution of market structure

Our estimates of m_ℓ and σ_ℓ suggest completely different patterns of growth before and after 2000, which also shows up in the evolution of market structure. We pay a special attention to the evolution of market structure because it is endogenous in our setup and hence a clear sign for the scale of competition in each economy.

In the panel A of Figure 4, we report the evolution of average number of firms (including the leader) across markets for each year. We see that this moment declined drastically during 1980s and keeps quite stable after 1990. In panel B, we see an opposite trend that the proportion of dominant markets were stable around 0.3 before 2000, and suddenly rose to 0.8 afterwards. Combining these two observations, we conclude that the whole period can be divided into two stages and the story of killer innovation mainly happens in the latter one.

In the first two decades (between 1980 and 2000), the market structure is getting more and more concentrated but the proportion of fringe markets is stable, meaning that the competition is not killed by the leaders but rather by the increasing cost of innovation and the less complementarity between

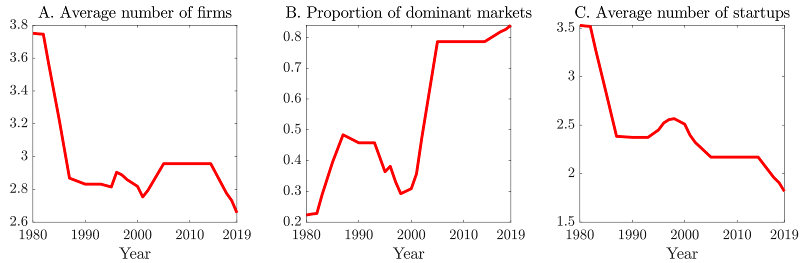

Figure 4: Evolution of market structure from 1980 to 2019

Notes: In panel A, we plot the estimated average number of firms (including the leader) across markets in each year. Panel B plots the proportion of dominant markets where the leaders operate in the market. All the sequences are plotted in the form of five-year centered moving average.

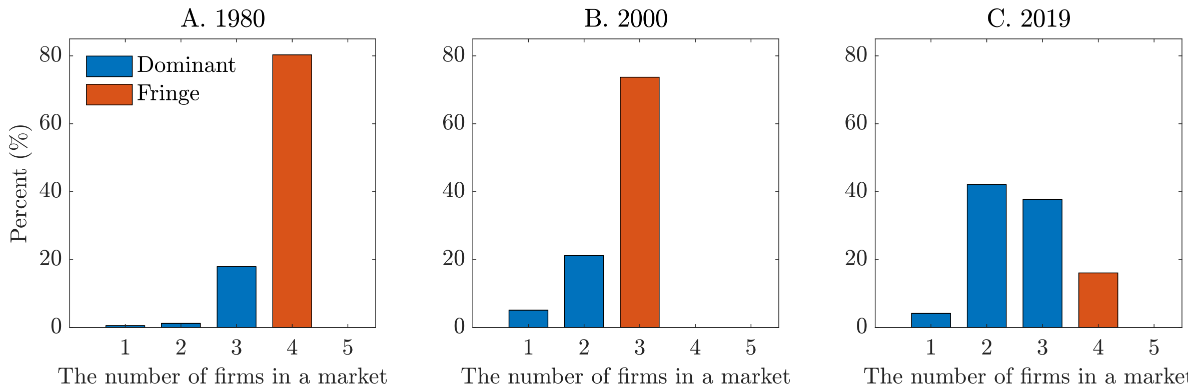

Figure 5: Estimated market structure in 1980, 2000, and 2019

Notes: The three histograms show the detailed market structure in those three years. The red bar indicates for fringe markets where the leader does not operate, while the blue ones represent markets with operating leaders.

innovation and firm type, as is shown by our estimates in Figure 3. The change from panel A to B in Figure 5 confirms this statement.

In the last two decades, however, the increasing number of leaders mainly kills competition and drives market power up. During this period, we see the fraction of dominant markets increases dramatically from 31.3% in 2000 to 85.2% in 2019, while more details for these two years are shown in Figure 5. More leaders operating in the economy makes it more likely for a leader to innovate strategically in order to kill competition, which increases the heterogeneity in productivities and hence contribute to market power. Other factors are less important in this period: the innovation cost β remains quite stable, while the index for complementarity, γ, does not increase until 2015.

5.2 Welfare effect of killer innovation

In this section, we further quantify the efficiency effects of killer innovation on outputs by specifying its upper and lower bounds via two counterfactual experiments. The lower bound is given by the solution of social planner who can choose innovation level for the leaders, while the upper one is computed via an counterfactual economy with exogenous market structure.

Specifically, the social welfare can be computed in the following way:

$$\begin{aligned}\mathcal{W} &= Y - \overline{\varphi}^{-\frac{1}{\varphi}} \frac{L^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}} - P^m M - RK \\ &= \int_0^1 \left[\sum_{\iota} \left(\underbrace{p_{\iota j} y_{\iota j} - W \left(n_{\iota j} + \phi^q_{\iota j} \right) - P^m m_{\iota j} - R k_{\iota j}}_{\text{Net profit } \pi_{\iota j}} + \underbrace{\frac{W}{1+\varphi} \left(n_{\iota j} + \phi^q_{\iota j} \right)}_{\text{Externality on HH}} \right) \right] \mathrm{d}j, \end{aligned} \tag{25}$$

where the second equation (25) is an aggregation of firm-level welfare enabled by the CES structure. The welfare generated by each firm is composed of two parts: the producer surplus, $\pi_{\iota j}$, and the household surplus that is captured by the gap between the wage and the *average* cost of providing labor, which happens to be $W/(1+\varphi)$.

It would be helpful to discuss the welfare trade-off in the innovation decision. Given market structure, the first order condition for firm ιj to maximize social welfare with regard to innovation $q_{\iota j}$ is:

$$0 = \underbrace{\frac{\partial \pi_{\iota j}}{\partial q_{\iota j}}}_{\text{Firm opt.}} + \underbrace{\sum_{\iota' \neq \iota} \left[\frac{\partial}{\partial q_{\iota j}} \mathbb{E}[\pi_{\iota' j} | q_{\iota j}] \right]}_{\text{Strategical interaction, } (-)} + \underbrace{\frac{\partial}{\partial q_{\iota j}} \left[\frac{W}{1+\varphi} \sum_{\iota'} \left(n_{\iota' j} + \phi^q_{\iota' j} \right) \right]}_{\text{Externality on households, } (+)}, \tag{26}$$

which implies that the welfare effect of killer innovation is ambiguous. The first part of this FOC is the competitive equilibrium where each firm maximizes its own profit. The second term captures the spillover effect of firm ιj's innovation on the profits of other firms, which is negative because other firms will lose the competition when one firm gets more productive. This channel suggests that the competitive level of innovation may be too high. The third part of the FOC (26) is the externality of innovation on households and is clearly positive as households can benefit from higher productivity, indicating that the competitive equilibrium may incur underinvestment. Since the killer mechanism will induce higher level of innovation for the leader through extensive margin on market structure, its welfare implication depends on the trade-off between these two opposite effects.

Lower bound: planner solution. Given the objective function (25), we first consider the problem of social planner who can control the innovation of the leaders. For model tractability, we solve the planner problem who maximizes the aggregate output. As we discuss above, this exercise informs us an lower bound of the efficiency effect due to killer innovation on outputs, because the output difference we identify includes not only the killer effect but also these externalities on entrants and households.

Upper bound: exogenous entry. The upper bound of the efficiency change due to killer innovation is specified by the counterfactual economy where we exogenously set the market structure I_j' to its equilibrium value I_j. Compared to the baseline equilibrium, the counterfactual economy differs in two channels that are both related to killer innovation. First, we directly shut down the this killer effect — as the market structure is exogenously given, leaders do not have incentive to kill competition by strategically innovating. Second, excluding the killer effect for leaders will have a general equilibrium effect on all firms. Lower innovation from the leader reduces the aggregate labor demand, which lowers the equilibrium wage and hence makes all firms able to produce more. Therefore, this counterfactual exercise endows us a measure of the efficiency loss or gain of the story of killer innovation. Our quantification results only tell us the upper bound of this efficiency difference. The reason is that, by exogenously setting the market structure, we overlook the welfare implication due to the change in variety. Less innovation from the leaders due to the lack of incentive to kill competition will actually induce more entry, increase the variety of goods, and hence contribute to a higher social welfare.

Results. The main results regarding efficiency of killer innovation are reported in panel A of Figure 6. The blue line corresponds to the counterfactual economy with exogenous market structure, which is the upper bound of this efficiency effect. The purple line, on the contrary, corresponds to the planner solution and is the lower bound of the effect. Therefore, the orange area between these two lines indicate the true efficiency gain or loss due to killer innovation on aggregate output. Overall, the killer mechanism reduces the efficiency of the economy, and this efficiency loss is enlarging across time. Specifically, the efficiency loss due to killer innovation is initially around 2.08 percent in 1980, which increases to the interval between 5.77 and 9.39 percent in 2000s, and finally ranges from 15.42 to 29.60 percent in 2019.

The corresponding welfare and markups are documented in panel B and C. In both counterfactual economies, we observe a robust and significant welfare loss due to killer innovation, which increases from roughly 1.78 percent in 1980 to 17.12 percent in 2019. Consistent with the welfare implication, the aggregate markups are lower under the counterfactual equilibria. The sales weighted markup increases from 1.63 to 2.53 in the baseline economy, while the one in the exogenous market structure case is slightly lower. In the planner solution where we allow the endogenous entry decision, we see a drastic decrease in markups, which only increases from 1.58 in 1980 to 1.90 in 2019.[11]

[11] The level of sales weighted markup is higher than the one estimated by De Loecker et al. (2020) because we do not target the correlation between sales and markups in this exercise. This simplification will not change our insights qualitatively.

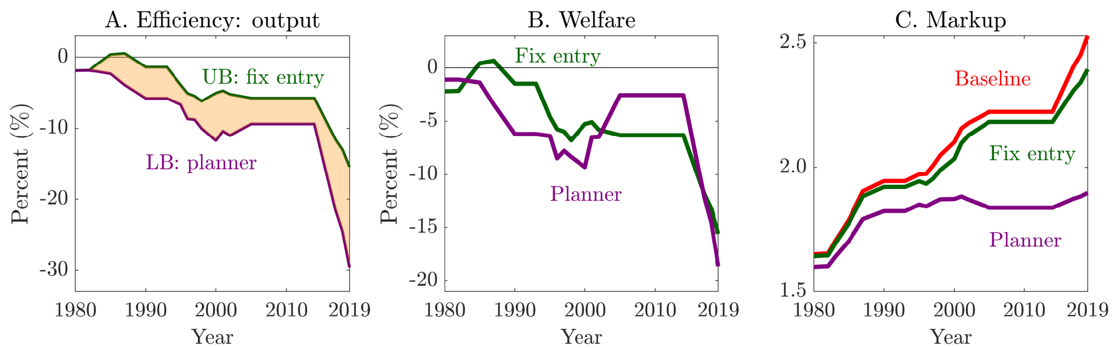

Figure 6: Effects of killer innovation: outputs, welfare, and markups

Notes: Panel A plots the difference in aggregate outputs between the baseline economy and the two counterfactual equilibria relative to the baseline output level. The blue line corresponds to the counterfactual economy with exogenous market structure, while the purple one corresponds to the planner solution. In panel B, we plot the difference in welfare relative to the baseline level. In panel C, we further plot and compare the time series sequence of sales weighted markup for each economy. All the sequences are plotted in the form of five-year centered moving average.

Table 3: Counterfactual policies: taxes and subsidies

Year	△ Welfare			△ Output			△ Wage		
	$(.1, 0)$	$(0, -.1)$	$(.1, -.1)$	$(.1, 0)$	$(0, -.1)$	$(.1, -.1)$	$(.1, 0)$	$(0, -.1)$	$(.1, -.1)$
1980	0.4%	−5.2%	−4.8%	0.5%	−3.8%	−3.3%	0.3%	2.4%	2.6%
2000	2.8%	−6.8%	−3.9%	2.9%	−4.2%	−1.1%	0.8%	4.6%	5.5%
2019	5.3%	−1.3%	2.2%	5.8%	1.1%	4.7%	1.6%	5.0%	5.6%

Notes: The results are normalized by corresponding moments in the baseline economy without taxes of each year.

5.3 Policy: taxes and subsidies

In this section, we evaluate a potential policy to deal with the problem of killer innovation — taxes and subsidies. Specifically, we allow the planner to tax or subsidize leaders and entrants on their gross production profits $\widetilde{\pi}_{\iota j}$. Consequently, firms will expect to earn profit $(1 - \tau_{\iota j})\mathbb{E}[\widetilde{\pi}_{\iota j}|\mathbf{a}_j]$ from the production stage where $\tau_{\iota j}$ is the corresponding tax (if positive) or subsidy (if negative). Therefore, the planner is able to shift the innovation incentive of firms by adjusting the taxes on leaders, τ_ℓ, and/or subsidies on followers, τ_f. For simplicity, we also assume the planner can keep the budget constraint by making an additional lump sum transfer to or from the households, which will thus not influence the equilibrium outcome.

Starting with the three representative economy in 1980, 2000 and 2019, we consider three sets of taxes and subsidies $(\tau_\ell, \tau_f) \in \{(0.1, 0), (0, -0.1), (0.1, -0.1)\}$ and investigate their effects on aggregate welfare, outputs, and wages. Results are reported in Table 3.

We first examine the effects of a 10% gross profit tax on incumbent leaders. Intuitively, profit tax will disincentivize leaders' innovation decision, which will, on one hand, release the problem of killer innovation, and on the other hand reduce the overall productivity. The counterfactual results suggest that in general the first channel dominates and this policy can enhance social welfare. Typically, the welfare gain from this tax rises from 0.4% in 1980 to 5.3% in 2019, which aligns with our previous findings that the problem of killer innovation is increasingly important. The same positive effects also show up in output and wage, which will respectively increase by 5.8% and 1.6% in 2019.

The effects of a 10% subsidy on entry is more ambiguous. On the positive side, subsidies make it easier for followers to enter and hence harder for leaders to kill competition. However, higher subsidies will also deviate the innovation decision of entrants by motivating them to make more innovation than the desirable level, which vitiates the social welfare. In practice, the inefficient side is dominating. We learn from the previous sections that killer innovation is not common before 2000, so entry subsidy has a huge, negative effect on both welfare and output during this period as is shown in Table 3. After 2000, the problem of killer innovation gets more important and the positive effect of this subsidy becomes greater. In 2019, the welfare change becomes -1.3%, which is less negative than the previous years. Moreover, the entry subsidy can overall increase the aggregate output by 1.1%. Finally, the wage will increase due to the subsidy on entrants because it elicits higher labor demand from both innovation and production procedures.

The last case we examine is a combination of a 10% tax on leaders and a 10% subsidy on entrants. The trade-off here involves all the effects of each individual policy. Quantitatively, its impacts on welfare and output lie between the ones from tax alone and subsidy alone, which is thus dominated by the 10% profit tax on leaders. Therefore, we conclude that among all the three policies we discuss here, the profit tax on leaders is the most efficient one.

6 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 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.

These killer innovation strategies have far-reaching macroeconomic implications. Competition is too low compared to first best, business dynamism defines and output and welfare are below optimal. In our quantitative exercise we find that the phenomenon of killer innovations has become especially prevalent starting in the early 2000s. We estimate a welfare cost rising from 3% early on to over 15% in recent times. This indicates that innovation in a strategic context leads to substantial inefficiencies that demand intervention. We propose several policies and evaluate their performance to improve welfare.

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