The Effect of Capital Investment on Firm Risk through Product Market Competition*

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Abstract

This paper theoretically and empirically analyzes the interactions among capacity investments, product market competition, and firm risk. In our model, firms can invest in inflexible or flexible capital. Our model predicts that firm risk is higher for more capital-intensive firms operating in a more concentrated market. This prediction arises because smaller investments would induce greater market competition, which effectively eliminates the right tail of the firm's profit distribution. We provide strong empirical support for our predictions. In particular, firm value is more volatile in less competitive markets for a given level of demand uncertainty.

JEL classification: G12, G31, L13.

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I. Introduction

One of the cornerstone principles in economics and finance is the recognition that the objective of firm managers, as agents of shareholders, is to maximize the value of shareholders' claims to the firm.[1] However, implementing the value maximization rule is notoriously difficult. Thus, much research in corporate finance, asset pricing, and economics attempts to understand how managers maximize shareholder wealth through strategic decisions regarding financial policies and resource allocation. For example, significant theoretical and empirical work now considers how various financial policies such as cash holdings and capital structure may affect the firm's product market.[2]

The interaction between capital investments and the product market competition has been intensively studied in the industrial organization literature (e.g., Spence, 1977; Dixit, 1980; Bulow, Geanakoplos, and Klemperer, 1985; Allen, Deneckere, Faith, and Kovenock, 2000, and many others.) However, these studies are often silent about the risk characteristics of stock returns. Recent financial research has overcome this deficit to identify various channels through which capital investments affect the risk characteristics of stock returns. For example, corporate investment decisions may reveal information regarding shifting investment opportunities (e.g., Cochrane, 1991; Liu, Whited, and Zhang, 2009). Furthermore, corporate investments also affect the risk of stock returns by changing financial and operating leverage, the proportion and type of growth options in corporate value, and the ability to capture positive economic shocks (e.g., Berk, Green, and Naik, 1999; Carlson, Fisher, and Giammarino, 2004; Cooper, 2006; Tuzel, 2010; Kogan and Papanikolaou, 2013, 2014; Babenko, Boguth, and Tserlukevich, 2014). In addition, other studies have introduced an exogenously imposed product market structure (Novy-Marx, 2007; Aguerrevere, 2009). However, the analysis of how financial policy can affect firm risk is further complicated by the need to recognize that managers must optimize among various forms of capital investments having differing degrees of flexibility and efficiency.

In this study, we develop a model that allows us to study how management decisions regarding heterogeneous capital investments endogenously affect the competitive environment in the firm's product market and eventually the riskiness of the firm. We then empirically test key predictions

[1] See Fama and Miller (1972) and the references therein for a complete discussion of the development of the 'market value rule' governing management decision making.

[2] In addition to seeking to maximize shareholder value through optimal financial policies, managers must also make decisions regarding the employment of capital and labor.

of the model by using U.S. corporate data. Without a model, one might casually conjecture that capital-intensive firms that operate in less competitive industries would exhibit lower risk than firms in more competitive industries because firms with greater market power may be able to protect themselves from market risk. Contrary to this conjecture, our model and empirical analysis indicate that capital intensive firms in less competitive industries exhibit higher risk for a given level of demand uncertainty. This is an often overlooked cost in a market with limited competition. Our findings also have implications on anti-trust policies as a ruling to block a merger or acquisition can have unwanted negative consequences on early capital investment. For example, regulatory actions in the telecommunications industry that have limited consolidation may result in lower spending on research and development.

Our model is based on the observation that capital can be either inflexible, which may offer strategic advantages, or flexible, but can be utilized by multiple firms.[3] Examples of inflexible capital include real estate in a unique location or with special features, specialized equipment (such as mining machinery), and patent protections. In contrast, flexible capital examples include railroad rolling stock or aircraft (since they are relatively generic items that can be redeployed by new firms with little or no modification), computer equipment (which only requires altering the software), and generic office space (that can be quickly reconfigured to meet a variety of firm space needs).[4] Since firms often face the choice between owning inflexible firm-specific capital or renting flexible capital, our model also sheds light on questions surrounding why firms continue to own real estate assets despite the development of tax efficient real property providers (e.g., real estate investment trusts and limited liability companies).

Historically, the California Gold Rush in the 19th century and the U.S. automobile manufacturing industry in the early 20th century provide examples of a negative relation between inflexible capital investments and the number of competitors. For example, at the beginning of the 20th Century, the U.S. had several hundred small automobile manufacturers.[5] However, by the 1930's,

[3]Our recognition of the flexibility of capital investment is not new. For example, He and Pindyck (1992) analyze flexible and inflexible capacity investment decisions.

[4]Gersbach and Schmutzler (2012) derive a model that allows for strategic investments in labor that produces similar insights. In their model, labor expenses associated with training serves as a firm-specific investment that affects the firm's product market by deterring potential competitors from entering the market.

[5]Estimates are that over 500 automobile manufacturers entered the U.S. market between 1902 and 1910. (Source: "The Automobile Industry, 1900-1909" accessed on June 1, 2014 at `http://web.bryant.edu/~ehu/h364/materials/cars/cars_10.htm`)

the industry had consolidated into a handful of firms dominated by the "Big Three." One of the factors leading to this consolidation was the Ford Motor Company's investment in the sprawling River Rouge manufacturing plant beginning in 1917. The massive River Rouge plant was capable of processing iron ore and other raw materials into finished products in a continuous production line, providing Ford with significant economies of scale.[6]

We develop a two-stage investment model in which one of $n + 1$ homogeneous firms precedes other firms by investing in inflexible but efficiency-improving capital. Investment in inflexible capital demonstrates the firm's credible commitment to production. The other n firms can subsequently employ flexible but less efficient capital when the realized demand is sufficiently large. The flexible capital is also available for the leading firm for capacity expansion. To counter potential competition, the leading firm takes into consideration the entry deterrence effect of inflexible capital investments. This leader-follower structure better captures the actual corporate behavior for many industries than a simultaneous-move structure. We solve a subgame-perfect Nash equilibrium and endogenously derive the firm's optimal early investment in inflexible capital and subsequent investment in flexible capital, the resulting product market competition, and the systematic risk of corporate assets for a given level of demand uncertainty.

The model generates two key insights. The first insight is that market competition is negatively related to the level of inflexible investments through two channels. First, irreversible investments in inflexible capital have a strong entry deterrence effect under small uncertainty (a causal relation). Second, uncertainty regarding market demand decreases investments but increases competition (a confounding factor). The causal relation suggests that the leading firm's investment in inflexible capital indicates the firm's commitment to production. As a result, other firms only enter or stay in the market when demand is sufficiently large to support the total production by the leading firm and all other competitors. Thus, a larger amount of inflexible capital increases the probability of monopolizing the market. On the other hand, the confounding factor suggests that the competition with other firms is more likely when demand uncertainty is high. This is because high levels of uncertainty imply a greater probability of experiencing a large positive demand shock that encourages entry. At the same time, when demand uncertainty is high, the leading firm employs a

[6] Source: "History of the Rouge" accessed on June 1, 2014 at `http://www.thehenryford.org/rouge/historyofrouge.aspx`

small amount of inflexible capital to avoid large losses under possible weak demand and thus relies more on subsequent flexible capital if realized demand is strong. A positive equilibrium correlation exists between inflexible capital and market concentration.[7]

The second key insight is that market competition makes firms less risky because other firms' options to enter the market eliminate the right tail of the leading firm's value distribution. Competitors can enter the market and take profits away from the leading firm when demand is high but stay away from the market if demand is low. However, without a competitor, the leading firm can earn large profits under high demand by expanding its production. Thus, both the expected value and the unconditional variance of the leading firm's value is greater in a more concentrated market.

Most components of our model are straightforward and consistent with well-established results in the literature. Our contribution is to integrate the fragmented knowledge about capital investment, competitive industry structure, and firm value in a single model and derive a new insight into the link between inflexible capital investments and firm risk. We also present strong empirical support for all key predictions.

Our primary result is to recognize the effect of state-contingent competition on the statistical distribution of the leading firm's value. This finding is closely related to the studies by Aguerrevere (2009), Novy-Marx (2007), and Babenko, Boguth, and Tserlukevich (2014). In particular, Aguerrevere (2009) shows how an exogenously given market structure impacts the risk and returns on firm assets. The key insights from his model are that firms in concentrated markets are less risky when demand is low but they are riskier when demand is high and an option to expand is more valuable. His prediction under high demand agrees with ours. In deriving these insights, Aguerrevere's model assumes a symmetric Nash equilibrium in a repeated Cournot competition among a given number of existing firms that invest in homogeneous capital. Our analysis relaxes these assumptions and endogenizes the market structure. Babenko, Boguth, and Tserlukevich (2014) also derive a lower risk under high demand although they do not take into account an entry deterrence effect of investment. Novy-Marx (2007) also recognizes a skewed return distribution but it is caused by asymmetric adjustment costs of capital for a given size of industry rather than state-contingent

[7] We do not preclude alternative explanations such as shifting investment opportunities and technological changes. Our explanation is complementary to these existing explanations.

competition.

Other results of the model establish two sources of a negative relation between market competition and inflexible investments. We confirm the causal relation between irreversible investments and limited market competition. It is an uncertainty-augmented version of an entry deterrence effect that was established in the industrial organization litterature.[8] We also find a positive relation between demand uncertainty and the probability of entry. This is an extension of the results of Pindyck (1988) and Maskin (1999), who show that leading firms need to employ a larger amount of capital to deter entry when demand is more uncertain. On the other hand, we find a negative relation between demand uncertainty and the optimal amount of inflexible capital. When demand uncertainty is high, the leading firm avoids being committed to a large amount of inflexible capital. This arises as a consequence of the leading firm's option to wait (e.g., Dixit and Pindyck, 1994).[9] These two effects of demand uncertainty establish a negative relation between inflexible capital and market competition.

While our model is general to any form of inflexible capital investment, we empirically test the model's predictions using corporate real estate investment as a laboratory.[10] Our analysis centers on real estate investment decisions by firms whose core business activities are not directly related to the development, investment, management, or financing of real estate properties. We approach real estate as a factor of production, similar to labor or other inputs. Typically, a firm's capital investments consist of assets necessary for production, including physical capital as well as intangible capital such as patents and human capital (labor). Real estate (including manufacturing facilities, warehouses, office buildings, equipment, and retail outlets) represents one of the largest physical capital investment categories. Far from being marginal, real estate represents an important investment that corporations must make in order to competitively produce the goods and services required by their customers. For example, the real estate owned by non-real estate, non-financial

[8] See for example, Bain (1954); Spence (1977); Dixit (1979, 1980); Spulber (1981); Bulow, Geanakoplos, and Klemperer (1985); Basu and Singh (1990); Allen, Deneckere, Faith, and Kovenock (2000). For empirical analysis, see Smiley (1988) and Ellison and Ellison (2011).

[9] Although Grenadier (2002)demonstrates that competition erodes an option premium and makes the model equivalent to Tobin's q model (e.g., Hayashi, 1982), a premium will be preserved under imperfect competition (Novy-Marx, 2007). This effect is also empirically confirmed (e.g., Holland, Ott, and Riddiough, 2000; Ott, Riddiough, Yi, and Yoshida, 2008).

[10] The capital in the model obviously includes but is not limited to real estate. For example, human capital and research and development may also be considered as inflexible capital.

corporations was valued at $7.76 trillion in 2010, accounting for roughly 28% of total assets.[11] However, its bulkiness, large and asymmetric adjustment costs, and relative illiquidity limit the ability of firms to maintain an optimal level of real estate as demand fluctuates.[12]

Our analysis uses data from Compustat on public, non-real estate firms for the period from 1984 to 2012. The results are consistent with all predictions. First, industry concentration is positively related to inflexible capital investments and negatively related to demand uncertainty after controlling for industry characteristics and year fixed effects (Predictions 1 and 2). Approximately 27% of the total explanatory power comes from the factors captured by capital and demand uncertainty, and the remaining 73% comes from various industry characteristics that are uncorrelated with these factors. More specifically, inflexible capital that was employed several years before production has a larger impact on market concentration than the more recently invested capital, implying a time lag for changes in market structure. Also, the market structure is affected by the demand uncertainty observed at the time of production rather than previously made forecasts. We also find that these effects of inflexible capital and demand uncertainty are counter-cyclical. Second, demand uncertainty forecasts negatively affect the amount of inflexible capital (Prediction 3). Specifically, our result is robust to the use of 4, 8, and 12-quarter ahead forecasts of demand uncertainty and the use of 20 and 40-quarter rolling volatility measures. Finally, we report that the firm value volatility is higher in more concentrated markets for a given level of demand uncertainty. This relation holds during both high and low demand periods (Prediction 4).

II. Model

We develop a dynamic model of corporate investments under demand uncertainty. Following Dixit (1980) and Bulow, Geanakoplos, and Klemperer (1985), we assume that firms make capital investment and production decisions in a two-period (i.e., three-date) setting.[13] The model features a leader-follower structure with a focus on the leading firm's inflexible investment. Figure 1 outlines the time line. We first characterize an asymmetric Nash equilibrium in a general setting without specifying functional forms for demand or production cost. Next, we numerically analyze the model

[11] Source: `http://www.federalreserve.gov/releases/z1/20110310/`

[12] Dixit and Pindyck (1994) note that real estate investments may provide firms with options to grow production.

[13] This is the simplest form of multi-period models to analyze long-term commitments. Extending the production period does not change our result.

by specifying a linear demand function and a quadratic cost function.

[Figure 1 about here.]

To frame the basic problem, we begin by assuming a monopoly environment where a firm (Firm 1) produces a good during the second period to sell in the market at t_2 but other firms stay away from the market. In subsequent sections, we consider alternative market structures, where the leading firm may compete with other firms (oligopoly with n other firms and full competition with an infinite number of firms).

A. Case 1: Monopoly

To begin, we assume that capital is the only factor of production. Thus, at t_0 the firm decides the initial size of production capital (e.g., amount of factories, equipment, and corporate real estate) and builds that capital during the first period. We refer to capital acquired during the first period as inflexible capital (K_{s1}) since the firm cannot reduce its initial capacity even if the realized demand shock is weak , and it potentially serves as an entry deterrent as we demonstrate in the following sections. This capital is customized to an efficient production process determined at t_0. As a result, inflexible capital incurs a high fixed cost and a low variable cost of production. The firm pays a one-time fixed cost at t_0 to enter the market and pays the costs of capital and depreciation at t_2.

At t_1, the firm observes a random demand shock (ε) revealing the price level. Based on this observation, it potentially revises its production plan upward by renting additional flexible capital, denoted as K_{g1}. A key advantage of flexible capital is that it offers the firm flexibility in setting up its production process in the face of an uncertain demand shock. We assume that the rent payments for the flexible capital are due at t_2, and this rental rate, which is determined in a competitive rental market, is less than the cost of inflexible capital because of the higher resale value associated with flexible capital. That is, flexible capital is not unique to the firm's production process and thus could be utilized by firms in other markets with little redeployment costs. However, flexible capital entails a higher production cost because it is not customized to a specific production process.[14] As a result, Firm 1 trades off production efficiencies (and their lower production costs) that accrue to

[14]He and Pindyck (1992) make the same assumption about the cost associated to flexible capital since it can interchangeably be used to produce either of two products whereas inflexible capital is product-specific in their model.

investment in inflexible capital at t_0 with less efficient (higher cost) production associated with the more flexible, flexible capital acquired at t_1.

We assume that the quantity produced is linear in capital, $F(K_s, K_g) = K_s + K_g$, and the variable cost of production is increasing and convex in quantity:

$$C_1 = C_1(K_{s1}, K_{g1}) \quad s.t., \frac{\partial C_1}{\partial K_{s1}} > 0, \frac{\partial C_1}{\partial K_{g1}} > 0, \frac{\partial^2 C_1}{\partial K_{s1}^2} > 0, \frac{\partial^2 C_1}{\partial K_{g1}^2} > 0, \frac{\partial^2 C_1}{\partial K_{s1} \partial K_{g1}} > 0. \tag{1}$$

The existence of a fixed cost and a convex variable cost implies a U-shaped average total cost, which is consistent with a production technology that exhibits first increasing returns to scale, then constant returns to scale, and eventually decreasing returns to scale. For example, at a low production level, the optimal production can exhibit economies of scale as capital intensity increases. At a larger scale, limitations to some factor inputs create diseconomies of scale because other factors exhibit diminishing marginal products. This production function is regarded as most realistic in standard mircroeconomics textbooks. We also assume the firm faces an inverse demand function P with the following properties:

$$P = P(K_{s1}, K_{g1}, \varepsilon), \quad s.t., \frac{\partial P}{\partial \varepsilon} > 0, \frac{\partial^2 P}{\partial \varepsilon^2} = 0, \frac{\partial P}{\partial K_{s1}} < 0, \frac{\partial P}{\partial K_{g1}} < 0, \tag{2}$$

where ε is a random variable that represents the demand shock. The realized value of the demand shock at t_1 is denoted by $\bar{\varepsilon}$.

Solving the firm's choices regarding capital investment by backward induction, we note that Firm 1 chooses the amount of flexible capital (K_{g1}) at t_1, taking K_{s1} and $\bar{\varepsilon}$ as given. Thus, at t_1 Firm 1 solves the following profit maximization problem

$$\max_{K_{g1}} \Pi_1 \equiv P(K_{s1}, K_{g1}, \bar{\varepsilon}) \times (K_{s1} + K_{g1}) - C_1(K_{g1}). \tag{3}$$

The first order condition (FOC) and second order condition (SOC) determine the optimal K_{g1}. If the optimal K_{g1} is zero or negative, then Firm 1 does not employ flexible capital. Since the sign of the optimal K_{g1} positively depends on the realized demand shock, this sign condition gives a threshold value of $\bar{\varepsilon}$. Thus, the solution is:

$$\begin{cases} K_{g1}^M(K_{s1}, \bar{\varepsilon}) & \text{if } \bar{\varepsilon} > \varepsilon^M \\ 0 & \text{otherwise.} \end{cases} \tag{4}$$

Because of this nonlinearity in the optimal amount of flexible capital, the maximized profit of Firm 1 is also a nonlinear function of the demand shock. This option-like feature of flexible capital creates the effect of demand volatility on the initial choice of the inflexible capital investment. Furthermore, the threshold value ε^M depends on the amount of K_{s1} and thus, also affects the initial choice of inflexible capital.

At t_0, Firm 1 chooses K_{s1} by maximizing its expected profit where the product price and the amount of flexible capital are uncertain because they depend on the random variable ε. Furthermore, the amount of flexible capital is a nonlinear function of ε due to the state contingency exhibited in Equation (4). Thus, Firm 1 faces the following optimization:

$$\begin{aligned} &\max_{K_{s1}} E\left[\Pi_1^M(K_{s1}, K_{g1}, \varepsilon)\right] \\ &= E\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\,\middle|\,\bar{\varepsilon} > \varepsilon^M(K_{s1})\right] Pr(\bar{\varepsilon} > \varepsilon^M(K_{s1})) \\ &+ E\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\,\middle|\,\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right] Pr(\bar{\varepsilon} \leq \varepsilon^M(K_{s1})), \end{aligned} \tag{5}$$

where Π_1^M denotes Firm 1's profit function and the superscript "M" denotes the monopoly market environment. $Pr(\mathcal{A})$ denotes the probability of event $\mathcal{A}$ and $E[\bullet\,|\mathcal{A}]$ denotes the expectation operator conditional on event $\mathcal{A}$. Equation (5) exhibits state contingency; the first term represents the profit generated by both inflexible and flexible capital when the demand shock is large, and the second term represents the profit generated only by inflexible capital when the demand shock is small. Because Firm 1 produces at full capacity even if the demand level is low, the firm compares potential losses from too large inflexible capital in bad states with extra costs of employing flexible capital in good states. We denote the solution to this problem as

$$\begin{cases} K_{s1}^M & \text{if } E\left[\Pi_1^M(K_{s1}^M, K_{g1}, \varepsilon)\right] > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

B. *Case 2: Oligopoly*

Having established the base conditions for the firm's choice of inflexible and flexible capital under the assumption of a monopoly environment, we now consider a subgame-perfect Nash equilibrium in an oligopoly market that is characterized by the potential competition with n identical firms (Firm $i, i = 2, \ldots, n+1$ without coalitions) at t_1. Firm i observes Firm 1's inflexible capital investment and the realized demand shock before deciding whether to pay a one-time fixed cost and enter the market.[15] The follower firms only employ flexible capital (K_{gi}) for production and face an increasing and convex cost function:

$$C_i = C_i(K_{gi}), \quad s.t., \frac{\partial C_i}{\partial K_{gi}} > 0, \frac{\partial^2 C_i}{\partial K_{gi}^2} > 0. \tag{7}$$

In a market characterized as an oligopoly, the inverse demand function P now has the following properties:

$$P = P\left(K_{s1}, K_{g1}, \sum_{i=2}^{n+1} K_{gi}, \varepsilon\right), \quad s.t., \frac{\partial P}{\partial \varepsilon} > 0, \frac{\partial^2 P}{\partial \varepsilon^2} = 0, \frac{\partial P}{\partial K_{s1}} < 0, \frac{\partial P}{\partial K_{g1}} < 0, \frac{\partial P}{\partial K_{gi}} < 0. \tag{8}$$

As in the monopoly case, the demand curve is downward sloping.

In this market environment, firms compete in the product market at t_2. Thus, taking the competitive environment into account, each firm chooses the amount of flexible capital at t_1. Firm 1 also chooses the amount of inflexible capital at t_0 by taking into account its effect on the competitive environment of the product market. For example, as will be discussed below, a sufficiently large investment in inflexible capital by Firm 1 could serve as a deterrent to potential entrants, leading to a monopoly product market.

At t_1, each entrant chooses K_{gi}, taking K_{s1}, K_{g1}, $K_{gj;\, j \neq i}$, and the realized value of demand shock $\bar{\varepsilon}$ as given in order to solve the following profit maximization problem:

$$\max_{K_{gi}} \Pi_i \equiv P\left(K_{s1}, K_{g1}, \sum_{i=2}^{n+1} K_{gi}, \bar{\varepsilon}\right) \times K_{gi} - C_i(K_{gi}). \tag{9}$$

[15] No entry and the resulting monopoly can also be interpreted as the exit of existing competitors.

In addition to the FOC and SOC, we impose the entry condition:

$$\max \Pi_i(K_{gi}, \bar{\varepsilon}) \geq 0 \tag{10}$$

because the maximized profit can be negative due to the fixed cost of entry. This condition implicitly gives a lower bound of the demand shock $\bar{\varepsilon}$ because $\partial\Pi_i / \partial\bar{\varepsilon} > 0$. Thus, the optimal K_{gi} is:

$$\begin{cases} K_{gi}^{O}(K_{s1}, K_{g1}, K_{gj;\, j\neq i}, \bar{\varepsilon}) & \text{if } \max \Pi_i \geq 0 \\ 0 & \text{otherwise.} \end{cases} \tag{11}$$

where the "O" superscript denotes the oligopoly market environment. If Firm i decides not to enter the market due to a low demand level, then the market devolves to a monopoly of Firm 1.

Similar to Firm i, Firm 1 also chooses K_{g1} at t_1, taking K_{s1}, $K_{gi,i=2,\ldots,n+1}$, and $\bar{\varepsilon}$ as given by solving the problem that is equivalent to Equation (3) with the respective first and second order conditions. The solution is:

$$\begin{cases} K_{g1}^{O}(K_{s1}, K_{gi;\, i=2,\ldots,n+1}, \bar{\varepsilon}) & \text{if } \bar{\varepsilon} > \varepsilon^{O} \\ 0 & \text{otherwise.} \end{cases} \tag{12}$$

The threshold value ε^{O} depends on K_{gi} and K_{s1} and thus, affects the initial choice of inflexible capital.

When both the leader and the follower firms employ positive amounts of flexible capital, the strategic environment in the second period becomes a Cournot competition. The Cournot Nash equilibrium is symmetric among the identical entrants and asymmetric between the leader and entrants. The Cournot Nash equilibrium levels of flexible capital, K_{g1}^{E} and K_{gi}^{E}, are expressed as:

$$K_{g1}^{E}\left(K_{s1}, \bar{\varepsilon}\right) = K_{g1}^{O}\left(K_{s1}, K_{gi}^{O}\left(K_{s1}, K_{g1}^{E}\left(K_{s1}, \bar{\varepsilon}\right), K_{gj;\, j\neq i}^{E}\left(K_{s1}, \bar{\varepsilon}\right), \bar{\varepsilon}\right), \bar{\varepsilon}\right), \tag{13}$$

$$K_{gi}^{E}\left(K_{s1}, \bar{\varepsilon}\right) = K_{gi}^{O}\left(K_{s1}, K_{g1}^{O}\left(K_{s1}, K_{gi;\, i=2,\ldots,n+1}^{E}\left(K_{s1}, \bar{\varepsilon}\right), \bar{\varepsilon}\right), K_{gj;\, j\neq i}^{E}\left(K_{s1}, \bar{\varepsilon}\right), \bar{\varepsilon}\right). \tag{14}$$

Firm i's entry condition (10) gives a threshold value of demand shock ε^{*} such that $\Pi_i(K_{gi}^{E}(K_{s1}, \varepsilon^{*}), \varepsilon^{*}) = 0$. Thus, Firm i will enter the market if $\bar{\varepsilon} \geq \varepsilon^{*}$. We also define the threshold value for Firm 1's expansion in this Cournot equilibrium, ε^{E}, which equals ε^{O} evaluated at K_{gi}^{E}. Therefore, we obtain the following entry deterrence effect of inflexible capital:

Proposition 1: *When demand function is an affine function of price, Firm 1's inflexible capital always has an entry deterrence effect:*

$$\frac{d\varepsilon^*}{dK_{s1}} > 0. \tag{15}$$

For more general demand functions, the existence of the entry deterrence effect depends on parameter values.

Proof. Proof. See Appendix A. □

Firm 1's profit is affected by whether the market becomes a monopoly or oligopoly. Thus, there are three variations in Firm 1's problem depending on the relation among the firms' threshold values: (1) $\varepsilon^M < \varepsilon^E < \varepsilon^*$; (2) $\varepsilon^M < \varepsilon^* < \varepsilon^E$; and (3) $\varepsilon^* < \varepsilon^M < \varepsilon^E$. We present the second variation below and other variations in Appendix B:

$$\begin{aligned}
&\max_{K_{s1}} E\left[\Pi_1(K_{s1}, K_{g1}, K_{gi}, \varepsilon)\right] \\
&\quad \equiv E\left[\Pi_1^O(K_{s1}, K_{g1}^E, K_{gi}^E, \varepsilon)\left|\bar{\varepsilon} > \varepsilon^E(K_{s1})\right.\right] Pr\left(\bar{\varepsilon} > \varepsilon^E(K_{s1})\right) \\
&\quad + E\left[\Pi_1^O(K_{s1}, 0, K_{gi}^E, \varepsilon)\left|\varepsilon^*(K_{s1}) \leq \bar{\varepsilon} \leq \varepsilon^E(K_{s1})\right.\right] Pr\left(\varepsilon^*(K_{s1}) \leq \bar{\varepsilon} \leq \varepsilon^E(K_{s1})\right) \\
&\quad + E\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\left|\varepsilon^M(K_{s1}) < \bar{\varepsilon} < \varepsilon^*(K_{s1})\right.\right] Pr\left(\varepsilon^M(K_{s1}) < \bar{\varepsilon} < \varepsilon^*(K_{s1})\right) \\
&\quad + E\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\left|\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right.\right] Pr\left(\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right)
\end{aligned} \tag{16}$$

where Π_1^O denotes Firm 1's profit function in the oligopoly market. In this problem, state contingency arises from both Firm 1's own option to expand and Firms i's option to enter the market. The four terms on the right hand side of Equation (16) corresponds to four possible types of market structures: (1) Both leader and followers employ flexible capital in a Cournot competition; (2) Only followers employs flexible capital and compete with the leader; (3) The leader monopolizes the market with both inflexible and flexible capital; and (4) No firm employs flexible capital and the leading firm monopolizes the market with inflexible capital. We denote the solution to this problem as

$$\begin{cases} K_{s1}^O & \text{if } E\left[\Pi_1^O(K_{s1}^O, K_{g1}^E, K_{gi}^E, \varepsilon)\right] > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{17}$$

The solution is characterized in a usual way by FOC and SOC.[16]

C. Case 3: Full Competition

We can easily generalize the oligopoly case to a market characterized as perfectly competitive (with an infinite number of firms) by noting that the inverse demand function is horizontal:

$$P = P(K_{s1}, K_{g1}, K_{gi}, \varepsilon), \quad s.t., \frac{\partial P}{\partial \varepsilon} > 0, \frac{\partial^2 P}{\partial \varepsilon^2} = 0, \frac{\partial P}{\partial K_{s1}} = \frac{\partial P}{\partial K_{g1}} = \frac{\partial P}{\partial K_{gi}} = 0. \tag{18}$$

In the competitive market, the solutions to the optimal flexible capital for Firm 1 (K_{g1}) becomes:

$$\begin{cases} K_{g1}^C(K_{s1}, \bar{\varepsilon}) & \text{if } \bar{\varepsilon} > \varepsilon^C \\ 0 & \text{otherwise.} \end{cases} \tag{19}$$

where as before, the threshold value ε^C depends on the amount of K_{s1}. As in the previous cases, Firm 1 chooses K_{s1} at t_0 by maximizing its expected profit:

$$\begin{aligned} &\max_{K_{s1}} E\left[\Pi_1^C(K_{s1}, K_{g1}, \varepsilon)\right] \\ &= E\left[\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon) \left| \bar{\varepsilon} > \varepsilon^C(K_{s1})\right.\right] Pr(\bar{\varepsilon} > \varepsilon^C(K_{s1})) \\ &+ E\left[\Pi_1^C(K_{s1}, 0, \varepsilon) \left| \bar{\varepsilon} \leq \varepsilon^C(K_{s1})\right.\right] Pr(\bar{\varepsilon} \leq \varepsilon^C(K_{s1})), \end{aligned} \tag{20}$$

where Π_1^C denotes Firm 1's profit function in the competitive market. The solution to this problem is given as

$$\begin{cases} K_{s1}^C & \text{if } E\left[\Pi_1^C(K_{s1}^C, K_{g1}, \varepsilon)\right] > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{21}$$

D. Linear demand and quadratic cost function

To obtain more concrete predictions of the model, we specify simple functions for the demand and production costs. First, we set the inverse demand function as linear in quantity: $P = A - BQ + \varepsilon$, where P is the product price, Q is the product quantity, A and B are non-negative

[16] Technically, the Leibniz integral rule is applied to conditional expectations to derive partial derivatives of the expected profit with respect to inflexible capital.

constants, and ε is a random variable that represents demand shocks. ε is drawn from a uniform distribution $U(-\sqrt{3}\sigma, \sqrt{3}\sigma)$ with $\sigma > 0$. Its mean and variance are $E[\varepsilon] = 0$ and $Var[\varepsilon] = \sigma^2$. This demand function is well-defined on $\{Q : Q > 0 \text{ and } BQ < A - \sqrt{3}\sigma\}$. In a competitive market, $B = 0$. In the monopoly market, $Q = K_{s1} + K_{g1}$. For the oligopoly market, we focus on the case of one competitor ($n = 1$): $Q = K_{s1} + K_{g1} + K_{g2}$ because analyzing a larger number of competitors does not give additional insights (nevertheless, we provide solutions of the n-entrant case in Appendix C).

The marginal cost of production is linear in quantity:

$$\text{Firm 1: } \begin{cases} \alpha K & \text{for } 0 \leq K \leq K_{s1}, \\ \alpha K_{s1} + \beta(K - K_{s1}) & \text{for } K > K_{s1}. \end{cases} \tag{22}$$

$$\text{Firm 2: } \beta K, \tag{23}$$

where $\beta > \alpha > 0$. α and β correspond to the slope of the marginal cost line for inflexible and flexible capital, respectively. The user cost of capital, which is paid at t_2, is $sK_{s1} + gK_{g1}$ and gK_{g2} for Firms 1 and 2, respectively. The parameter s denotes the user cost of inflexible capital for two periods; i.e., $s = r(1 + r) + (r + \delta)$, where $r(1 + r)$ is the compounded interest cost for the first period, and $r + \delta$ is the sum of interest and depreciation costs for the second period. The parameter g denotes the rental rate of flexible capital for one period, which compensates for the interest and depreciation costs for the lessor. The depreciation rate is smaller for flexible capital than for inflexible capital because the resale value of inflexible capital is low due to customization. Given these costs, the total cost functions for Firms 1 and 2 become quadratic in quantity:

$$C_1(K_{s1}, K_{g1}) = (1 + r)^2 f + sK_{s1} + gK_{g1} + \frac{\alpha}{2} K_{s1}^2 + \alpha K_{s1} K_{g1} + \frac{\beta}{2} K_{g1}^2, \tag{24}$$

$$C_2(K_{g2}) = (1 + r)f + gK_{g2} + \frac{\beta}{2} K_{g2}^2, \tag{25}$$

where f is the fixed cost of entry. C_1 and C_2 satisfy the conditions specified in Equations (1) and (7).

Appendix C presents the solutions to both firms' problems for each market structure; i.e., K_{g2}^C and K_{g2}^O for Firm 2, and $K_{g1}^C, K_{g1}^M, K_{g1}^O, K_{s1}^C, K_{s1}^M$, and K_{g1}^O for Firm 1. Because these solutions are long polynomial equations, we present numerical values for a set of parameters that satisfies the regularity conditions for the demand function and probabilities in the case of Equation (B.1a): $B = 0.5, \alpha = 0.8, \beta = 1.4, r = 0.05, s = 0.3, g = 0.2,$ and $f = 3.2$. The demand level A is set around 4. We change demand uncertainty σ from 0.6 to 2 to obtain our theoretical predictions.

Figure 2a depicts the optimal amount of inflexible capital for various levels of demand uncertainty in the competitive market. For each level of demand uncertainty, we set the price level A such that the entrant's expected profit becomes zero. The price levels vary between 3.9 and 4.3 in this exercise. Figure 2b depicts inflexible capital in the monopoly market and the potential oligopoly market. The demand level A is fixed at 4.3. We find a negative effect of demand uncertainty on inflexible capital in all market structures.

[Figure 2 about here.]

This negative effect is created by a trade-off between efficiency and inflexibility of inflexible capital. Firm 1 compares the efficiency gain and potential loss from holding a inflexible capital. By using inflexible capital, Firm 1 benefits from a more efficient production than by expanding its operations with flexible capital. Thus, inflexible capital is advantageous in a strong market to the extent of the efficiency gap between inflexible and flexible capital. However, in a weak market, greater amounts of inflexible capital result in larger losses. Because potential losses increase with uncertainty, Firm 1 employs a smaller amount of inflexible capital when demand is more uncertain.

Figure 2b also exhibits greater amounts of inflexible capital in the potential oligopoly market than in the monopoly market. This gap represents Firm 1's motive to deter entry of a potential competitor. In the low end of the uncertainty range, the gap is smaller because Firm 1 can successfully deter entry with a smaller amout of extra capital.

Figure 3a demonstrates how the probability of deterring entry changes by uncertainty when Firm 1 adopts the optimal investment strategy. When $\sigma = 0.6$, the probability of oligopoly (i.e., entry) is only 0.1%, and Firm 1 is likely to monopolize the market. When $\sigma = 2.0$, the probability of oligopoly becomes 36.3%. Thus, the probability of monopoly is negatively related with uncertainty. Under high uncertainty, a large amount of inflexible capital is needed to completely deter entry. However, such a large amount of capital is not optimal because it will cause a large amount of loss under weak demand. This is a novel finding. As demonstrated in the literature, uncertainty makes entry deterrence more difficult (e.g., Maskin, 1999). We further demonstrate that complete entry deterrence is not only difficult but also suboptimal under uncertainty when losses from overcapacity are taken into account.

[Figure 3 about here.]

Figure 3b exhibits these probabilities in terms of the ranges of ε that are defined by the threshold values ε^* and ε^M. The upper range ($\varepsilon \geq \varepsilon^*$) corresponds to an oligopoly when entries are accommodated. As σ increases, the probability of entry increases and approaches 0.5 because a mean-preserving spread brings greater probability mass to the range above the threshold value ε^*. The middle range $\left(\varepsilon \in \left(\varepsilon^M, \varepsilon^*\right)\right)$ and the lower range $\left(\varepsilon \leq \varepsilon^M\right)$ correspond to a monopoly with and without expansion, respectively.

The degree of market concentration can also be plotted against the optimal amount of inflexible capital. Figure 4 plots the probability of monopoly, which is a measure of the degree of market concentration in the model. The figure exhibits a positive relationship between inflexible capital and market concentration.

[Figure 4 about here.]

Figures 5 depicts distributions of Firm 1's realized profits for different values of demand uncertainty ε based on 5,000 simulations. Figures 5a is for the monopoly market and 5b is for the potential oligopoly market. Note that the profit in our single-period production model represents periodic profits as well as the total firm value. When demand uncertainty is small, both distributions are relatively symmetric and similar to each other. However, when demand uncertainty is large, then the monopoly profit distribution exhibits positive skewness. This positive skewness is a result of exercising the expansion option; the firm earns profits from high demand while limiting losses from weak demand. In contrast, the distribution in the potential oligopoly market is bi-modal and narrower than in the monopoly case. When demand is high, the second firm enters the market and eliminates Firm 1's opportunities to earn high profits. The downward shift of profits forms the second peak around the value of 3 in profits.

[Figure 5 about here.]

Figure 6 plots relative volatility of profits against relative volatility of demand (σ) for three market structures. The smallest volatility is normalized to unity. Note that the correlation coefficient between demand shocks and the firm value is one because the demand is the sole source of uncertainty in this economy. Thus, as Aguerrevere (2009) defines, the elasticity of the firm value with respect to demand shocks represents the systematic risk (i.e., the market beta) of the firm value.

When the monopoly structure is imposed, the volatility of profits is almost directly proportional to demand volatility because the demand uncertainty is absorbed by one firm. In particular, the monopoly firm captures the entire profit from large demand by exercising the option to expand. In contrast, the slope is much flatter in the potential oligopoly market. In this market, the profit must be shared with a competitor that enters the market when demand is large. The large upside potential is absent for the leading firm due to the endogenous change in market structure. This limited upside potential is the reason why the value uncertainty is reduced. Finally, in the competitive market, the line is flat because profits are always zero. In summary, greater competition reduces the systematic risk of firm value. On one hand, competition decreases the expected firm value, but on the other hand, competition creates a benefit of decreasing the systematic risk.

[Figure 6 about here.]

E. Empirical Predictions

Our model generates four inter-related predictions. First, as seen in Figure 4, we find a positive relation between inflexible capital and market concentration, with greater amounts of inflexible capital creating a stronger effect of entry deterrence. In other words, leading firms can deter competitive entrants by increasing investment in inflexible capital. This observation leads to the first prediction:

Prediction 1: *Market concentration increases as the reliance on inflexible capital increases.*

Second, as noted in Figure 3a, the probability of market competition increases as demand uncertainty increases. Our model suggests that when demand uncertainty is high, a firm's ability to deter entry is smaller for a given amount of inflexible capital. Thus, our second prediction is:

Prediction 2: *Market concentration increases as demand uncertainty declines.*

Third, as seen in Figure 2, greater demand uncertainty causes the firm's option to expand to be more valuable. In addition, uncertainty makes inflexible capital less effective in entry deterrence. Thus, the firm employs a smaller amount of inflexible capital when faced with greater uncertainty. This observation leads to the third prediction:

Prediction 3: *The amount of inflexible capital utilized by firms is greater when demand uncertainty is smaller.*

Finally, from Figure 6, we obtain the last prediction:

Prediction 4: *The volatility of firm value is less than directly proportional to the demand volatility and the slope is steeper in a more concentrated market.*

Our predictions concerning the interaction of competition and inflexible capital were generated from a stylized two-period model. Thus, in order to empirically test these predictions, we must adjust the stylized predictions to reflect a multi-period world. For example, the model does not differentiate between a stock or flow measure of inflexible capital investment. However, empirically testing the predictions requires that we carefully consider the application of the model to whether the various predictions apply to a stock or flow measurement of inflexible investment.

III. Empirical Analysis

In this section, we present the formal empirical analysis of the model's predictions using a sample of public firms listed on NYSE, AMEX, and NASDAQ that have balance sheet and income statement data available on the Compustat annual and quarterly accounting databases and monthly stock returns reported on the Center for Research in Security Prices (CRSP) database. The sample comprises firms with two-digit SIC numbers between 01 and 87, excluding real estate investment trusts (REITs) and other public real estate firms, hotels and lodging, and investment holding companies.

We restrict our analysis to firms with information recorded in the Compustat dataset over the period 1984 to 2012 that have positive total assets (TA), property, plant and equipment (PPE), net sales (Sales), and real estate data reported on the balance sheet.[17] Our final sample consists of 11,708 firms belonging to 65 two-digit SIC code industries.[18] We also conduct robustness checks by excluding the utility industries (i.e., electric, gas, sanitary services, and water transportation industries). Table I shows the frequency distribution of firms and industries over the sample period. The sample contains an average of 3,993 firms per year, ranging from 2,874 firms in 2012 to 5,627 firms in 1997.

In the theoretical model, we characterize inflexible capital as (1) taking time to build, (2) being fixed in size, (3) determining the production capacity, and (4) improving operational efficiency. Thus, in order to test the model's predictions we use owned corporate real estate as a proxy for inflexible capital. Corporate real estate assets include factories, warehouses, offices, and retail facilities. Investing in real estate requires a significant amount of time. Real estate largely determines production capacity, and it is difficult to adjust its size once developed. Owned real estate that is tailored for a firm improves production efficiency (e.g., a factory designed for a particular production process). We also consider long-term leased real estate as equivalent to owned real estate (e.g., a single-tenant warehouse that is designed specifically for the tenant firm). By contrast, short-term rental spaces are considered to be flexible capital.

We construct capital measures using the Compustat PPE account, which includes buildings, machinery and equipment, capitalized leases, land and improvements, construction in progress, natural resources, and other assets. Following the literature, we measure inflexible capital by adding buildings, land and improvements, and construction in progress in PPE (RE_Assets). Then we construct a normalized measure of inflexible capital (SC) by taking the ratio of RE_Assets to PPE. [19]

We measure industry concentration using the Herfindahl-Hirschman Index (HHI) computed on the basis of net sales.[20] To ensure that our results are not driven by the HHI measure, we also

[17]Prior to 1984, PPE accounts were reported net of depreciations. Compustat switched to a cost basis reporting with accrued depreciation contra accounts from 1984 onward. For consistency purposes, we restrict our analyze to this period. However, reported tests based on the 40-year period from 1973 to 2012 show similar results.

[18]We also conducted our analysis excluding utilities and the results are qualitatively the same.

[19]We could also use capital investment as a measure of inflexible capital because, in the theoretical model, capital investment is equivalent to the stock of capital. Our current stock measure is relevant as a proxy for capacity.

[20]The HHI of an industry is the sum of the squares of the individual firms' net sales to total industry net sales. The higher the number of firms in an industry is, the smaller the resulting industry's HHI will be. The HHI is based on net sale because gross sales figures are not available on Compustat. Our industry concentration measure does not account the effect of imports from non-US listed firms. But since it omits exports by US firms, the net effect should be smaller.

use industry concentrations based on the three largest firms in terms of net sales. Again, industry classifications are based on two-digit SICs, with industry concentrations computed every year using the annual net sales from Compustat.

In the theoretical model, the industry-wide demand shock is the sole source of uncertainty and affects the revenue and profits of both leading and following firms. To construct a proxy for the demand uncertainty, we use the year-on-year quarterly net sales growth from the Compustat data series. The sales growth is primarily driven by demand shocks rather than supply shocks because a demand shock changes price and quantity in the same direction whereas a supply shock changes price and quantity in the opposite directions. We first compute the time-series variance of the industry mean quarterly sales growth rate. The variance is measured on a rolling basis using 20- and 40-quarter look-back windows. Because this variance measure is biased due to the time-varying number of observations in an industry, we make a statistical adjustment as detailed in Appendix D to remove the effect of the number of observations. We use the standard deviation as the volatility measure.

The realized volatility at the time of production is suitable for studying the effect of volatility on HHI because the contemporaneous level of uncertainty affects firms' entry decisions. However, this realized measure is not the best to study the effect of volatility on corporate investments because firms make their investment decisions on the basis of forecasts of the future demand uncertainty that will affect their production. In the theoretical model, this timing gap is not an issue because the demand uncertainty is constant over time. In our empirical analysis, we mimic firms' forecasts of the industry sales volatility by estimating an ARIMA(1,1,0) model on a 20- and 40-quarter rolling basis.[21]

In addition, we compute the volatility of firm value to test Prediction 4. Because the theoretical model is a two-period model, firms' profits are equivalent to the firm value. In the empirical test, periodic profits are not a good measure because profit growth is highly correlated with sales growth, which we use for demand uncertainty. Moreover, the gap between sales volatility and profit volatility is primarily determined by the operating leverage (i.e., the amount of fixed costs in production). Thus, we use the variance of quarterly changes in firm value based on the monthly CRSP data

[21] The positive autocorrelations of our volatility measure almost completely disappear when we take the first difference. Thus, we estimate a simple AR(1) model for volatility changes.

series.

A. *Descriptive Statistics*

Table II presents the industry level descriptive statistics for the 29-year period from 1984 to 2012. The average industry contains 69 firms and has an HHI of 0.19 - the corresponding median values are 27 firms and an HHI of 0.14. The average level of concentration among the 65 industries varies considerably from 0.02, which is characteristic of a very competitive industry, to 0.83, indicating a highly concentrated industry - we impose a cutoff of three firms minimum per industry. The most competitive industry in our sample consists of 534 firms.

Also, average firm size (whether measured by market value, sales, or total assets in 2012 U.S. dollars) increases with industry concentration. The distribution of firm sizes in our sample is positively skewed with a mean and a median total assets per firm of $615 million and $64 million, respectively. Understandably, our sample is dominated by relatively small firms mostly operating in competitive industries. As expected, leverage and industry concentration are also positively related for good reasons. As noted in the introduction, the average amount of inflexible capital owned by firms in our sample is 27% of PPE. The average annual rent expense for our sample is roughly $2.3 million. The average stock of flexible capital derived from rent expenses is 46.6%, indicating that firms use significant amounts of this more flexible type of capital as well.[22]

The bottom section of Table II presents the summary statistics of our measures of sales volatility and firm value volatility computed on the rolling 20- and 40-quarter basis. The adjusted variance of sales growth sometimes exhibits negative values because of the adjustment outlined in Appendix D. However, this does not affect our results because the relative volatilities are what matters.

B. *Results*

B.1. Predictions 1 and 2.

Prediction 1 concerns a causal relationship that the use of inflexible capital increases industry concentration (the entry deterrence effect). Prediction 2 indicates that demand uncertainty also affects industry concentration. To test these predictions, we estimate via ordinary least squares

[22] Generic Capital (GC) is the ratio of capitalized rent expenses (using corporate bond yields) to PPE plus capitalized rent expenses.

(OLS) the following industry-level panel regression model that controls for industry characteristics and year fixed effects:

$$HHI_{it} = \beta_0 + \beta_1 SC_{it} + \beta_2 GC_{it} + \beta_3 VOL_{it} + \gamma X_i + y_t + \varepsilon_{it}. \tag{26}$$

where HHI_{it} is the Herfindahl-Hirschman Index for industry i in year t and represents our proxy for market concentration; SC_{it} represents our proxy for inflexible capital; GC_{it} represents our proxy for flexible capital; VOL_{it} represents our proxy for the industry demand uncertainty; and X_i represents industry characteristics.[23] The industry characteristics include the mean growth rate of industry sales, industry age, mean leverage, the number of firms, the mean asset size of firms, and the return on asset (ROA).

Key challenges to this identification are potential reverse causality and the existence of a confounding factor. However, reverse causality is not a serious issue in our estimation because our strategic capital (SC_{it}) measure is based on the past accumulation of capital. Furthermore, with the use of year fixed effects, our estimation mainly relies on cross-sectional variations. Thus, persistent variables in time-series are not a serious issue, either. To clarify the causal effects of past inflexible investments, we decompose SC_{it} into $SC_{i,t-3} + \Delta SC_{i,t-2} + \Delta SC_{i,t-1} + \Delta SC_{i,t}$, where $\Delta SC_{i,t}$ represents the change in inflexible capital between $t-1$ and t. Thus, the β coefficient on the single current variable equals the weighted average of the coefficients on the decomposed terms. This decomposition also enables us to infer the time lag in the effect of capital investments on market concentration.

We control for demand uncertainty as a confounding factor because it is predicted to affect both industry concentration and the investment in inflexible capital. Although there are various methods to deal with confoundedness such as matching methods, there is no fundamental difference between regression methods and matching methods (see Angrist and Pischke, 2009, for detailed discussions). It is also important to note that inflexible capital is not entirely driven by demand uncertainty; i.e., an entry deterrence effect exists even without demand uncertainty. Thus, it is necessary to include both SC_{it} and VOL_{it}. The current level of uncertainty is our primary measure because the entry decision of a competitor is based on the current level of demand uncertainty. However, previous

[23] HHI_{it} is bounded between 0 and 1, with monopoly industries having a value of 1 and perfectly competitive industries having a value of 0. SC_{it} is also bounded between 0 and 1 because it is the ratio to total PPE.

forecasts may affect the market concentration if the entry decision was made several years before production on the basis of volatility forecasts. Thus, we also include the 1, 2, and 3-year forecast errors of our ARIMA(1,1,0) model.

Table III reports the results, all of which are consistent with the predictions. When we impose $\beta_3 = 0$ to test Prediction 1 (column 1), the estimated β_1 for inflexible capital is 0.15 and statistically significant at the 1% level. Moreover, the coefficient is 55% larger for inflexible capital (0.15) than for flexible capital (0.10), indicating the entry deterrence effect of inflexible capital. Alternatively, when we impose $\beta_1 = \beta_2 = 0$ to test Prediction 2 (column 2), the estimated coefficient on the current sales volatility is -0.20 and statistically significant at the 1% level. Greater demand uncertainty makes the market more competitive. We report the result with the 20-quarter rolling volatility measure, but the 40-quarter rolling volatility gives a consistent result. Regarding the coefficients on industry characteristics, the average growth rate, leverage, and the average firm size do not exhibit significant effects on market concentration. The industry age has a profound positive effect but it disappears when we decompose inflexible capital by seniority.

[Table III about here.]

The results are largely unchanged when we remove restrictions on $\beta_1, \beta_2, \text{or} \beta_3$ to estimate the causal effect of inflexible capital on the market concentration by controlling for sales volatility as a confounding factor. In column 3, the coefficient on inflexible capital is 0.15, which is statistically significant and greater than the coefficient on flexible capital (0.09). Thus, investments in inflexible capital has a positive causal effect on market concentration. The coefficients imply that, on average, a one standard deviation increase in inflexible capital (from 26% to 38%) increases the average HHI by 0.018 points. A one standard deviation increase in demand uncertainty (from 3.9 % to 13.9%) decreases the average HHI by 0.014 points. On the basis of the adjusted R^2, approximately 27% of the total explanatory power comes from the factors captured by capital and demand uncertainty, and the remaining 73% comes from various industry characteristics that are uncorrelated with these factors. Since our variables for capital and uncertainty are measured with errors, the proportion could increase by using more accurate measures.

When SC_{it} is decomposed and past forecast errors in sales volatility are added (column 4), we see that inflexible capital that was in place 3-years before production makes the largest impact on market concentration (0.18). The impact monotonically decreases as the timing of investment becomes closer to production. However, all coefficients are positive and statistically significant at least at the 10% level. Thus, market concentration increases with several years of lags as the reliance on inflexible capital increases. The estimated coefficient on the current sales volatility is −0.12, which is statistically significant at the 5% level. However, coefficients on the past forecast errors are not statistically significant. Thus, the demand volatility at the time of production negatively affects market concentration, which suggests a relatively quick response of entrants to the market condition.

In addition to the average relation, we also investigate the temporal variation in the effect of inflexible capital by estimating the following regression that allows for time-varying betas:

$$HHI_{it} = \beta_0 + \beta_t SC_{it} + y_t + \varepsilon_{it}. \tag{27}$$

Figure 7 plots the yearly estimated coefficients. We note that in all years, we obtain a positive coefficient, which is consistent with Prediction 1. Although cycles are observed, the year-specific coefficient appears stationary. Interestingly, the coefficient is larger during the recession periods of the early 1990's, the early 2000's, and the late 2000's.

[Figure 7 about here.]

Similarly, for Prediction 2, we estimate the following model with time-varying beta:

$$HHI_{it} = \beta_0 + \beta_t VOL_{it} + y_t + \varepsilon_{it}. \tag{28}$$

Figure 8 plots the yearly estimated coefficients. The estimated coefficient is negative for 26 years during the 36-year sample period when we use 20-quarter volatility. The coefficient is negative for 25 years during the 32-year period when we use 40-quarter volatility. The mean coefficient is −0.23 and −0.30 for the 20- and 40-quarter measures, respectively. These mean values are consistent with the estimated coefficient from the constant-coefficient model.

[Figure 8 about here.]

B.2. Prediction 3.

We now turn to the model's prediction concerning the negative relation between the investment in inflexible capital and demand uncertainty. We note the timing gap between the initial investment and the demand uncertainty in the production phase. Thus, we use the ARIMA(1,1,0) volatility forecasts in the following panel regression model with year fixed effects:

$$SC_{it} = \beta_0 + \beta_1 E_t \left[VOL_{i,t+q}\right] + \beta_2 GC_{it} + \gamma X_i + y_t + \varepsilon_{it}, \tag{29}$$

where $E_t \left[VOL_{i,t+q}\right]$ is the q-quarter ahead forecast of industry i's level of sales volatility. We compute the 20- and 40-quarter rolling volatility measures adjusted for the time-varying sample size as described in Appendix D. Then we construct the 4, 8, and 12-quarter ahead forecasts.

Table IV reports the estimation result. Consistent with the theoretical prediction, the estimated coefficients on the expected volatility are negative and statistically significant at the 5% level or higher in all specifications. For the 40-quarter rolling volatility measure (columns 4, 5, and 6), the estimated coefficients are -0.0956, -0.0778, and -0.0634 when 4-, 8-, and 12-quarter ahead forecasts are used, respectively. The effect of uncertainty is strongest when the 4-quarter forecasting horizon is used. Thus, firms employ a smaller amount of inflexible capital if they expect greater demand uncertainty for the next year. The effects are economically significant because a one percentage point change in the ratio requires a large change in capital investment that increases the total PPE by more than one percent after depreciation. We also observe strong substitution between inflexible capital and flexible capital; the coefficient on flexible capital is -0.21 and statistically significant at the 1% level.

[Table IV about here.]

In addition to the average impact of demand uncertainty on the use of inflexible capital, we also investigate the time variation in the parameter coefficient by estimating the following regression that allows for time-varying betas:

$$SC_{it} = \beta_0 + \beta_t E_t \left[VOL_{i,t+q}\right] + y_t + \varepsilon_{it}. \tag{30}$$

Figure 9 depicts the estimation result using the 8-quarter ahead forecasts of demand volatility.[24] The estimated coefficient is negative for 17 years in the 29-year period when we use 20-quarter volatility, and for 19 years in the 27-year period when we use 40-quarter volatility. Interestingly, the coefficients are positive during recessions in the early 1990's and early and late 2000's especially when 20-quarter rolling volatility is used.

[Figure 9 about here.]

B.3. Prediction 4.

Tables V and VI report the result of the OLS estimation of panel regression model:

$$\begin{aligned} VOL_{it}^{value} =& \beta_0 + (\beta_1 + \beta_2 HHI_{it}) VOL_{it}^{sales} \\ & + LD_t\{\beta_3 + (\beta_4 + \beta_5 HHI_{it}) VOL_{it}^{sales}\} \\ & + \gamma X_i + y_t + \varepsilon_{it}, \end{aligned} \tag{31}$$

where VOL_{it}^{value} is industry i's corporate value volatility at time t and LD_t is a dummy variable that represents the low demand state. We use three measures of LD_t: the NBER recession periods and periods of low growth in aggregate sales. Our model's predictions are: $\beta_1 \in (0, 1)$ and $\beta_2 > 0$. In addition we test Aguerrevere's (2009) predictions: $\beta_5 < 0$, $\beta_2 + \beta_5 < 0$, $\beta_1 + \beta_4 > 0$, and $\beta_1 + \beta_2 + \beta_4 + \beta_5 > 0$.

Table V reports the results when we impose $\beta_3 = \beta_4 = \beta_5 = 0$. When $\beta_2 = \gamma = 0$ is further imposed (columns 1 and 3), the estimated value of β_1 is 0.22 and 0.31 when the 20- and 40-quarter rolling volatility measures are used, respectively. These coefficients represents the average slope for various concentration levels in both demand states. Both estimates are consistent with our model's prediction. When the restriction on β_2 and γ is relaxed in columns 2 and 4, the coefficient on the interaction term is positive and statistically significant. When the 40-quarter rolling volatility measure is used, the estimated slopes are 0.12 for a perfectly competitive market (β_2) and 0.81 for a monopoly market ($\beta_1 + \beta_2$). The estimated coefficients confirm that firm value volatility is greater in a more concentrated market. Regarding the coefficients on the control variables, firm

[24] The results with other forecast horizons are almost identical.

value volatility is greater for an industry with a high sales growth rate, high leverage, a short history, smaller firms, and a lower yield.

[Table V about here.]

Table VI reports the results when we condition on the low demand state. Column 2 is for the NBER recession dummy and columns 3 and 4 are for aggregate low sales dummy. Column 4 reports the result with a nonlinear effect of a high HHI dummy. The main effects of sales volatility (β_1) and market concentration (β_2) are positive and statistically significant at the 1% level for all specifications. Firm value volatility is high during low demand states; β_3 is 0.01 for NBER recession periods and 0.02 for low growth periods. The estimate of β_5 on the product of volatility, HHI, and a low demand indicator is positive when NBER recession periods are used (0.06), but is negative when low sales growth measures are used (-0.70). Although this negative coefficient in column 3 is consistent with Aguerrevere's (2009) model, the sum of β_2 (1.08) and β_5 (-0.70) is still positive. Thus, we find that firm value is riskier in more concentrated market regardless of demand levels. One possible explanation for this result is that the U.S. market since 1984 has been in a sufficiently high demand state where the option to expand has a large value.

[Table VI about here.]

B.4. Robustness Check.

Unfortunately, the Compustat data does not include private or non-U.S. firms. Therefore, we recognize that our HHI measure may give an inaccurate representation of industry structure. However, to be clear, the issue here is about data availability and representativeness rather than the methodology used to compute our concentration index. Yet, it is also important to note that the data availability bias inherent in using Compustat is probably minimal since in most industries public firms are likely to be larger than private firms, and therefore, the level of competition among public firms should give a realistic estimate of industry structure.

Nevertheless, we check the robustness of our results by using an additional measure of industry concentration based on the market share of the three largest firms. Since the HHI uses squared market shares, which may amplify the missing data problem, we compute a secondary industry concentration index that attenuates this problem by directly adding the individual three largest firms' market shares. Furthermore, this measure is consistent with the concept of early strategic capital investment by leading firms. We used this measure to retest the effects of strategic capital investment and demand volatility on industry concentration (Predictions 1 and 2) and the impact of industry concentration on firm risk (Prediction 4). Tables E.1 and E.2 in the appendix show that our findings are generally robust to this alternative measure of industry concentration. Even though this measure has some drawbacks, we rely on the preponderance of the evidence in support of our predictions to convince the reader that our results generally obtain.

IV. Conclusion

We investigate how the interplay between inflexible investments and demand uncertainty simultaneously determines industry market structure and firm riskiness. This study also provides a better understanding for why firms own inflexible capital as opposed to leasing more flexible capital. In our model which captures realistic features of investment and production, firms invest in inflexible capital after taking into account its effect on the product market competition.

The main results of our analysis are that the use of inflexible capital investment is negatively related to market competition and that greater market competition results in a smaller risk in corporate value for a given level of demand uncertainty. These results do not depend on traditional leverage effects or asymmetric adjustment costs within a firm. Rather, our key insight is that the riskiness of a firm critically depends on the level of market competition that is contingent on the state of stochastic demand and the firm's capital investments. This state-contingent competition with potential entrants is often implicit but relevant for most industries. The state-contingency arises from a combination of an entry deterrence effect of inflexible investments, the incumbent firm's option to expand by using flexible capital, and potential competitors' options to enter the market. Our findings are distinguished from the result of the extant studies that exogenously impose market competition.

Our findings have implications on anti-trust policies. Our model predictions about a positive relation between uncertainty and competition imply that a current risky economic environment naturally enhances market competition. Moreover, the positive relation between inflexible capital investments and market concentration implies that the observed market concentration can be a consequence of large inflexible investments, which typically improve the production efficiency. For example, in the telecommunications industry, firms spend considerable resources on research and development and build inflexible communication networks and information infrastructure to improve their service quality and reduce operating costs. However, such large-scale capital investments may not be rationalized without acquiring a larger market share. Thus, many firms attempt to combine mergers and acquisitions with large capital investments. An anti-trust ruling to block a merger and acquisition is rightly intended to prevent the social cost of oligopoly pricing. However, such a ruling can also have unwanted negative consequences on the accumulation of inflexible capital, which could improve the efficiency of the economy. As a result, recent Department of Justice antitrust actions in the telecommunications and pharmaceutical industries could result in a significantly lower level of future research and development spending and capital intensity.

References

Aguerrevere, Felipe L., 2009, Real options, product market competition, and asset returns, *The Journal of Finance* 64, 957–983.

Allen, Beth, Raymond Deneckere, Tom Faith, and Dan Kovenock, 2000, Capacity precommitment as a barrier to entry: A bertrand-edgeworth approach, *Economic Theory* 15, 501–530.

Angrist, J.D., and J.S. Pischke, 2009, *Mostly Harmless Econometrics: An Empiricist's Companion* (Princeton University Press).

Babenko, Ilona, Oliver Boguth, and Yuri Tserlukevich, 2014, Idiosyncratic cash flows and systematic risk, Western Finance Association 2013 Annual Meeting 2139735.

Bain, Joe S., 1954, Economies of scale, concentration, and the condition of entry in twenty manufacturing industries, *The American Economic Review* 44, 15–39.

Basu, Kaushik, and Nirvikar Singh, 1990, Entry-deterrence in stackelberg perfect equilibria, *International Economic Review* 31, pp. 61–71.

Berk, Jonathan B., Richard C. Green, and Vasant Naik, 1999, Optimal investment, growth options, and security returns, *The Journal of Finance* 54, 1553–1607.

Bulow, Jeremy, John Geanakoplos, and Paul Klemperer, 1985, Holding idle capacity to deter entry, *The Economic Journal* 95, 178–182.

Carlson, Murray, Adlai Fisher, and Ron Giammarino, 2004, Corporate investment and asset price dynamics: Implications for the cross-section of returns, *The Journal of Finance* 59, 2577–2603.

Cochrane, John H., 1991, Production-based asset pricing and the link between stock returns and economic fluctuations, *The Journal of Finance* 46, 209–237.

Cooper, Ilan, 2006, Asset pricing implications of nonconvex adjustment costs and irreversibility of investment, *The Journal of Finance* 61, 139–170.

Dixit, Avinash, 1979, A Model of Duopoly Suggesting a Theory of Entry Barriers, *Bell Journal of Economics* 10, 20–32.

———, 1980, The role of investment in entry-deterrence, *The Economic Journal* 90, 95–106.

Dixit, Avinash K, and Robert S Pindyck, 1994, *Investment under uncertainty* (Princeton University Press).

Ellison, Glenn, and Sara Fisher Ellison, 2011, Strategic entry deterrence and the behavior of pharmaceutical incumbents prior to patent expiration, *American Economic Journal: Microeconomics* 3, 1–36.

Fama, Eugene F, and Merton H Miller, 1972, *The Theory of Finance* (Dryden Press, Hinsdale, IL).

Gersbach, Hans, and Armin Schmutzler, 2012, Product markets and industry-specific training, *The RAND Journal of Economics* 43, 475–491.

Grenadier, Steven R., 2002, Option exercise games: An application to the equilibrium investment strategies of firms, *Review of Financial Studies* 15, 691–721.

Hayashi, Fumio, 1982, Tobin's Marginal q and Average q: A Neoclassical Interpretation, *Econometrica* 50, 213–24.

He, Hua, and Robert S. Pindyck, 1992, Investments in flexible production capacity, *Journal of Economic Dynamics and Control* 16, 575 – 599.

Holland, A. Steven, Steven H. Ott, and Timothy J. Riddiough, 2000, The role of uncertainty in investment: An examination of competing investment models using commercial real estate data, *Real Estate Economics* 28, 33–64.

Kogan, Leonid, and Dimitris Papanikolaou, 2013, Firm characteristics and stock returns: The role of investment-specific shocks, *Review of Financial Studies* 26, 2718–2759.

———, 2014, Growth opportunities, technology shocks, and asset prices, *The Journal of Finance* 69, 675–718.

Liu, Laura Xiaolei, Toni M. Whited, and Lu Zhang, 2009, Investment-Based Expected Stock Returns, *Journal of Political Economy, University of Chicago Press* 117, 1105–1139.

Maskin, Eric S., 1999, Uncertainty and entry deterrence, *Economic Theory* 14, pp. 429–437.

Novy-Marx, Robert, 2007, An equilibrium model of investment under uncertainty, *Review of Financial Studies* 20, 1461–1502.

Ott, Steven H., Timothy J. Riddiough, Ha-Chin Yi, and Jiro Yoshida, 2008, On Demand: Cross-Country Evidence From Commercial Real Estate Asset Markets, *International Real Estate Review, Asian Real Estate Society* 11, 1–37.

Pindyck, Robert S., 1988, Irreversible investment, capacity choice, and the value of the firm, *The American Economic Review* 78, pp. 969–985.

Smiley, Robert, 1988, Empirical evidence on strategic entry deterrence, *International Journal of Industrial Organization* 6, 167 – 180.

Spence, A. Michael, 1977, Entry, capacity, investment and oligopolistic pricing, *The Bell Journal of Economics* 8, 534–544.

Spulber, Daniel F., 1981, Capacity, output, and sequential entry, *The American Economic Review* 71, 503–514.

Tuzel, Selale, 2010, Corporate real estate holdings and the cross-section of stock returns, *Review of Financial Studies* 23, 2268–2302.

Year	*Nb. Firms*	*Nb. Industries*	*Year*	*Nb. Firms*	*Nb. Industries*
1984	2,978	59	*1999*	5,355	65
1985	3,233	60	*2000*	5,206	64
1986	3,658	61	*2001*	4,721	63
1987	3,809	61	*2002*	4,224	61
1988	3,746	62	*2003*	3,893	62
1989	3,644	61	*2004*	3,522	63
1990	3,582	62	*2005*	3,782	63
1991	3,629	61	*2006*	4,003	63
1992	3,423	61	*2007*	3,872	64
1993	3,289	61	*2008*	3,577	63
1994	4,372	62	*2009*	3,376	64
1995	4,929	63	*2010*	3,320	64
1996	5,567	63	*2011*	3,092	64
1997	5,627	63	*2012*	2,874	63
1998	5,481	64			

Table I: Number of Firms and Industries. The total sample spanning 29 years from 1984 to 2012 comprises 11,708 firms belonging to 65 industries according to their 2-digit SIC numbers.

Variables	*Description*	*Mean*	*Median*	*Std. Dev.*	*Min.*	*Max.*
Firms	Number of Firms per industry	69	27	110	3	534
HHI (Net Sales)	Industry Concentration Herfindahl based on Net Sales	0.187	0.142	0.150	0.017	0.825
HHI (Total Assets)	Industry Concentration Herfindahl based on Total Asset	0.193	0.157	0.143	0.017	0.737
MV	Total Market Value of all Firms	$195,374	$50,141	$349,077	$349	$1,675,834
TA	Total Assets	$614,940	$64,226	$1,977,151	$707	$14,777,544
Sales	Total Net Sales	$221,607	$69,685	$336,656	$698	$1,639,086
Sales Growth	Changes in Quarterly Sales	9.27%	9.22%	15.15%	-188.61%	263.85%
LT_Debt	Long-Term Debt	$77,902	$11,609	$207,778	$79	$1,410,921
EBITDA	Earnings Before Interest and Depreciation	$27,790	$5,684	$49,421	-$14	$278,668
Net_Income	Annual Net Income	$8,623	$2,219	$16,227	-$33	$88,430
ROA	Ratio of Net Income to Total Assets	0.12%	0.96%	6.72%	-65.55%	35.45%
Leverage	Ratio of Long-Term Debt to Equity (Total Assets - Total Liabilities)	1.53	0.76	7.61	0.00	303.25
Rent Expenses	Annual Rental Expenses	$2,336	$779	$3,615	$1	$21,194
PPE	Gross Properties Plants and Equipment	$77,492	$20,897	$141,051	$153	$668,679
RE_Assets	Buildings, Construction in Progress, and Land and Improvements	$12,952	$2,905	$24,745	$57	$113,746
SC	Specific Capital: Ratio of RE_Assets to PPE	27.43%	26.26%	11.72%	7.11%	62.88%
GC	Generic Capital: Ratio of capitalized rent expenses to PPE plus capitalized rent expenses	46.62%	46.32%	17.71%	2.99%	93.56%
Volatility Sales	Adjusted 20-quarter rolling standard deviation of sales growth	0.0392	0.0410	0.0997	-1.1038	1.2393
	Adjusted 40-quarter rolling standard deviation of sales growth	0.0492	0.0515	0.0797	-0.8578	0.9996
Volatitliy Firm Value	Adjusted 20-quarter rolling standard deviation of firm value growth	0.1315	0.1245	0.1137	-0.2668	1.0864
	Adjusted 40-quarter rolling standard deviation of firm value growth	0.1417	0.1319	0.0948	-0.1639	1.0430

Table II: Industry-Level Descriptive Statistics for the 29-year Period from 1984 to 2012. Dollar Amounts in Thousands 2012 Dollar.

VARIABLES	Model (1)	Model (2)	Model (3)	Model (4)
Firm-specific capital	0.1499***		0.1479***	
	(0.0179)		(0.0185)	
Firm-specific capital (3 years before)				0.1817***
				(0.0179)
Change in firm-specific capital (3 years before)				0.1559***
				(0.0353)
Change in firm-specific capital (2 years before)				0.1216***
				(0.0371)
Change in firm-specific capital (previous year)				0.0586*
				(0.0315)
Generic Capital	0.0968***		0.0890***	0.1245***
	(0.0149)		(0.0156)	(0.0156)
Sales volatility (20-qtr.)		-0.1950***	-0.1427***	-0.1159**
		(0.0502)	(0.0520)	(0.0465)
4-qtr. forecast error (20-qtr.)				-0.0072
				(0.0659)
8-qtr. forecast error (20-qtr.)				0.0576
				(0.0474)
12-qtr. forecast error (20-qtr.)				0.0349
				(0.0288)
Average growth rate industry	0.0120	0.0078	0.0044	-0.0363*
	(0.0238)	(0.0251)	(0.0256)	(0.0214)
Industry age	3.3392***	4.2268***	3.3020***	0.6688
	(0.4372)	(0.3871)	(0.4331)	(0.4109)
Leverage	0.0001	0.0000	0.0001	0.0003
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
No. of firms	-0.0005***	-0.0005***	-0.0004***	-0.0004***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Average firm size (Assets)	-0.0015	-0.0049**	-0.0004	0.0060***
	(0.0018)	(0.0020)	(0.0019)	(0.0019)
Profitability industry (ROA)	0.0771*	0.1612***	0.0731*	0.0492
	(0.0416)	(0.0437)	(0.0410)	(0.0442)
Constant	-25.2110***	-31.7969***	-24.9200***	-5.0406
	(3.3069)	(2.9321)	(3.2757)	(3.1064)
Year f.e.	Yes	Yes	Yes	Yes
Observations	7,047	7,204	7,031	6,143
Adjusted R-squared	0.148	0.144	0.152	0.163

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table III: Test of Predictions 1 and 2. This table reports the result of the OLS estimation of the panel regression model (Equation (26)) with year fixed effects. The dependent variable is the Herfindahl-Hirschman Index for industries by the 2-digit SIC classification. White's heteroskedasticity-consistent standard errors are also reported.

VARIABLES	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
4-qtr. ahead forecast of sales volatility (20-qtr.)	-0.0757**					
	(0.0306)					
8-qtr. ahead forecast of sales volatility (20-qtr.)		-0.0550**				
		(0.0224)				
12-qtr. ahead forecast of sales volatility (20-qtr.)			-0.0411**			
			(0.0178)			
4-qtr. ahead forecast of sales volatility (40-qtr.)				-0.0956***		
				(0.0308)		
8-qtr. ahead forecast of sales volatility (40-qtr.)					-0.0778***	
					(0.0259)	
12-qtr. ahead forecast of sales volatility (40-qt.r)						-0.0634***
						(0.0221)
Generic capital	-0.2084***	-0.2071***	-0.2062***	-0.2052***	-0.2049***	-0.2045***
	(0.0116)	(0.0115)	(0.0115)	(0.0120)	(0.0120)	(0.0119)
Average growth rate industry	-0.0064	-0.0061	-0.0056	-0.0136	-0.0138	-0.0136
	(0.0183)	(0.0182)	(0.0181)	(0.0182)	(0.0182)	(0.0182)
Industry age	0.5652	0.5589	0.5502	0.5621	0.5738	0.5785
	(0.4337)	(0.4338)	(0.4342)	(0.4629)	(0.4607)	(0.4593)
Leverage	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
No. of firms	-0.0003***	-0.0003***	-0.0003***	-0.0003***	-0.0003***	-0.0003***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Average firm size (Assets)	-0.0084***	-0.0085***	-0.0086***	-0.0065***	-0.0067***	-0.0068***
	(0.0014)	(0.0014)	(0.0014)	(0.0015)	(0.0015)	(0.0015)
Profitability industry (ROA)	0.2134***	0.2135***	0.2137***	0.1972***	0.1975***	0.1978***
	(0.0267)	(0.0267)	(0.0268)	(0.0291)	(0.0291)	(0.0291)
Constant	-3.8516	-3.8048	-3.7387	-3.8322	-3.9211	-3.9568
	(3.2853)	(3.2860)	(3.2887)	(3.5058)	(3.4895)	(3.4789)
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,969	6,969	6,969	6,124	6,124	6,124
Adjusted R-squared	0.139	0.138	0.138	0.139	0.139	0.138

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table IV: Test of Prediction 3. This table reports the result of the OLS estimation of the panel regression model (29) with year fixed effects. The dependent variable is the industry-average firm-specific real estate based on the 2-digit SIC classification. The explanatory variable is the 4, 8, and 12-quarter ahead forecasts of industry sales growth volatility. The sales growth volatility is measured on the basis of 20-quarter and 40-quarter rolling estimation. Forecasts are based on an ARIMA(1,1,0) model that is estimated with the previous 20 quarter observations. White's heteroskedasticity-consistent standard errors are also reported.

VARIABLES	Model (1)	Model (2)	Model (3)	Model (4)
Sales volatility (20-qtr.)	0.2244***	0.1211***		
	(0.0289)	(0.0313)		
Sales volatility (20-qtr.) × HHI		0.3455**		
		(0.1620)		
Sales volatility (40-quarter)			0.3071***	0.1169***
			(0.0277)	(0.0316)
Sales volatility (40-quarter) × HHI				0.6951***
				(0.1633)
Average growth rate industry		0.0413***		0.0424***
		(0.0151)		(0.0147)
Leverage		0.0014***		0.0014***
		(0.0001)		(0.0001)
Industry age		-0.7641***		-0.9050***
		(0.2238)		(0.2068)
No. of firms		0.0001***		0.0001***
		(0.0000)		(0.0000)
Average firm size (Assets)		-0.0088***		-0.0087***
		(0.0012)		(0.0010)
Profitability industry (ROA)		-0.0894***		-0.0751***
		(0.0280)		(0.0256)
Constant	0.1360***	6.0373***	0.1223***	7.1019***
	(0.0058)	(1.6940)	(0.0047)	(1.5675)
Year f.e.	Yes	Yes	Yes	Yes
Observations	7,109	6,989	6,989	6,989
Adjusted R-squared	0.154	0.182	0.142	0.209

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table V: Test of Prediction 4. This table reports the result of the OLS estimation of regression equation (31). The dependent variable is the volatility of the average corporate value growth rates for each industry with the 2-digit SIC classification. The explanatory variables are the industry sales volatility and the interaction terms of the sales volatility and the Herfindahl-Hirschman Index. The low demand variables are also used as a conditioning variable. The volatility is measured on the basis of 40-quarter rolling estimation and adjusted for the number of observation as outlined in Appendix D. White's heteroskedasticity-consistent standard errors are also reported.

VARIABLES	Model (1)	Model (2)	Model (3)	Model (4)
Sales volatility	0.1169***	0.1857***	0.1129**	0.2778***
	(0.0316)	(0.0368)	(0.0526)	(0.0300)
Sales volatility × NBER recession dummy		0.0108		
		(0.0892)		
Sales volatility × Aggregate low sales dummy			0.1315*	0.0389
			(0.0672)	(0.0437)
Sales volatility × HHI	0.6951***	0.7042***	1.0847***	
	(0.1633)	(0.1915)	(0.2826)	
Sales volatility × High HHI dummy				0.2023***
				(0.0495)
Sales volatility × HHI × NBER recession dummy		0.0600		
		(0.4566)		
Sales volatility × HHI × Aggregate low sales dummy			-0.7024**	
			(0.3423)	
Sales volatility × High HHI dummy × Aggregate low sales dummy				-0.1203*
				(0.0720)
NBER recession dummy		0.0100**		
		(0.0050)		
Aggregate low sales dummy			0.0196***	0.0212***
			(0.0034)	(0.0035)
Average growth rate industry	0.0424***	0.0120	0.0338**	0.0328**
	(0.0147)	(0.0143)	(0.0143)	(0.0159)
Leverage	0.0014***	0.0014***	0.0014***	0.0015***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Industry age	-0.9050***	-0.3724*	-0.3629*	-0.2996
	(0.2068)	(0.2181)	(0.2155)	(0.2189)
No. of firms	0.0001***	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Average firm size (Assets)	-0.0087***	-0.0018**	-0.0020**	-0.0031***
	(0.0010)	(0.0009)	(0.0008)	(0.0010)
Profitability industry (ROA)	-0.0751***	-0.0278	-0.0255	-0.0262
	(0.0256)	(0.0249)	(0.0244)	(0.0262)
Constant	7.1019***	2.9531*	2.8741*	2.3983
	(1.5675)	(1.6526)	(1.6324)	(1.6580)
Year f.e.	Yes	No	No	No
Observations	6,989	6,989	6,989	6,989
Adjusted R-squared	0.209	0.112	0.126	0.108

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table VI: Test of Prediction 4. This table reports the result of the OLS estimation of regression equation (31). The dependent variable is the volatility of the average corporate value growth rates for each industry with the 2-digit SIC classification. The explanatory variables are the industry sales volatility and the interaction terms of the sales volatility and the Herfindahl-Hirschman Index. The low demand variables are also used as a conditioning variable. The volatility is measured on the basis of 40-quarter rolling estimation and adjusted for the number of observation as outlined in Appendix D. White's heteroskedasticity-consistent standard errors are also reported.

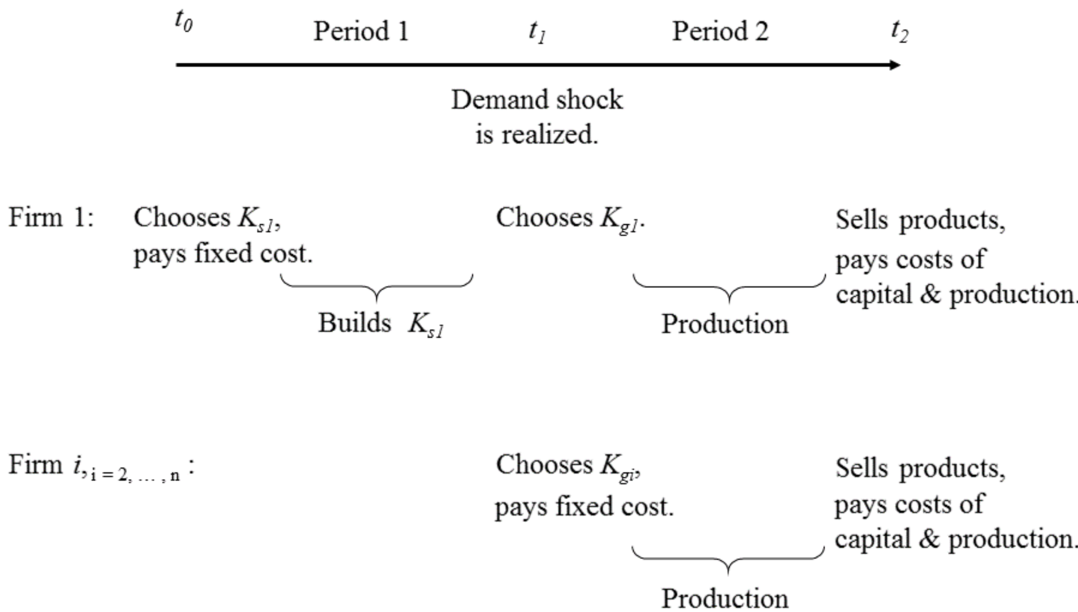
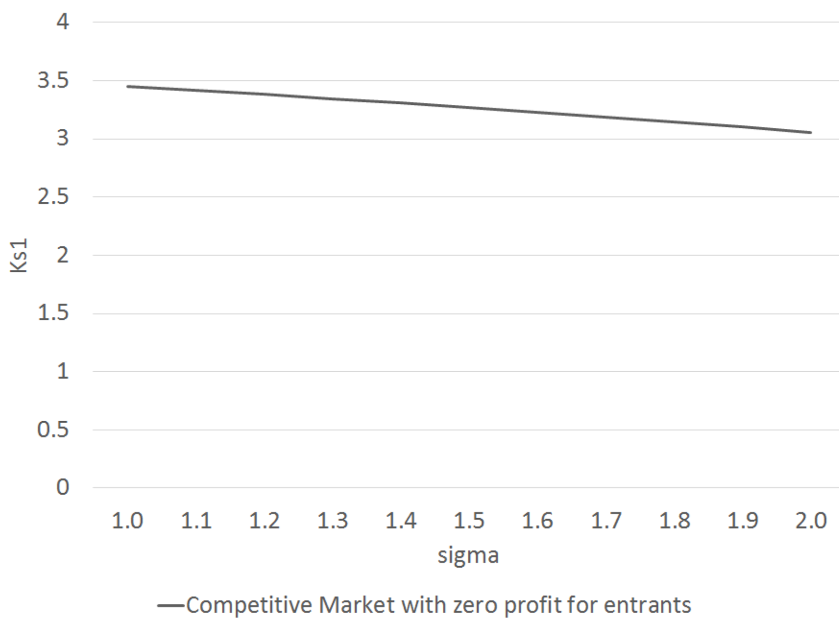
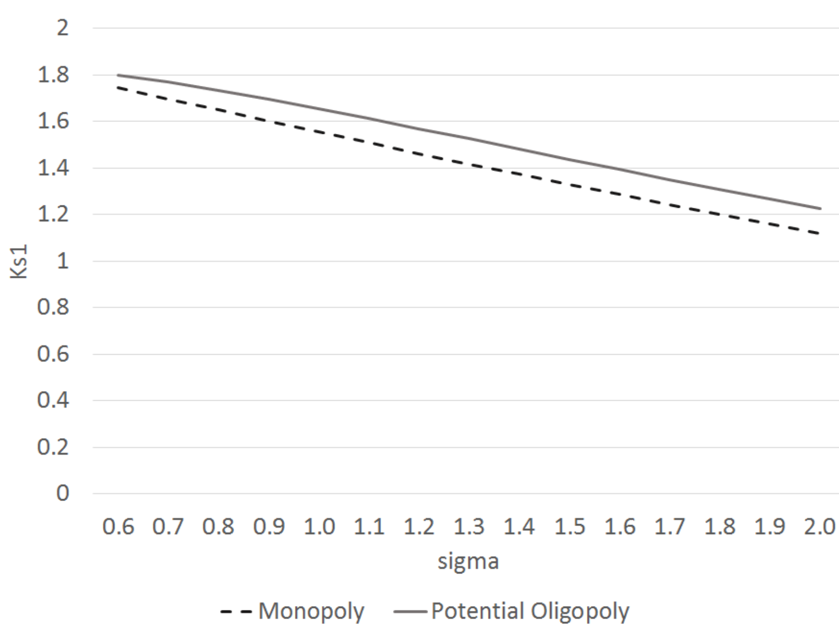


Figure 1: Time line

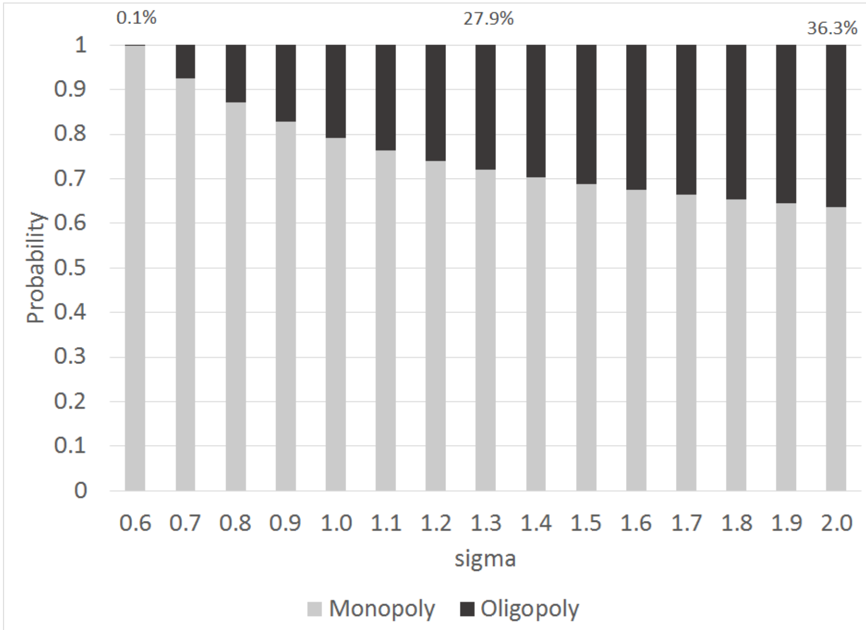


(a) Competitive market

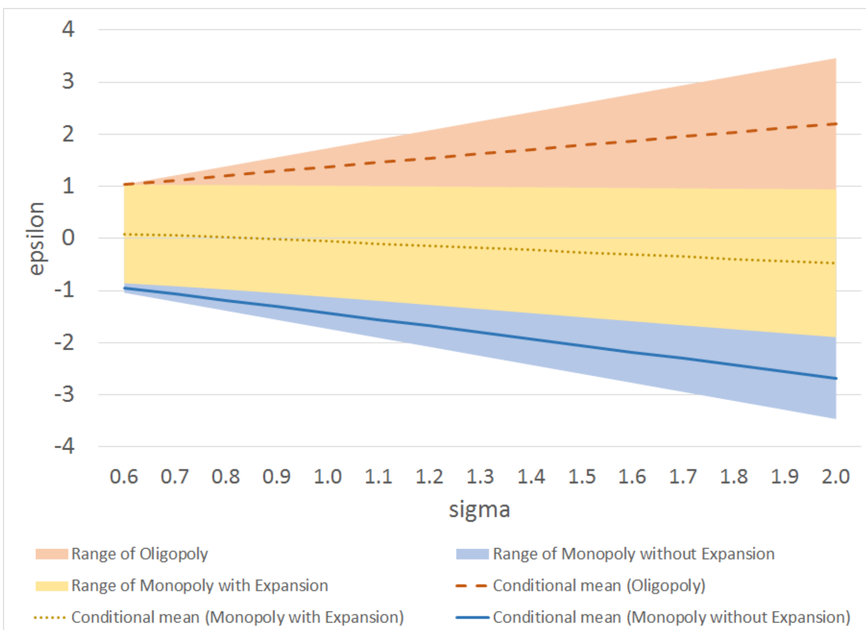


(b) Monopoly and potential oligopoly markets

Figure 2: Firm-specific capital and demand uncertainty. The demand uncertainty σ is on the horizontal axis. For a competitive market, the price level A is adjusted for each value of σ so that an entrant earns zero profit. Parameter values are: $B = 0.5, \alpha = 0.8, \beta = 1.4, r = 0.05, s = 0.3, g = 0.2,$ and $f = 7$. For monopoly and potential oligopoly markets, parameter values are: $A = 4.3, B = 0.5, \alpha = 0.8, \beta = 1.4, r = 0.05, s = 0.3, g = 0.2, f = 3.2$.



(a) Probabilities of entry



(b) Conditional values of ϵ

Figure 3: Comparative statics in a potential oligopoly market. The demand uncertainty σ is on the horizontal axis. Parameter values are: $A = 4.3, B = 0.5, \alpha = 0.8, \beta = 1.4, r = 0.05, s = 0.3, g = 0.2,$ and $f = 3.2$.

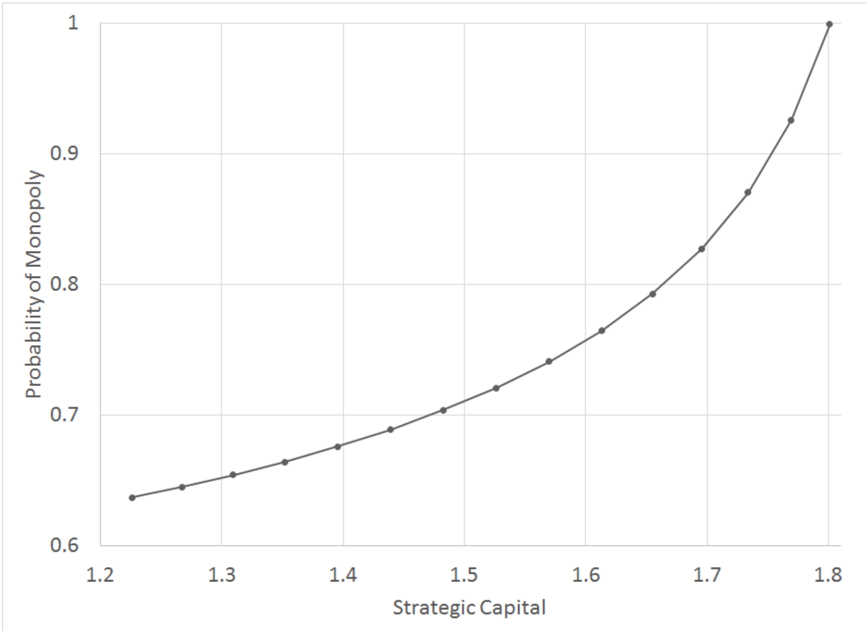
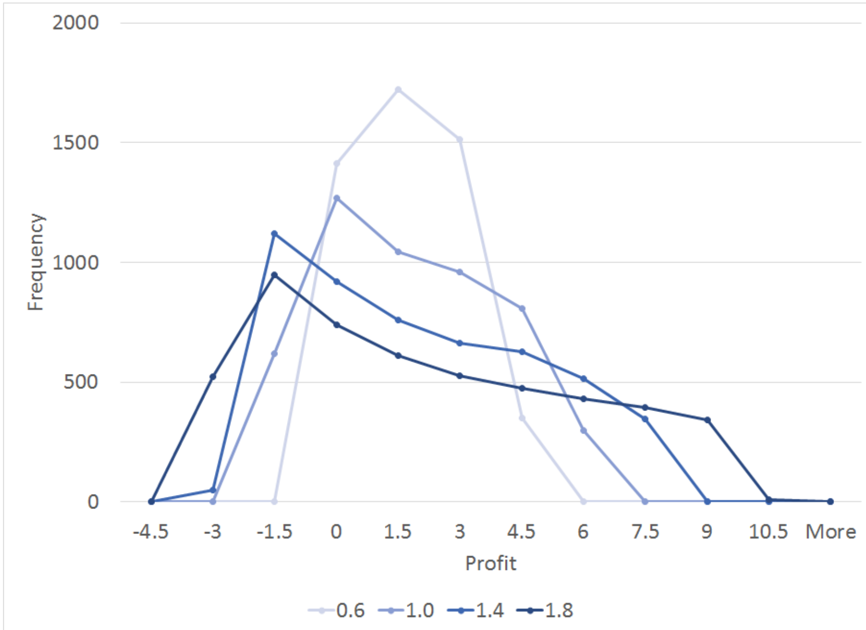
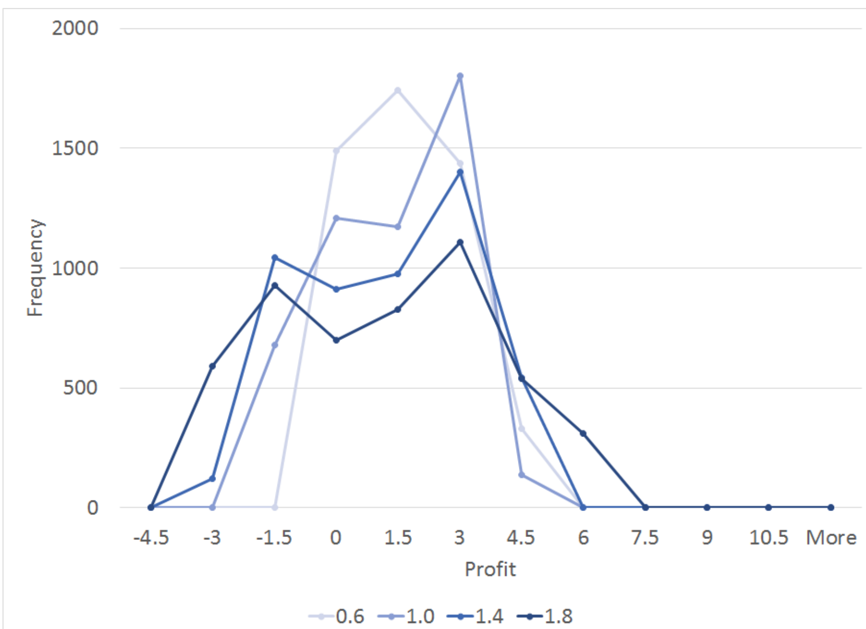


Figure 4: Firm-specific capital and market structure. The amount of firm-specific capital is on the horizontal axis. $A = 4.3, B = 0.5, \alpha = 0.8, \beta = 1.4, r = 0.05, s = 0.3, g = 0.2,$ and $f = 3.2$.



(a) Monopoly



(b) Potential oligopoly

Figure 5: Distribution of Firm 1's realized profits for different values of σ. Parameter values are: $A = 4.3, B = 0.5, \alpha = 0.8, \beta = 1.4, r = 0.05, s = 0.3, g = 0.2,$ and $f = 3.2$.

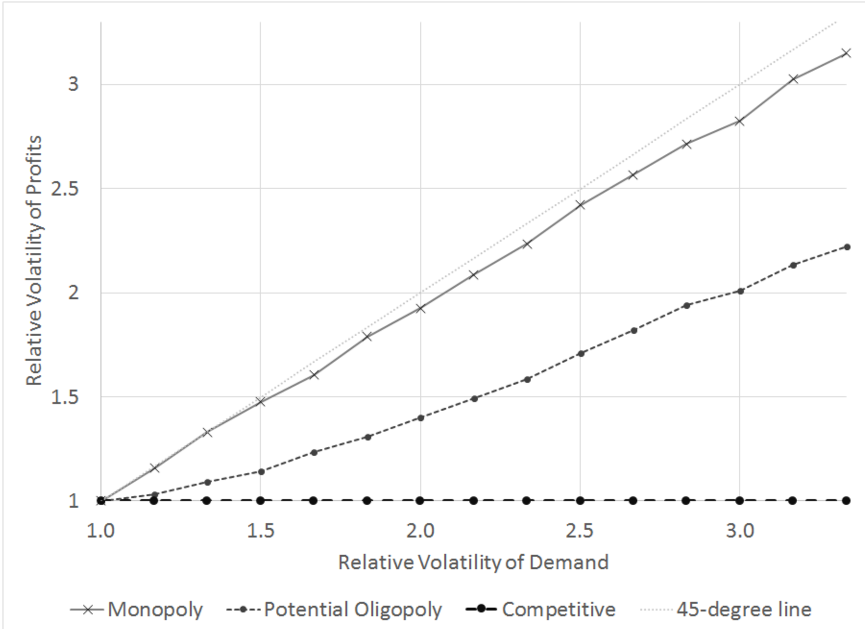


Figure 6: Relative volatilities of demand and profits. $A = 4.3, B = 0.5, \alpha = 0.8, \beta = 1.4, r = 0.05, s = 0.3, g = 0.2,$ and $f = 3.2$.

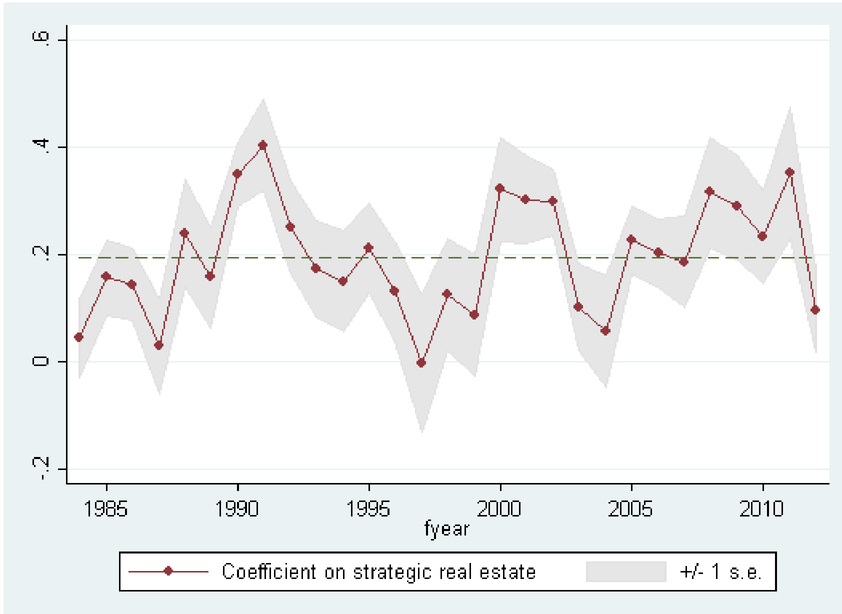
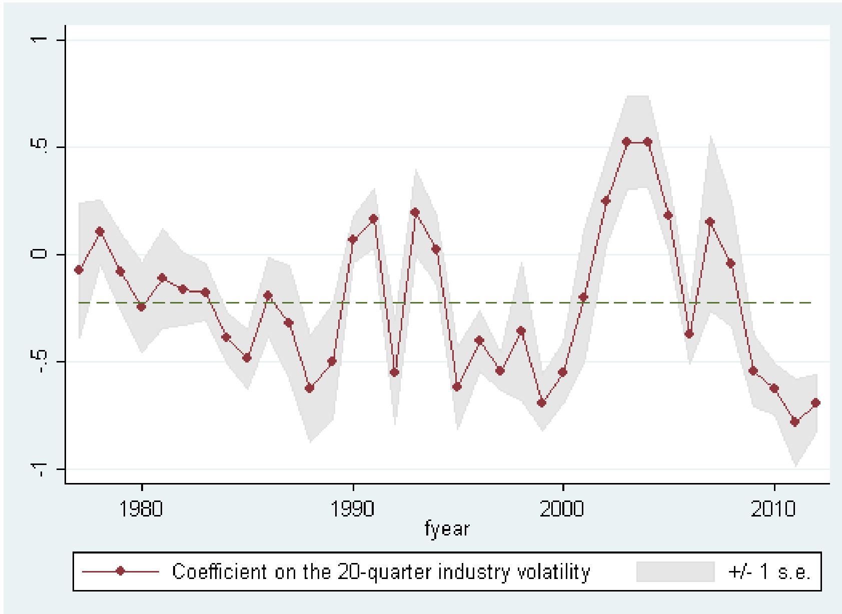
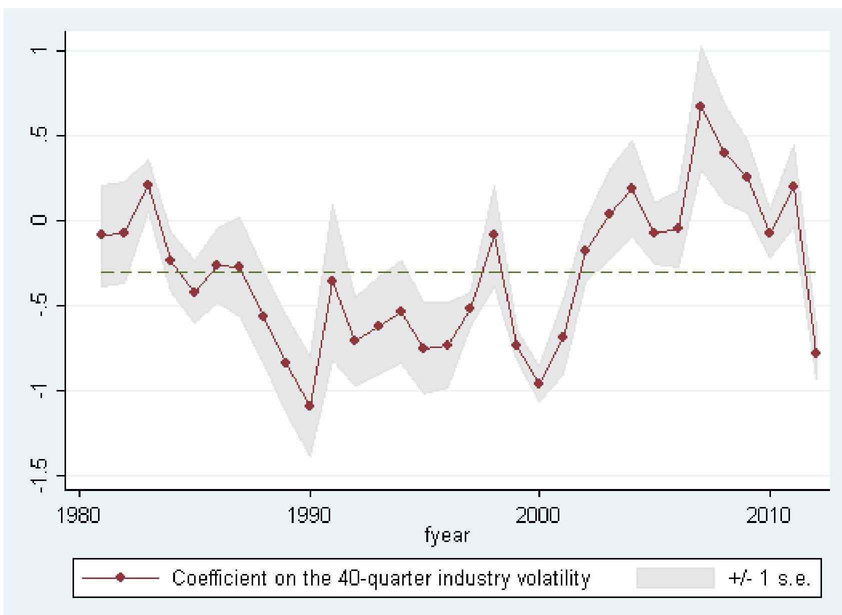


Figure 7: Relation between the Herfindahl-Hirschman Index and firm-specific capital. This figure depicts the OLS estimation result of a regression equation (27), which corresponds to Prediction 1. White's heteroskedasticity-consistent standard errors are also reported.

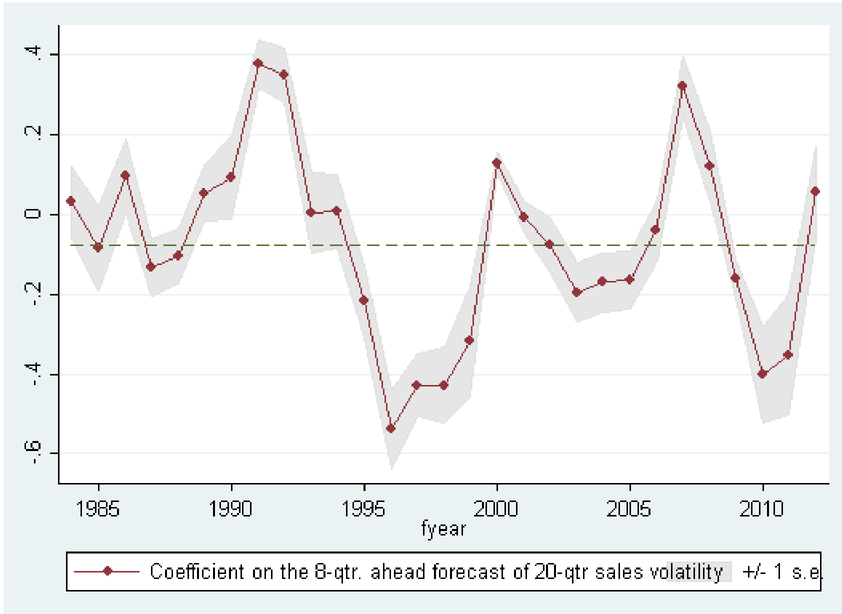


(a) 20-quarter rolling volatility

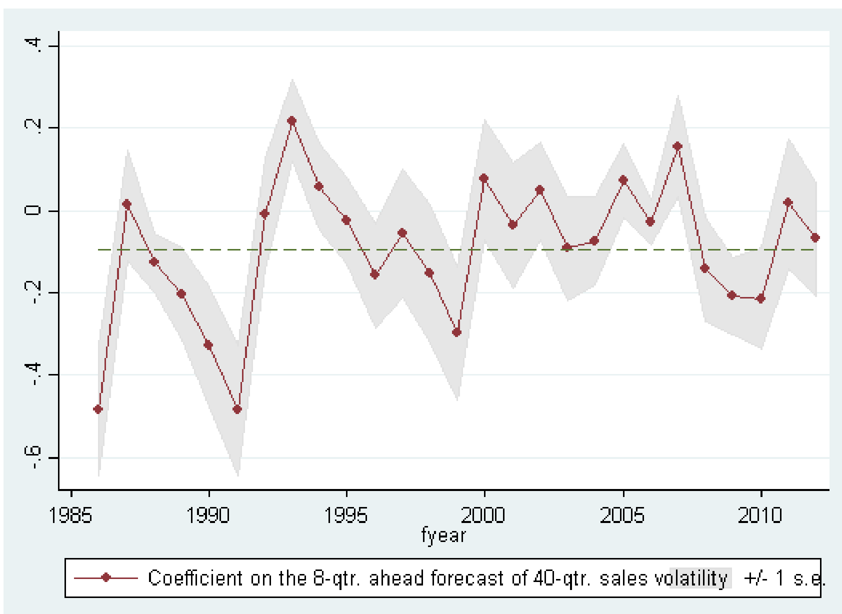


(b) 40-quarter rolling volatility

Figure 8: Relation between the Herfindahl-Hirschman Index and the industry volatility. This figure depicts the OLS estimation result of a regression equation (28), which corresponds to Prediction 2. White's heteroskedasticity-consistent standard errors are also reported.



(a) 20-quarter rolling volatility



(b) 40-quarter rolling volatility

Figure 9: Relation between firm-specific capital and the demand uncertainty. This figure depicts the OLS estimation result of a regression equation (30), which corresponds to Prediction 3. The 8-quarter ahead volatility forecast is used. White's heteroskedasticity-consistent standard errors are also reported.

Appendix A Proof of Proposition 1

Without loss of generality, consider the 2-firm Cournot equilibrium represented by Equations (13) and (14). When $\varepsilon = \varepsilon^*$, Firm 2's profit is zero:

$$\Pi_2 = P\left(K_{s1}, K_{g1}^E\left(K_{s1}, \varepsilon^*\right), K_{g2}^E\left(K_{s1}, \varepsilon^*\right), \varepsilon^*\right) \times K_{g2} - C_2\left(K_{g2}^E\left(K_{s1}, \varepsilon^*\right)\right) = 0 \qquad \text{(A.1)}$$

We rewrite Equation (A.1) by using Firm 2's FOC:

$$\begin{aligned}\Pi_2 = &- \frac{\partial P\left(K_{s1}, K_{g1}^E\left(K_{s1}, \varepsilon^*\right), K_{g2}^E\left(K_{s1}, \varepsilon^*\right), \varepsilon^*\right)}{\partial K_{g2}^E} \times {K_{g2}^E}^2\left(K_{s1}, \varepsilon^*\right) \\ &+ C_2'\left(K_{g2}^E\left(K_{s1}, \varepsilon^*\right)\right) \times K_{g2}\left(K_{s1}, \varepsilon^*\right) - C_2\left(K_{g2}^E\left(K_{s1}, \varepsilon^*\right)\right) = 0 \end{aligned} \qquad \text{(A.2)}$$

By totally differentiating Equation (A.2), we obtain

$$\begin{aligned}&- \frac{\partial^2 P}{\partial {K_{g2}^E}^2} {K_{g2}^E}^2 \times \left(dK_{s1} + \frac{\partial K_{g1}^E}{\partial K_{s1}} dK_{s1} + \frac{\partial K_{g1}^E}{\partial \varepsilon^*} d\varepsilon^* + \frac{\partial K_{g2}^E}{\partial K_{s1}} dK_{s1} + \frac{\partial K_{g2}^E}{\partial \varepsilon^*} d\varepsilon^* + d\varepsilon^*\right) \\ &- 2\frac{\partial P}{\partial K_{g2}^E} K_{g2}^E \times \left(\frac{\partial K_{g2}^E}{\partial K_{s1}} dK_{s1} + \frac{\partial K_{g2}^E}{\partial \varepsilon^*} d\varepsilon^*\right) + C_2'' K_{g2}^E \times \left(\frac{\partial K_{g2}^E}{\partial K_{s1}} dK_{s1} + \frac{\partial K_{g2}^E}{\partial \varepsilon^*} d\varepsilon^*\right) \\ &+ C_2' \times \left(\frac{\partial K_{g2}^E}{\partial K_{s1}} dK_{s1} + \frac{\partial K_{g2}^E}{\partial \varepsilon^*} d\varepsilon^*\right) - C_2' \times \left(\frac{\partial K_{g2}^E}{\partial K_{s1}} dK_{s1} + \frac{\partial K_{g2}^E}{\partial \varepsilon^*} d\varepsilon^*\right) = 0. \end{aligned} \qquad \text{(A.3)}$$

By assuming an affine demand function, the first term is eliminated ($\partial^2 P / \partial {K_{g2}^E}^2 = 0$). The last two terms cancel out. By rearranging the equation, we obtain:

$$\frac{d\varepsilon^*}{dK_{s1}} = -\left(\frac{\partial {K_{g2}^E}^*}{\partial \varepsilon}\right)^{-1} \left(\frac{\partial K_{g2}^E}{\partial K_{s1}}\right). \qquad \text{(A.4)}$$

Since Firm 2 chooses a larger amount of capital for a greater demand and a smaller amount of Firm 1's inflexible capital, $\partial K_{g2}^E / \partial \varepsilon^* > 0$ and $\partial K_{g2}^E / \partial K_{s1} < 0$. As a result, we derive Equation (15) in Proposition 1:

$$\frac{d\varepsilon^*}{dK_{s1}} > 0. \qquad \text{(A.5)}$$

■

Appendix B Variations in Firm 1's problem under potential oligopoly

Variation 1: If $\varepsilon^M < \varepsilon^E < \varepsilon^*$,

$$\begin{aligned}
&\max_{K_{s1}} E\left[\Pi_1(K_{s1}, K_{g1}, K_{g2}, \varepsilon)\right] \\
&\equiv E\left[\Pi_1^O(K_{s1}, K_{g1}^E, K_{g2}^E, \varepsilon)\left|\varepsilon \geq \varepsilon^*(K_{s1})\right.\right] Pr\left(\varepsilon \geq \varepsilon^*(K_{s1})\right) \\
&+ E\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\left|\varepsilon^*(K_{s1}) > \varepsilon > \varepsilon^M(K_{s1})\right.\right] Pr\left(\varepsilon^*(K_{s1}) > \varepsilon > \varepsilon^M(K_{s1})\right) \\
&+ E\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\left|\varepsilon \leq \varepsilon^M(K_{s1})\right.\right] Pr\left(\varepsilon \leq \varepsilon^M(K_{s1})\right). \qquad \text{(B.1a)}
\end{aligned}$$

Variation 2: If $\varepsilon^M < \varepsilon^* < \varepsilon^E$, Equation (16)

Variation 3: If $\varepsilon^* < \varepsilon^M < \varepsilon^E$,

$$\begin{aligned}
&\max_{K_{s1}} E\left[\Pi_1(K_{s1}, K_{g1}, K_{g2}, \varepsilon)\right] \\
&\equiv E\left[\Pi_1^O(K_{s1}, K_{g1}^E, K_{g2}^E, \varepsilon)\left|\varepsilon > \varepsilon^E(K_{s1})\right.\right] Pr\left(\varepsilon > \varepsilon^E(K_{s1})\right) \\
&+ E\left[\Pi_1^O(K_{s1}, 0, K_{g2}^E, \varepsilon)\left|\varepsilon^*(K_{s1}) \leq \varepsilon \leq \varepsilon^E(K_{s1})\right.\right] Pr\left(\varepsilon^*(K_{s1}) \leq \varepsilon \leq \varepsilon^E(K_{s1})\right) \\
&+ E\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\left|\varepsilon < \varepsilon^*(K_{s1})\right.\right] Pr\left(\varepsilon < \varepsilon^*(K_{s1})\right), \qquad \text{(B.1b)}
\end{aligned}$$

Appendix C Solution of the model

A Firms' Decision for the second period

A.1 Firm 1.

At t_1, Firm 1 solves the problem specified in Equation (3), taking K_{s1}, K_{g2}, and $\bar{\varepsilon}$ as given. Since the objective function is quadratic, SOC is readily satisfied. From FOC and the sign condition on K_{g1}, the optimal choice of K_{g1} is:[25]

Monopoly:

$$\begin{cases} K_{g1}^M = \dfrac{A - g - (2B+\alpha)K_{s1} + \bar{\varepsilon}}{2B+\beta} & \text{if } \bar{\varepsilon} > g - A + (2B+\alpha)K_{s1} \equiv \varepsilon^M \\ 0 & \text{otherwise.} \end{cases} \tag{C.1}$$

Oligopoly:

$$\begin{cases} K_{g1}^O = \dfrac{A - g - (2B+\alpha)K_{s1} - BK_{g2} + \bar{\varepsilon}}{2B+\beta} & \text{if } \bar{\varepsilon} > g - A + (2B+\alpha)K_{s1} + BK_{g2} \equiv \varepsilon^O \\ 0 & \text{otherwise.} \end{cases} \tag{C.2}$$

Competitive:

$$\begin{cases} K_{g1}^C = \dfrac{A - g + \bar{\varepsilon} - \alpha K_{s1}}{\beta} & \text{if } \bar{\varepsilon} > g - A + \alpha K_{s1} \equiv \varepsilon^C \\ 0 & \text{otherwise.} \end{cases} \tag{C.3}$$

A.2 Firm 2.

At t_1, Firm 2 solves the problem specified in Equation (9), taking K_{s1}, K_{g1}, and $\bar{\varepsilon}$ as given. Since the objective function is quadratic, SOC is readily satisfied. From FOC and the entry condition

[25] When there are n entrants, K_{g2} is simply replaced with $\sum_{i=2}^{n+1} K_{gi}$ in Equations (C.2) and (C.4).

(10), the optimal choice of K_{g2} is

Oligopoly:

$$\begin{cases} K_{g2}^{O} = \dfrac{A - g - B(K_{s1} + K_{g1}) + \bar{\varepsilon}}{2B + \beta} & \text{if } \bar{\varepsilon} \geq g - A + B(K_{s1} + K_{g1}) + \sqrt{2(2B+\beta)(1+r)f} \\ 0 & \text{otherwise.} \end{cases} \tag{C.4}$$

Competitive:

$$\begin{cases} K_{g2}^{C} = \dfrac{A - g + \bar{\varepsilon}}{\beta} & \text{if } \bar{\varepsilon} \geq g - A + \sqrt{2\beta(1+r)f} \\ 0 & \text{otherwise.} \end{cases} \tag{C.5}$$

B Cournot Nash Equilibrium in the second period

When both firms employ positive amounts of flexible capital, the Cournot Nash equilibrium levels of flexible capital, Equations (13) and (14), are expressed as:[26]

$$K_{g1}^{E} = L - (1 - M)K_{s1}, \tag{C.6}$$

$$K_{g2}^{E} = L - NK_{s1}, \tag{C.7}$$

where

$$L \equiv \frac{A - g + \bar{\varepsilon}}{3B + \beta} > 0,$$
$$M \equiv \frac{(\beta - \alpha)(2B + \beta)}{(3B + \beta)(B + \beta)} \in (0, 1)$$
$$N \equiv \frac{B(\beta - \alpha)}{(3B + \beta)(B + \beta)} > 0.$$

Firm 2's entry condition (10) gives the threshold value of demand shock ε^*:

$$\varepsilon^*(K_{s1}) \equiv g - A + \sqrt{\frac{2(3B + \beta)^2(1 + r)f}{2B + \beta}} + \frac{B(\beta - \alpha)}{B + \beta}K_{s1}. \tag{C.8}$$

We confirm the entry deterrence effect (15); i.e., a larger inflexible capital of Firm 1 makes it less

[26] When there are n entrants, $L = \frac{A-g+\bar{\varepsilon}}{(n+1)B+\beta}$, $M = \frac{2B+\alpha}{2B+\beta} - \frac{(n-1)B^2(\beta-\alpha)}{((n+1)B+\beta)(B+\beta)(2B+\beta)}$, and$N = \frac{B(\beta-\alpha)}{((n+1)B+\beta)(B+\beta)} > 0$.

unlikely for Firm 2 to enter the market. We can also rewrite Firm 1's expansion condition (C.2) for this Cournot equilibrium:

$$\bar{\varepsilon} > g - A + \left(3B + \beta - \frac{(\beta-\alpha)(2B+\beta)}{B+\beta}\right) K_{s1} \equiv \varepsilon^E(K_{s1}). \tag{C.9}$$

C Initial choice of inflexible capital

At t_0, Firm 1 solves the problems specified in Equations (5), (16), and (20). In this appendix, we solve for the optimal choice of inflexible capital for each market structure.

C.1 Monopoly Market.

In the monopoly market, Firm 1's problem is:

$$\begin{aligned}
&\max_{K_{s1}} E\left[\Pi_1^M(K_{s1}, K_{g1}, \varepsilon)\right] \\
&\quad = E\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\,\middle|\bar{\varepsilon} > \varepsilon^M(K_{s1})\right] Pr(\bar{\varepsilon} > \varepsilon^M(K_{s1})) \\
&\quad + E\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\,\middle|\bar{\varepsilon} \le \varepsilon^M(K_{s1})\right] Pr(\bar{\varepsilon} \le \varepsilon^M(K_{s1})), && \text{(C.10a)}\\
\Pi_1^M(K_{s1}, 0, \varepsilon) &= -(1+r)^2 f + \varepsilon K_{s1} + (A-s)K_{s1} - \left(B + \frac{\alpha}{2}\right) K_{s1}^2, && \text{(C.10b)}\\
\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon) &= R^M + S^M\varepsilon^2 + T^M\varepsilon + U^M\varepsilon K_{s1} + V^M K_{s1} + W^M K_{s1}^2, && \text{(C.10c)}\\
R^M &\equiv -(1+r)^2 f + \frac{(A-g)^2}{2(2B+\beta)}, && \text{(C.10d)}\\
S^M &\equiv \frac{1}{2(2B+\beta)}, && \text{(C.10e)}\\
T^M &\equiv \frac{A-g}{2B+\beta}, && \text{(C.10f)}\\
U^M &\equiv \frac{\beta-\alpha}{2B+\beta} && \text{(C.10g)}\\
V^M &\equiv \frac{A(\beta-\alpha) + g(2B+\alpha)}{2B+\beta} - s, && \text{(C.10h)}\\
W^M &\equiv -\frac{\alpha}{2} - \frac{B(\beta-\alpha)^2}{(2B+\beta)^2} + \frac{\alpha(2B+\alpha)}{2B+\beta} - \frac{\beta(2B+\alpha)^2}{2(2B+\beta)^2}. && \text{(C.10i)}
\end{aligned}$$

The first-order condition is:

$$\begin{aligned}
&\frac{dE\left[\Pi_1^M(K_{s1}, K_{g1}, \varepsilon)\right]}{dK_{s1}} \\
&= \frac{dE\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\,\middle|\bar{\varepsilon} > \varepsilon^M(K_{s1})\right]}{dK_{s1}} \times Pr\left(\bar{\varepsilon} > \varepsilon^M(K_{s1})\right) \\
&+ E\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\,\middle|\bar{\varepsilon} > \varepsilon^M(K_{s1})\right] \times \frac{dPr\left(\bar{\varepsilon} > \varepsilon^M(K_{s1})\right)}{dK_{s1}} \\
&+ \frac{dE\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\,\middle|\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right]}{dK_{s1}} \times Pr\left(\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right) \\
&+ E\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\,\middle|\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right] \times \frac{dPr\left(\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right)}{dK_{s1}} \\
&= 0.
\end{aligned} \tag{C.11}$$

The specific expression for each of eight elements is as follows.

$$Pr\left(\bar{\varepsilon} > \varepsilon^M(K_{s1})\right) = \frac{\sqrt{3}\sigma - \varepsilon^M}{2\sqrt{3}\sigma} = \frac{1}{2} + \frac{A-g}{2\sqrt{3}\sigma} - \frac{2B+\alpha}{2\sqrt{3}\sigma}K_{s1}, \tag{C.12}$$

$$\frac{dPr\left(\bar{\varepsilon} > \varepsilon^M(K_{s1})\right)}{dK_{s1}} = -\frac{2B+\alpha}{2\sqrt{3}\sigma}, \tag{C.13}$$

$$Pr\left(\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right) = \frac{1}{2} + \frac{-A+g}{2\sqrt{3}\sigma} + \frac{2B+\alpha}{2\sqrt{3}\sigma}K_{s1}, \tag{C.14}$$

$$\frac{dPr\left(\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right)}{dK_{s1}} = \frac{2B+\alpha}{2\sqrt{3}\sigma}, \tag{C.15}$$

$$\begin{aligned}
&E\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\,\middle|\bar{\varepsilon} > \varepsilon^M(K_{s1})\right] \\
&= \int_{\varepsilon^M(K_{s1})}^{\sqrt{3}\sigma} \left(R^M + S^M\varepsilon^2 + T^M\varepsilon + U^M\varepsilon K_{s1} + V^M K_{s1} + W^M K_{s1}^2\right)\frac{1}{2\sqrt{3}\sigma}d\bar{\varepsilon} \\
&= \frac{\left(R^M + V^M K_{s1} + W^M K_{s1}^2\right)\left(\sqrt{3}\sigma - \epsilon^M\right)}{2\sqrt{3}\sigma} + \frac{\left(T^M + U^M K_{s1}\right)\left(3\sigma^2 - {\varepsilon^M}^2\right)}{4\sqrt{3}\sigma} \\
&+ \frac{S^M\left(3\sqrt{3}\sigma^3 - {\varepsilon^M}^3\right)}{6\sqrt{3}\sigma},
\end{aligned} \tag{C.16}$$

$$\begin{aligned}
&E\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\,\middle|\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right] \\
&= \int_{-\sqrt{3}\sigma}^{\varepsilon^M(K_{s1})} \left(-(1+r)^2 f + \varepsilon K_{s1} + (A-s)K_{s1} - \left(B + \frac{\alpha}{2}\right)K_{s1}^2\right)\frac{1}{2\sqrt{3}\sigma}d\bar{\varepsilon} \\
&= \frac{\left[-(1+r)^2 f + (A-s)K_{s1} - \left(B+\frac{\alpha}{2}\right)K_{s1}^2\right]\left(\varepsilon^M + \sqrt{3}\sigma\right)}{2\sqrt{3}\sigma} + \frac{K_{s1}\left({\varepsilon^M}^2 - 3\sigma^2\right)}{4\sqrt{3}\sigma}.
\end{aligned} \tag{C.17}$$

By using Leibniz rule of integration,

$$\begin{aligned}
&\frac{dE\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\,\middle|\bar{\varepsilon} > \varepsilon^M(K_{s1})\right]}{dK_{s1}} \\
&= \frac{\left(V^M + 2W^M K_{s1}\right)\left(\sqrt{3}\sigma - \varepsilon^M\right)}{2\sqrt{3}\sigma} + \frac{U^M\left(3\sigma^2 - \varepsilon^{M\,2}\right)}{4\sqrt{3}\sigma} \\
&- \frac{(2B+\alpha)}{2\sqrt{3}\sigma}\left(R^M + S^M\,\varepsilon^{M\,2} + T^M\varepsilon^M + U^M\varepsilon^M K_{s1} + V^M K_{s1} + W^M K_{s1}^2\right), \qquad \text{(C.18)} \\
&\frac{dE\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\,\middle|\bar{\varepsilon} \le \varepsilon^M(K_{s1})\right]}{dK_{s1}} \\
&= \frac{\left[A - s - (2B+\alpha)\,K_{s1}\right]\left(\varepsilon^M + \sqrt{3}\sigma\right)}{2\sqrt{3}\sigma} + \frac{\varepsilon^{M\,2} - 3\sigma^2}{4\sqrt{3}\sigma} \\
&+ \frac{(2B+\alpha)}{2\sqrt{3}\sigma}\left[-(1+r)^2 f + \varepsilon^M K_{s1} + (A-s)K_{s1} - \left(B + \frac{\alpha}{2}\right)K_{s1}^2\right]. \qquad \text{(C.19)}
\end{aligned}$$

The first order condition (C.11) is a cubic function of K_{s1}. The solution needs to satisfy non-negativity conditions on quantity and price and regularity conditions on probabilities. The existence and uniqueness of the solution depends on specific parameter values. In our numerical exercise, a unique solution exists after applying regularity conditions.

C.2 Potential Oligopoly Market.

In our numerical analysis, we focus on the first variation ($\varepsilon^M < \varepsilon^E < \varepsilon^*,$) of Firm 1's problem (B.1a) as a reasonable case:

$$\begin{aligned}
&\max_{K_{s1}} E\left[\Pi_1^O(K_{s1}, K_{g1}, K_{g2}, \varepsilon)\right] \\
&\qquad \equiv E\left[\Pi_1^O(K_{s1}, K_{g1}^E, K_{g2}^E, \varepsilon)\,|\varepsilon \geq \varepsilon^*(K_{s1})\right] Pr\left(\varepsilon \geq \varepsilon^*(K_{s1})\right) \\
&\qquad + E\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\left|\varepsilon^*(K_{s1}) > \varepsilon > \varepsilon^M(K_{s1})\right.\right] \qquad \text{(C.20a)} \\
&\qquad\quad \times Pr\left(\varepsilon^*(K_{s1}) > \varepsilon > \varepsilon^M(K_{s1})\right) \\
&\qquad + E\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\left|\varepsilon \leq \varepsilon^M(K_{s1})\right.\right] Pr\left(\varepsilon \leq \varepsilon^M(K_{s1})\right), \qquad \text{(C.20b)}
\end{aligned}$$

$$\Pi_1^O(K_{s1}, K_{g1}^E, K_{g2}^E, \varepsilon) = R^O + S^O\varepsilon^2 + T^O\varepsilon + U^O\varepsilon K_{s1} + V^O K_{s1} + W^O K_{s1}^2, \qquad \text{(C.20c)}$$

$$R^O \equiv -(1+r)^2 f + \frac{(A-g)^2(2B+\beta)}{2(3B+\beta)^2}, \qquad \text{(C.20d)}$$

$$S^O \equiv \frac{2B+\beta}{2(3B+\beta)^2}, \qquad \text{(C.20e)}$$

$$T^O \equiv \frac{(A-g)(2B+\beta)}{(3B+\beta)^2}, \qquad \text{(C.20f)}$$

$$U^O \equiv \frac{BN+\beta-\alpha}{3B+\beta} \qquad \text{(C.20g)}$$

$$V^O \equiv g - s + \frac{(A-g)(BN+\beta-\alpha)}{3B+\beta}, \qquad \text{(C.20h)}$$

$$W^O \equiv BMN + (\beta-\alpha)(M-\frac{1}{2}) - \frac{M^2}{2}(2B+\beta). \qquad \text{(C.20i)}$$

The first-order condition is:

$$
\begin{aligned}
&\frac{dE\left[\Pi_1^O(K_{s1}, K_{g1}^E, K_{g2}^E, \varepsilon)\right]}{dK_{s1}} \\
&= \frac{dE\left[\Pi_1^O(K_{s1}, K_{g1}^E, K_{g2}^E, \varepsilon)\,|\bar{\varepsilon} \geq \varepsilon^*(K_{s1})\right]}{dK_{s1}} \times Pr\left(\bar{\varepsilon} \geq \varepsilon^*(K_{s1})\right) \\
&+ E\left[\Pi_1^O(K_{s1}, K_{g1}^E, K_{g2}^E, \varepsilon)\,|\bar{\varepsilon} \geq \varepsilon^*(K_{s1})\right] \times \frac{dPr\left(\bar{\varepsilon} \geq \varepsilon^*(K_{s1})\right)}{dK_{s1}} \\
&+ \frac{dE\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\,\middle|\varepsilon^M(K_{s1}) < \bar{\varepsilon} < \varepsilon^*(K_{s1})\right]}{dK_{s1}} \times Pr\left(\varepsilon^M(K_{s1}) < \bar{\varepsilon} < \varepsilon^*(K_{s1})\right) \\
&+ E\left[\Pi_1^M(K_{s1}, K_{g1}^M, \varepsilon)\,\middle|\varepsilon^M(K_{s1}) < \bar{\varepsilon} < \varepsilon^*(K_{s1})\right] \times \frac{dPr\left(\varepsilon^M(K_{s1}) < \bar{\varepsilon} < \varepsilon^*(K_{s1})\right)}{dK_{s1}} \\
&+ \frac{dE\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\,\middle|\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right]}{dK_{s1}} \times Pr\left(\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right) \\
&+ E\left[\Pi_1^M(K_{s1}, 0, \varepsilon)\,\middle|\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right] \times \frac{dPr\left(\bar{\varepsilon} \leq \varepsilon^M(K_{s1})\right)}{dK_{s1}} \\
&= 0. \qquad \text{(C.21)}
\end{aligned}
$$

The specific expression for each of twelve elements is as follows.

$$Pr\left(\bar{\varepsilon} \geq \varepsilon^{*}(K_{s1})\right)$$

$$= \frac{\sqrt{3}\sigma - \varepsilon^{*}}{2\sqrt{3}\sigma} = \frac{1}{2} + \frac{1}{2\sqrt{3}\sigma}\left(A - g - \sqrt{\frac{2(3B+\beta)^{2}(1+r)f}{2B+\beta}}\right) - \frac{1}{2\sqrt{3}\sigma}\frac{B(\beta-\alpha)}{(B+\beta)}K_{s1}, \tag{C.22}$$

$$\frac{dPr\left(\bar{\varepsilon} \geq \varepsilon^{*}(K_{s1})\right)}{dK_{s1}} = -\frac{1}{2\sqrt{3}\sigma}\frac{B(\beta-\alpha)}{(B+\beta)}, \tag{C.23}$$

$$Pr\left(\varepsilon^{M}(K_{s1}) < \bar{\varepsilon} < \varepsilon^{*}(K_{s1})\right)$$

$$= \frac{\varepsilon^{*} - \varepsilon^{M}}{2\sqrt{3}\sigma} = \frac{1}{2\sqrt{3}\sigma}\sqrt{\frac{2(3B+\beta)^{2}(1+r)f}{2B+\beta}} - \frac{1}{2\sqrt{3}\sigma}\frac{(2B+\beta)(B+\alpha)}{(B+\beta)}K_{s1}, \tag{C.24}$$

$$\frac{dPr\left(\varepsilon^{M}(K_{s1}) < \bar{\varepsilon} < \varepsilon^{*}(K_{s1})\right)}{dK_{s1}} = -\frac{1}{2\sqrt{3}\sigma}\frac{(2B+\beta)(B+\alpha)}{(B+\beta)} \tag{C.25}$$

$$Pr\left(\bar{\varepsilon} \leq \varepsilon^{M}(K_{s1})\right) = \frac{1}{2} - \frac{A-g}{2\sqrt{3}\sigma} + \frac{2B+\alpha}{2\sqrt{3}\sigma}K_{s1}, \tag{C.26}$$

$$\frac{dPr\left(\bar{\varepsilon} \leq \varepsilon^{*}(K_{s1})\right)}{dK_{s1}} = \frac{2B+\alpha}{2\sqrt{3}\sigma}, \tag{C.27}$$

$$E\left[\Pi_{1}^{O}(K_{s1}, K_{g1}^{E}, K_{g2}^{E}, \varepsilon)\,|\bar{\varepsilon} \geq \varepsilon^{*}(K_{s1})\right]$$

$$= \int_{\varepsilon^{*}(K_{s1})}^{\sqrt{3}\sigma}\left(R^{O} + S^{O}\varepsilon^{2} + T^{O}\varepsilon + U^{O}\varepsilon K_{s1} + V^{O}K_{s1} + W^{O}K_{s1}^{2}\right)\frac{1}{2\sqrt{3}\sigma}d\bar{\varepsilon}$$

$$= \frac{\left(R^{O} + V^{O}K_{s1} + W^{O}K_{s1}^{2}\right)\left(\sqrt{3}\sigma - \epsilon^{*}\right)}{2\sqrt{3}\sigma} + \frac{\left(T^{O} + U^{O}K_{s1}\right)\left(3\sigma^{2} - \varepsilon^{*\,2}\right)}{4\sqrt{3}\sigma}$$

$$+ \frac{S^{O}\left(3\sqrt{3}\sigma^{3} - \varepsilon^{*\,3}\right)}{6\sqrt{3}\sigma}, \tag{C.28}$$

$$E\left[\Pi_{1}^{M}(K_{s1}, K_{g1}^{M}, \varepsilon)\,\left|\varepsilon^{M}(K_{s1}) < \bar{\varepsilon} < \varepsilon^{*}(K_{s1})\right.\right]$$

$$= \int_{\varepsilon^{M}(K_{s1})}^{\varepsilon^{*}(K_{s1})}\left(R^{M} + S^{M}\varepsilon^{2} + T^{M}\varepsilon + U^{M}\varepsilon K_{s1} + V^{M}K_{s1} + W^{M}K_{s1}^{2}\right)\frac{1}{2\sqrt{3}\sigma}d\bar{\varepsilon}$$

$$= \frac{\left(R^{M} + V^{M}K_{s1} + W^{M}K_{s1}^{2}\right)\left(\varepsilon^{*} - \varepsilon^{M}\right)}{2\sqrt{3}\sigma} + \frac{\left(T^{M} + U^{M}K_{s1}\right)\left(\varepsilon^{*\,2} - \varepsilon^{M\,2}\right)}{4\sqrt{3}\sigma}$$

$$+ \frac{S^{M}\left(\varepsilon^{*\,3} - \varepsilon^{M\,3}\right)}{6\sqrt{3}\sigma}, \tag{C.29}$$

$$E\left[\Pi_{1}^{M}(K_{s1}, 0, \varepsilon)\,\left|\bar{\varepsilon} < \varepsilon^{M}(K_{s1})\right.\right]$$

$$= \frac{\left[-(1+r)^{2}f + (A-s)K_{s1} - \left(B + \frac{\alpha}{2}\right)K_{s1}^{2}\right]\left(\varepsilon^{M} + \sqrt{3}\sigma\right)}{2\sqrt{3}\sigma} + \frac{K_{s1}\left(\varepsilon^{M\,2} - 3\sigma^{2}\right)}{4\sqrt{3}\sigma}. \tag{C.30}$$

By using Leibniz rule of integration,

$$
\begin{aligned}
&\frac{dE\left[\Pi_1^O(K_{s1},K_{g1}^E,K_{g2}^E,\varepsilon)\left|\bar{\varepsilon}\geq\varepsilon^M(K_{s1})\right.\right]}{dK_{s1}} \\
&= \frac{\left(V^O+2W^OK_{s1}\right)\left(\sqrt{3}\sigma-\varepsilon^*\right)}{2\sqrt{3}\sigma}+\frac{U^O\left(3\sigma^2-\varepsilon^{*\,2}\right)}{4\sqrt{3}\sigma} \\
&-\frac{(B(\beta-\alpha))}{2\sqrt{3}\sigma(B+\beta)}\left(R^O+S^O\,\varepsilon^{*\,2}+T^O\varepsilon^*+U^O\varepsilon^*K_{s1}+V^OK_{s1}+W^OK_{s1}^2\right), \qquad \text{(C.31)} \\
&\frac{dE\left[\Pi_1^M(K_{s1},K_{g1}^M,\varepsilon)\left|\varepsilon^M(K_{s1}<\bar{\varepsilon}<\varepsilon^*(K_{s1})\right.\right]}{dK_{s1}} \\
&= \frac{\left(V^M+2W^MK_{s1}\right)\left(\varepsilon^*-\varepsilon^M\right)}{2\sqrt{3}\sigma}+\frac{U^M\left(\varepsilon^{*\,2}-\varepsilon^{M\,2}\right)}{4\sqrt{3}\sigma} \\
&+\frac{(B(\beta-\alpha))}{2\sqrt{3}\sigma(B+\beta)}\left(R^M+S^M\,\varepsilon^{*\,2}+T^M\varepsilon^*+U^M\varepsilon^*K_{s1}+V^MK_{s1}+W^MK_{s1}^2\right) \\
&-\frac{(2B+\alpha)}{2\sqrt{3}\sigma}\left(R^M+S^M\,\varepsilon^{M\,2}+T^M\varepsilon^M+U^M\varepsilon^MK_{s1}+V^MK_{s1}+W^MK_{s1}^2\right), \qquad \text{(C.32)} \\
&\frac{dE\left[\Pi_1^M(K_{s1},0,\varepsilon)\left|\bar{\varepsilon}<\varepsilon^M(K_{s1})\right.\right]}{dK_{s1}} \\
&= \frac{\left[A-s-(2B+\alpha)\,K_{s1}\right]\left(\varepsilon^M+\sqrt{3}\sigma\right)}{2\sqrt{3}\sigma}+\frac{\varepsilon^{M\,2}-3\sigma^2}{4\sqrt{3}\sigma} \\
&+\frac{(2B+\alpha)}{2\sqrt{3}\sigma}\left[-(1+r)^2f+\varepsilon^MK_{s1}+(A-s)K_{s1}-\left(B+\frac{\alpha}{2}\right)K_{s1}^2\right]. \qquad \text{(C.33)}
\end{aligned}
$$

The first order condition (C.21) is also a cubic function of K_{s1}.

C.3 Competitive Market.

In the competitive market, Firm 1's problem is:

$$\begin{aligned}
&\max_{K_{s1}} E\left[\Pi_1^C(K_{s1}, K_{g1}, \varepsilon)\right] \\
&\quad = E\left[\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon)\,\middle|\varepsilon > \varepsilon^C(K_{s1})\right] Pr(\varepsilon > \varepsilon^C(K_{s1})) \\
&\quad + E\left[\Pi_1^C(K_{s1}, 0, \varepsilon)\,\middle|\varepsilon \leq \varepsilon^C(K_{s1})\right] Pr(\varepsilon \leq \varepsilon^C(K_{s1})), && \text{(C.34a)}
\end{aligned}$$

$$\Pi_1^C(K_{s1}, 0, \varepsilon) = -(1+r)^2 f + \varepsilon K_{s1} + (A-s)K_{s1} - \frac{\alpha}{2}K_{s1}^2, \tag{C.34b}$$

$$\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon) = R^C + S^C\varepsilon^2 + T^C\varepsilon + U^C\varepsilon K_{s1} + V^C K_{s1} + W^C K_{s1}^2, \tag{C.34c}$$

$$R^C \equiv -(1+r)^2 f + \frac{(A-g)^2}{2\beta}, \tag{C.34d}$$

$$S^C \equiv \frac{1}{2\beta}, \tag{C.34e}$$

$$T^C \equiv \frac{A-g}{\beta}, \tag{C.34f}$$

$$U^C \equiv 1 - \frac{\alpha}{\beta} \tag{C.34g}$$

$$V^C \equiv A - s - \frac{\alpha(A-g)}{\beta}, \tag{C.34h}$$

$$W^C \equiv -\frac{\alpha(\beta-\alpha)}{2\beta}. \tag{C.34i}$$

The first-order condition is

$$\begin{aligned}
&\frac{dE\left[\Pi_1^C(K_{s1}, K_{g1}, \varepsilon)\right]}{dK_{s1}} \\
&= \frac{dE\left[\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon)\,\middle|\varepsilon > \varepsilon^C(K_{s1})\right]}{dK_{s1}} \times Pr\left(\varepsilon > \varepsilon^C(K_{s1})\right) \\
&+ E\left[\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon)\,\middle|\varepsilon > \varepsilon^C(K_{s1})\right] \times \frac{dPr\left(\varepsilon > \varepsilon^C(K_{s1})\right)}{dK_{s1}} \\
&+ \frac{dE\left[\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon)\,\middle|\varepsilon \leq \varepsilon^C(K_{s1})\right]}{dK_{s1}} \times Pr\left(\varepsilon \leq \varepsilon^C(K_{s1})\right) \\
&+ E\left[\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon)\,\middle|\varepsilon \leq \varepsilon^C(K_{s1})\right] \times \frac{dPr\left(\varepsilon \leq \varepsilon^C(K_{s1})\right)}{dK_{s1}} \\
&= 0. && \text{(C.35)}
\end{aligned}$$

For each element of Equation (C.35), the specific expression is as follows.

$$Pr\left(\varepsilon > \varepsilon^C(K_{s1})\right) = \frac{\sqrt{3}\sigma - \varepsilon^C}{2\sqrt{3}\sigma} = \frac{1}{2} + \frac{A-g}{2\sqrt{3}\sigma} - \frac{\alpha}{2\sqrt{3}\sigma}K_{s1}, \tag{C.36}$$

$$\frac{dPr\left(\varepsilon > \varepsilon^C(K_{s1})\right)}{dK_{s1}} = -\frac{\alpha}{2\sqrt{3}\sigma}, \tag{C.37}$$

$$\begin{aligned}
&E\left[\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon)\,\middle|\,\varepsilon > \varepsilon^C(K_{s1})\right] \\
&= \int_{\varepsilon^C(K_{s1})}^{\sqrt{3}\sigma} \left(R^C + S^C\varepsilon^2 + T^C\varepsilon + U^C\varepsilon K_{s1} + V^C K_{s1} + W^C K_{s1}^2\right)\frac{1}{2\sqrt{3}\sigma}d\varepsilon \\
&= \frac{R^C + V^C K_{s1} + W^C K_{s1}^2}{2} + \frac{3\sigma(T^C + U^C K_{s1}}{4\sqrt{3}} + \frac{\sigma^2}{2} \\
&- \frac{(R^C + V^C K_{s1} + W^C K_{s1}^2)(\alpha K_{s1} - A + g)}{2\sqrt{3}\sigma} \\
&- \frac{(T^C\varepsilon + U^C\varepsilon K_{s1})(\alpha K_{s1} - A + g)^2}{4\sqrt{3}\sigma} \\
&- \frac{S^C(\alpha K_{s1} - A + g)^3}{6\sqrt{3}\sigma}.
\end{aligned} \tag{C.38}$$

$$\begin{aligned}
&E\left[\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon)\,\middle|\,\varepsilon \leq \varepsilon^C(K_{s1})\right] \\
&= \int_{-\sqrt{3}\sigma}^{\varepsilon^C(K_{s1})} \left(-(1+r)^2 f + \varepsilon K_{s1} + (A-s)K_{s1} - \frac{\alpha}{2}K_{s1}^2\right)\frac{1}{2\sqrt{3}\sigma}d\varepsilon \\
&= \frac{\left(-(1+r)^2 f + (A-s)K_{s1} - \frac{\alpha K_{s1}^2}{2}\right)(\alpha K_{s1} - A + g)}{2} \\
&+ \frac{(\alpha K_{s1} - A + g)^2 K_{s1}}{3\sqrt{3}\sigma} \\
&+ \frac{-(1+r)^2 f + (A-s)K_{s1} - \frac{\alpha K_{s1}^2}{2}}{2} \\
&- \frac{3\sigma}{4\sqrt{3}}K_{s1}.
\end{aligned} \tag{C.39}$$

By using Leibniz rule of integration,

$$\begin{aligned}
&\frac{dE\left[\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon)\,\middle|\,\varepsilon > \varepsilon^C(K_{s1})\right]}{dK_{s1}} \\
&= \frac{V^C}{2} + W^C K_{s1} + \frac{3\sigma U^C}{4\sqrt{3}} - \frac{\left(V^C + 2W^C K_{s1}\right)\varepsilon^C}{2\sqrt{3}\sigma} - \frac{U^C\left(\varepsilon^C\right)^2}{4\sqrt{3}\sigma} \\
&- \frac{\alpha}{2\sqrt{3}\sigma}\left(R^C + S^C\varepsilon^2 + T^C\varepsilon + U^C\varepsilon K_{s1} + V^C K_{s1} + W^C K_{s1}^2\right).
\end{aligned} \tag{C.40}$$

$$\begin{aligned}
&\frac{dE\left[\Pi_1^C(K_{s1}, K_{g1}^C, \varepsilon)\,\middle|\,\varepsilon \leq \varepsilon^C(K_{s1})\right]}{dK_{s1}} \\
&= \frac{(A - s - \alpha K_{s1})\,\varepsilon^C}{2\sqrt{3}\sigma} + \frac{\left(\varepsilon^C\right)^2}{4\sqrt{3}\sigma} + \frac{(A - s - \alpha K_{s1})}{2} - \frac{3\sigma}{4\sqrt{3}} \\
&+ \frac{\alpha}{2\sqrt{3}\sigma}\left(-(1+r)^2 f + \varepsilon^C K_{s1} + (A - s)K_{s1} - \frac{\alpha}{2}K_{s1}^2\right).
\end{aligned} \tag{C.41}$$

The first order condition (C.35) is also a cubic function of K_{s1}.

Appendix D Adjusted measure of industry sales volatility

We use the following method to estimate the industry demand volatility. A measure of demand volatility is the time-series variance of the mean sales growth rates. However, the variance of sample mean depends on the sample size (i.e., the number of firms in an industry), which varies by industry and changes over time in the Compustat data. Thus, we remove the effect of the sample size on our measure of demand volatility by the following method.

The sales growth rate x_{it} for firm i in quarter t can be decomposed into the industry common factor and the inflexible factor: $x_{it} = c_t + f_i$, where c_t is the latent industry common factor and f_i is the firm specific disturbance. We assume homoskedasticity: $c_t \sim N(C, \sigma_c^2)$ and $f_i \sim i.i.d.N(0, \sigma_f^2)$, where σ_c^2 is the constant time-series variance of c_t and σ_f^2 is the constant cross-sectional variance of f_i. Since f_i is independent random variable, $cov[c_t, f_i] = 0$. At time t, there are n_t observations of firms.

We can compute the empirical average of x_{it} for each t:

$$\bar{x}_t \equiv \frac{1}{n_t}\sum_{i=1}^{n_t} x_{it} = \frac{1}{n_t}\left(n_t c_t + \sum_{i=1}^{n_t} f_{it}\right) = c_t + \frac{1}{n_t}\sum_{i=1}^{n_t} f_{it}. \tag{D.1}$$

An unbiased estimator of c_t is the mean sales growth rate $\bar{x}_t$ because

$$E\left[c_t\right] = E\left[\bar{x}_t - \frac{1}{n_t}\sum_{i=1}^{n_t} f_{it}\right] = E\left[\bar{x}_t\right]. \tag{D.2}$$

For each t, we can also estimate cross-sectional variance σ_f^2 by $s_t^2 = \frac{1}{n_t-1}\sum_{i=1}^{n_t}\left(x_{it} - \bar{x}_t\right)^2$, which depends on the sample size n_t. The time-series variance of the mean sales growth rate is:

$$var_t\left[\bar{x}_t\right] = var_t\left[c_t + \frac{1}{n_t}\sum_{i=1}^{n_t} f_{it}\right] = E_t\left[\left(c_t + \frac{1}{n_t}\sum_{i=1}^{n_t} f_{it} - C\right)^2\right] = \sigma_c^2 + E_t\left[\left(\frac{1}{n_t}\sum_{i=1}^{n_t} f_{it}\right)^2\right], \tag{D.3}$$

where E_t is the expectation operator over time. In the last equality, we also assume that $cov\left(c_t, n_t\right) = 0$. If $n_t = n$ (constant), Equation (D.3) becomes

$$var_t\left[\bar{x}_t\right] = \sigma_c^2 + \frac{1}{n^2}E_t\left[\sum_{i=1}^{n}\sum_{j=1}^{n} f_{it} f_{jt}\right] = \sigma_c^2 + \frac{1}{n^2}\sum_{i=1}^{n} E_t\left[f_{it}^2\right] = \sigma_c^2 + \frac{\sigma_f^2}{n}. \tag{D.4}$$

Then, an unbiased estimator of σ_c^2 is $var_t\left[\bar{x}_t\right] - \frac{s^2}{n}$, assuming $s_t^2 = s^2$ (constant). However, if n_t changes over time, we need to evaluate $E_t\left[\frac{1}{n_t^2}\left(\sum_{i=1}^{n_t} f_{it}\right)^2\right]$. An approximation is $\frac{1}{T}\sum_{t=1}^{T}\frac{s_t^2}{n_t}$.

In our empirical tests, for each t, we compute the adjusted rolling volatility over the length of T_r:

$$\bar{\sigma}_{c,t} = \left[\frac{1}{T_r}\sum_{u=t-T_r}^{t}\left\{\left(\bar{x}_u - \frac{1}{T_r}\sum\nolimits_{v=t-T_r}^{t}\bar{x}_v\right)^2 - \frac{s_u^2}{n_u}\right\}\right]^{\frac{1}{2}} \tag{D.5}$$

Appendix E Additional Tables

VARIABLE	Model (1)	Model (2)	Model (3)	Model (4)
Firm-specific capital	0.1450***		0.1368***	
	(0.0201)		(0.0208)	
Firm-specific capital (3 years before)				0.1532***
				(0.0226)
Change in firm-specific capital (3 years before)				0.1480***
				(0.0438)
Change in firm-specific capital (2 years before)				0.1171**
				(0.0461)
Change in firm-specific capital (previous year)				0.0682*
				(0.0407)
Generic Capital	0.1548***		0.1406***	0.1571***
	(0.0164)		(0.0166)	(0.0178)
Sales volatility (20-qtr.)		-0.2672***	-0.2328***	-0.2630***
		(0.0433)	(0.0449)	(0.0468)
4-qtr. forecast error (20-qtr.)				0.0575
				(0.0637)
8-qtr. forecast error (20-qtr.)				0.0681*
				(0.0400)
12-qtr. forecast error (20-qtr.)				0.0129
				(0.0293)
Average Growth Rate Industry	-0.0117	-0.0104	-0.0267	-0.0657***
	(0.0233)	(0.0246)	(0.0257)	(0.0251)
Industry Age	3.8148***	5.2689***	3.6732***	1.2416**
	(0.5671)	(0.5380)	(0.5594)	(0.5889)
No. of Firms	-0.0009***	-0.0010***	-0.0009***	-0.0009***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Leverage	-0.0000	-0.0002	-0.0001	0.0000
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Average Firm Size (Assets)	-0.0007	-0.0036	0.0010	0.0071***
	(0.0022)	(0.0022)	(0.0022)	(0.0023)
Profitability Industry (ROA)	0.0764	0.1458***	0.0661	0.0790
	(0.0474)	(0.0474)	(0.0465)	(0.0528)
Constant	-28.4470***	-39.2916***	-27.3554***	-8.9832**
	(4.2961)	(4.0794)	(4.2385)	(4.4602)
Year f.e.	Yes	Yes	Yes	Yes
Observations	7047	7204	7031	6143
Adjusted R-squared	0.247	0.249	0.253	0.260

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table E.1: Test of Predictions 1 and 2. This table reports the result of the OLS estimation of the panel regression model (Equation (26)) with year fixed effects. The dependent variable is the combined market share of the three largest firms for industries based on 2-digit SIC classification. White's heteroskedasticity-consistent standard errors are also reported.

VARIABLES	Model (1)	Model (2)	Model (3)	Model (4)
Sales volatility (20-qtr.)	0.2244***	0.2354***		
	(0.0289)	(0.0279)		
Sales volatility (20-qtr.) × I.C. Index		-0.0257		
		(0.1037)		
Sales volatility (40-quarter)			0.3071***	0.1169***
			(0.0277)	(0.0316)
Sales volatility (40-quarter) × I.C. Index				0.6951***
				(0.1633)
Average Growth Rate Industry		0.0300*		0.0424***
		(0.0157)		(0.0147)
Leverage		0.0007*		0.0014***
		(0.0004)		(0.0001)
Industry Age		-1.7198***		-0.9050***
		(0.2495)		(0.2068)
No. of Firms		0.0001***		0.0001***
		(0.0000)		(0.0000)
Average Firm Size (Assets)		-0.0093***		-0.0087***
		(0.0013)		(0.0010)
Profitability Industry (ROA)		-0.1118***		-0.0751***
		(0.0287)		(0.0256)
Constant	0.1360***	13.2983***	0.1223***	7.1019***
	(0.0058)	(1.8899)	(0.0047)	(1.5675)
Year f.e.	Yes	Yes	Yes	Yes
Observations	7109	7109	6989	6989
Adjusted R-squared	0.154	0.188	0.142	0.209

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table E.2: Test of Prediction 4. This table reports the result of the OLS estimation of regression equation (31). The dependent variable is the volatility of the average corporate value growth rates for each industry with the 2-digit SIC classification. The explanatory variables are the industry sales volatility and the interaction terms of the sales volatility and industry concentration (I.C. Index) measured by the combined market share of the three largest firms in each industry.. The low demand variables are also used as a conditioning variable. The volatility is measured on the basis of 40-quarter rolling estimation and adjusted for the number of observation as outlined in Appendix D. White's heteroskedasticity-consistent standard errors are also reported.