External Financing and Customer Capital: A Financial Theory of Markups

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Abstract

We develop a continuous-time industry equilibrium model of monopolistic competition to understand how product markups are determined in the presence of external financing costs and customer capital. Firms optimally set markups to balance the trade-off between profiting from their existing customer base and developing their future customer base. We characterize how the equilibrium markups are determined by the interaction between the marginal value of corporate liquidity and the marginal value of customer base. Firms' markups are more responsive to changes in their marginal value of corporate liquidity when the marginal value of customer base is higher. Moreover, the model predicts that greater product market threats lead to more conservative financial policies, which is supported by the data.

Keywords: Markups, Customer base, External financing costs, Monopolistic competition, Corporate liquidity, Industry dynamics.
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1 Introduction

A central question in economics is how markups, the ratio of product prices to the marginal costs of production, are determined. For the aggregate economy, the variation in markups affects the dynamics of inflation (e.g., Gilchrist et al., 2017), the fluctuations of output and employment over business cycles (e.g., Chari, Kehoe and McGrattan, 2007), and the transmission of macroeconomic policies (e.g., Loecker et al., 2016). At the firm level, the variation in markups reflects time-varying market power, influencing firms' cash flows, customer base accumulation, financial decisions, risk management, and valuation. Despite these previous studies, the theoretical link between markup dynamics and financial constraints in the presence of dynamic corporate liquidity management is still poorly understood. Establishing such a link is particularly desirable given the recent empirical studies documenting the crucial role of financial constraints in determining markups (e.g., Fresard, 2010; Koijen and Yogo, 2015; Gilchrist et al., 2017).

In this paper, we study how firms set markups in the presence of endogenous corporate liquidity due to costly external financing. The core mechanism we emphasize is the intertemporal tradeoff between setting low markups to invest in customer base for future profits versus setting high markups to harvest locked-in customers. This *customer-market mechanism* was pioneered by Phelps and Winter (1970) and further developed in various dynamic equilibrium models.[1] We depart from existing models by allowing firms to optimally make financial decisions and manage corporate liquidity as in Bolton, Chen and Wang (2011), Belo, Lin and Yang (2019), and Dou et al. (2019), whereas existing models of markups usually exogenously specify financial decisions.[2] By explicitly modeling corporate liquidity (or cash holdings) and customer base as two endogenous state variables, we characterize the rich interactions between financial constraints and customer base, as well as their effect on firms' markup decisions.

Our model provides several new theoretical insights and predictions. First, we characterize how firms' equilibrium markups are determined by the interaction between financial constraints and customer base, expanding the scope of the theories of markups offered by existing models (e.g., Ravn, Schmitt-Grohe and Uribe, 2006; Gilchrist et al., 2017). For example, our model reveals that when the firm is more liquidity constrained, its markup becomes more sensitive to its financial condition but less sensitive to its opportunities for customer base development.

[1] E.g., Ravn, Schmitt-Grohe and Uribe (2006), Gourio and Rudanko (2014), and Gilchrist et al. (2017).

[2] For example, Chevalier and Scharfstein (1996) Rotemberg and Woodford (1991, 1992), Ravn, Schmitt-Grohe and Uribe (2006), and Gilchrist et al. (2017) analyze markups without considering dynamic corporate liquidity management.

Second, we analyze how firms' financial decisions are influenced by product market threats, extending the existing corporate theories (e.g., Bolton, Chen and Wang, 2011) with endogenous cash flows microfounded by firms' optimal markup decisions. Our paper highlights the important role of markups in connecting firms' decisions in the product and financial markets.[3] For example, when firms become more liquidity constrained, they raise markups to gain higher short-run cash flows at the cost of lower future customer base. For another example, our model reveals that when the market structure is more competitive, firms will charge lower markups, resulting in lower cash flows. The lower cash flows make it more likely for firms to be liquidity constrained, which motivates these firms to adopt more conservative financial policies. In particular, our model implies that firms in the industries with more competitive market structure hold more cash and are less likely to offer payouts. Such a relationship is more pronounced during periods of higher external financing costs.

We use the calibrated model to evaluate the effect of financial constraints on markup dynamics and study the quantitative implications of the customer-market mechanism. One of the most convincing event-study type of cross-sectional evidence is from Gilchrist et al. (2017), who document that during the 2007 – 2009 financial crisis, liquidity-constrained firms significantly increased their prices relative to the industry average. Similar to Gilchrist et al. (2017), we simulate the economy with increased external financing costs to mimic the 2007 – 2009 financial crisis. In our simulation, the markup dynamics of low liquidity firms implied by our model are quantitatively consistent with the data.

While our contribution is mainly theoretical, we also provide empirical support for the implication of product market competition on financial policies. By exploiting the fluidity measure of competitive threats constructed by Hoberg, Phillips and Prabhala (2014), we find that industries with greater fluidity are associated with fewer share repurchases and higher cash holdings, suggesting that firms in these industries adopt more conservative financial policies. Moreover, we find that during the 2007 – 2009 financial crisis, the negative effect of product market threats on industry share repurchases and cash holdings is more significant. Our industry-level evidence is consistent with the firm-level evidence in the literature. For example, Hoberg, Phillips and Prabhala (2014) show that fluidity decreases the firm's propensity to make payouts and increases the firm's incentives to hoard cash, especially for the firms with more constrained access to financial markets. Morellec, Nikolov and Zucchi (2014) find that equity issuance and cash holdings are positively associated with

[3]Our paper is related to the work studying the impact of industry competition on corporate decisions. For example, Grenadier (2002) studies the effects of industry competition on the exercise of real options. Hackbarth and Miao (2012) analyze the dynamics of mergers and acquisitions in oligopoly industries. Bustamante (2015) and Bustamante and Fresard (2017) study the strategic interactions in firms' investment decisions. Bustamante and Donangelo (2017) study the relation between product market competition and expected stock returns. Hackbarth and Taub (2018) investigate the interactions between product market dynamics and mergers.

various measures of product market competition. Based on innovation proximity measures (Jaffe, 1986) of competition intensity, Lyandres and Palazzo (2016) find that financially constrained firms hold more cash when expected competition intensity via innovation in the product market increases. By applying a difference-in-differences analysis on the contraction in the supply of credit in 1989, they further show that the association between expected competition intensity via innovation and cash holdings is more significant among the firms headquartered in the northeastern part of the U.S., a region more exposed to the collapse of the junk bond market in 1989.

Additional related literature. Our paper is related to four strands of literature. First, it is related to the literature highlighting the importance of customer base in determining markups (e.g., Phelps and Winter, 1970; Rotemberg and Woodford, 1991, 1992; Ravn, Schmitt-Grohe and Uribe, 2006; van Binsbergen, 2016). In a seminal work, Ravn, Schmitt-Grohe and Uribe (2006) provide a micro-foundation for customer market based on consumers' deep habits, which can generate countercyclical markups. Our model differs from these models by highlighting the role of dynamic corporate liquidity management.

Second, our paper contributes to the emerging literature on the impact of industry competition in customer markets on corporate decisions and valuations. Titman (1984) and Titman and Wessels (1988) provide the first piece of theoretical insight into and empirical evidence on the impact of product market characteristics on a firm's financial decisions. The specific contributions in this literature include Banerjee, Dasgupta and Kim (2008), Hoberg, Phillips and Prabhala (2014), and D'Acunto et al. (2018) who investigate the effect of industry competition and customer base on firms' leverage decisions. Moreover, Dumas (1989), Kovenock and Phillips (1997), Grenadier (2002), Novy-Marx (2007), Hoberg and Phillips (2010), Hackbarth and Miao (2012), Gourio and Rudanko (2014), Hackbarth, Mathews and Robinson (2014), and Bustamante (2015) investigate the implication of industry competition and customer base on various corporate policies such as investment, mergers and acquisitions, and entries and exits. Finally, a growing number of recent papers focus on the implication of industry competition and customer base on firms' valuation and equity returns (e.g., Hou and Robinson, 2006; Aguerrevere, 2009; Larkin, 2013; Belo, Lin and Vitorino, 2014; Bustamante, 2015; Loualiche, 2016; Bustamante and Donangelo, 2017; Corhay, 2017; Corhay, Kung and Schmid, 2017; Belo et al., 2019; Dou et al., 2019; Dou, Ji and Wu, 2020; Chen et al., 2020). Our model differs from the existing papers by investigating the interaction of corporate liquidity and sticky customer base in a dynamic setting and stressing its importance in determining corporate decisions.

Third, our paper is related to the burgeoning literature on how firms' financial conditions influence their behavior in product markets. In the early seminal works, Titman (1984) and Maksimovic and Titman (1991) study how capital structure affects a firm's choice of product quality and the viability of its products' warranties. Brander and Lewis (1986) focus on the "limited liability" effect of debt financing on product competition behavior. Bolton and Scharfstein (1990) show that financial constraints give rise to rational predation behavior. Phillips (1995) empirically investigates whether a firm's capital structure affects its own and its competitors' output and product pricing decisions. Chevalier and Scharfstein (1996) and Gilchrist et al. (2017) show both in model and data that liquidity-constrained firms tend to set higher markups to increase their short-term cash flows. Hoberg and Phillips (2016) investigate how R&D expenses affect product market competition behavior, and Hackbarth and Taub (2018) study how M&A activities affect product market competition behavior. Chen et al. (2020) extend the work of Bolton and Scharfstein (1990) to a dynamic Leland framework with long-term debt and endogenous customer base accumulation. Opp, Parlour and Walden (2014), Dou, Ji and Wu (2020), and Chen et al. (2020) show that the time-varying discount rates affect firms' collusion incentive and thus their market power.

Our paper focuses on monopolistically competitive firms for simplicity and transparency. The main theoretical results would remain unchanged if we allow for imperfect competition. Most earlier dynamic models of imperfect competition focus on identical firms and therefore do not have within-industry implications (e.g., Grenadier, 2002; Aguerrevere, 2009; Opp, Parlour and Walden, 2014). More recent models started to focus on heterogeneous firms within the industry (e.g., Bustamante, 2015; Hackbarth and Taub, 2018; Dou, Ji and Wu, 2020; Chen et al., 2020). We hope to provide a generic framework for studying firms' markups, cash holdings, and payout decisions. Not only is the framework useful in its own right, its contributions also constitute the foundation for several generalizations that go beyond the setup considered in this paper. For example, Dou, Ji and Wu (2020) build on this framework to investigate the amplification effect of endogenous markups on firms' exposure to aggregate discount-rate shocks; and Chen et al. (2020) shed light on firms' endogenous predatory pricing behavior in a structural model of default with long-term debt. Besides assuming imperfect competition, there are three additional main differences between the aforementioned papers and ours. First, our model analyzes how firms set markups without tacitly colluding with each other, whereas Dou, Ji and Wu (2020) and Chen et al. (2020) both focus on firms' collusive decisions on setting markups. One crucial implication of tacit collusion is that it generates a countervailing force on the relation between financial constraints and markups. Markups may become pro-cyclical with tacit collusion in the sense that firms set lower markups when they become more liquidity constrained due to increased deviation incentive. Second, our model emphasizes the role of endogenous liquidity buffers in determining firms' markups by directly modeling firms' endogenous external financing and payout decisions, whereas firms modeled by Dou, Ji and Wu (2020) and Chen et al. (2020) do not accumulate liquidity buffers. Third, our paper does not provide asset pricing implications, whereas Dou, Ji and Wu (2020) and Chen et al. (2020) focus on cross-sectional asset pricing implications, providing explanations for the gross profitability premium puzzle and the financial distress anomaly at the industry level.

There are also a growing number of empirical papers that explore how firms' financial conditions influence their behavior in product markets in the data. Fresard (2010) shows that large cash reserves lead to systematic future market share gains at the expense of industry rivals based on a difference-in-differences estimate. Koijen and Yogo (2015) show that insurance companies' aggressive pricing behavior with extremely low markups can be caused by worsened financial conditions, especially when the statutory reserve regulation becomes more binding. Gilchrist et al. (2017) use the product-level price data underlying the PPI (producer price index) and the data on respondents' balance sheets to show that liquidity constrained firms increased prices in 2008, while their unconstrained counterparts cut prices, relative to the industry price indices. Cookson (2017) empirically investigates the effect of leverage on strategic preemption using the data on entry plans and incumbent investments from the American casino industry. By exploiting reforms in trade credit contracts, Beaumont and Lenoir (2020) find that relaxing firms' liquidity constraints leads to greater investment in the expansion of their customer base. In a recent paper, Chen et al. (2020) provide difference-in-difference empirical evidence on how the competition-distress feedback effect and the financial contagion effect are influenced by the variation in the competitiveness of market structure.

Fourth, our paper is related to the literature on dynamic structural corporate finance (e.g., Grenadier and Wang, 2005; Hackbarth, Miao and Morellec, 2006; Hackbarth, Hennessy and Leland, 2007; Manso, 2008; Manso, Strulovici and Tchistyi, 2010; Bolton, Chen and Wang, 2011; Hackbarth and Mauer, 2012; Manso, 2013). Existing dynamic corporate theories typically assume that the product market offers exogenous cash flows unrelated to firms' debt-equity positions or corporate liquidity conditions. Our model differs from those in this literature by explicitly considering an industry of monopolistic competition in which firms' optimal markup decisions generate endogenous cash flows. This allows us to jointly study firms' financial decisions in the financial market and their markup-setting decisions in the product market, as well as the interactions.

2 Model

We consider a model of monopolistic competition in which there is an industry populated by a continuum of firms of measure one. Each firm is atomistic and indexed by $i \in [0,1]$. Firms produce differentiated goods and set product prices to maximize shareholder value.

2.1 Customer Base

Industry demand. Similar to Pindyck (1993) and Caballero and Pindyck (1996), we focus on the industry equilibrium by specifying an isoelastic industry demand curve:

$$C_t = M_t P_t^{-\epsilon}, \tag{2.1}$$

where the industry demand C_t is negatively related to the industry's price index P_t, with $\epsilon > 1$ capturing the industry's price elasticity of demand. The variable M_t is an endogenous stochastic process that captures the total customer base in the industry.

Differentiated goods and firm-level demand. The demand for the industry's final good C_t is a basket of firm-level differentiated products $C_{i,t}$, determined by a Dixit-Stiglitz constant elasticity of substitution (CES) aggregation:

$$C_t = \left[\int_0^1 \left(\frac{M_{i,t}}{M_t}\right)^{\frac{1}{\eta}} C_{i,t}^{\frac{\eta-1}{\eta}} \mathrm{d}i\right]^{\frac{\eta}{\eta-1}}, \tag{2.2}$$

where $M_t = \int_0^1 M_{i,t} \mathrm{d}i$ and the parameter η captures the elasticity of substitution among goods produced in the same industry. The weight $M_{i,t}/M_t > 0$ captures consumers' relative "taste" for firm i's products at time t within the industry. A higher $M_{i,t}/M_t$ means that households prefer firm i's goods more relative to the goods of other firms in the industry.

Given the industry demand C_t and the price of firm i's goods $P_{i,t}$, solving a standard expenditure minimization problem gives the demand for firm i's goods $C_{i,t}$:

$$C_{i,t} = \frac{M_{i,t}}{M_t}\left(\frac{P_{i,t}}{P_t}\right)^{-\eta} C_t, \quad \text{with} \quad P_t = \left[\int_0^1 \left(\frac{M_{i,t}}{M_t}\right) P_{i,t}^{1-\eta} \mathrm{d}i\right]^{\frac{1}{1-\eta}}. \tag{2.3}$$

In the demand function (2.3), the coefficient $M_{i,t}$ linearly determines the demand for firm i's good $C_{i,t}$, thereby naturally capturing the customer base of firm i from the firm's perspective. Consistent with the literature (e.g., Atkeson and Burstein, 2008; Corhay, Kung and Schmid, 2017; Dou, Ji and Wu, 2020), we consider the empirically relevant demand function by assuming that $\eta > \epsilon > 1$, meaning that goods produced within the same industry are more substitutable. For example, the elasticity of substitution between the Apple iPhone and the Samsung Galaxy is much higher than that between a cell phone and coffee.

Combining equations (2.1) and (2.3), the firm-level demand $C_{i,t}$ is fully characterized by:

$$C_{i,t} = M_{i,t} \left(\frac{P_{i,t}}{P_t} \right)^{-\eta} P_t^{-\epsilon}, \text{ with } P_t = \left[\int_0^1 \left(\frac{M_{i,t}}{M_t} \right) P_{i,t}^{1-\eta} \mathrm{d}i \right]^{\frac{1}{1-\eta}}. \tag{2.4}$$

Because there is a continuum of atomistic firms in the industry, each firm takes the industry's price index P_t as given. Thus, the demand function (2.4) implies that the elasticity of substitution η also captures the price elasticity of demand for firm i's goods.

Evolution of customer base. Firms can attract consumers through undercutting prices or offering discounts. Lowering prices can have a persistent positive effect on the firm's demand due to consumption inertia, information frictions, and switching costs. To capture this idea, we follow Phelps and Winter (1970) and Ravn, Schmitt-Grohe and Uribe (2006), and model the evolution of firm i's customer base $M_{i,t}$ as

$$\mathrm{d}M_{i,t} = \beta C_{i,t} \mathrm{d}t - \rho M_{i,t} \mathrm{d}t. \tag{2.5}$$

In the above equation, the term $\beta C_{i,t}$ captures the endogenous accumulation of customer base. Intuitively, by setting a lower price $P_{i,t}$, firm i can increase the contemporaneous demand flow rate $C_{i,t}$, thereby accumulating a larger customer base over $[t, t + \mathrm{d}t]$. The parameter $\beta > 0$ captures the speed of customer base accumulation. A greater β indicates that customer base accumulation is more sensitive to contemporaneous demand $C_{i,t}$. Consistent with the empirical evidence, the slow-moving customer base $M_{i,t}$ implies that the long-run price elasticity of demand is higher than the short-run elasticity (e.g., Rotemberg and Woodford, 1991). The term ρ captures industry-level customer base depreciation.

The preference towards differentiated goods, combining (2.2) and (2.5), is similar to *relative deep habits* (Ravn, Schmitt-Grohe and Uribe, 2006, see their Online Appendix). The specification of relative deep habits is inspired by the habit formation of Abel (1990), which features *catching up with the Joneses*. The defining feature of relative deep habits is that agents form habits of consuming individual varieties of goods as opposed to a composite consumption good. The coefficient β captures the strength of relative deep habits. When $\beta = 0$, the customer-market mechanism is shut down, and firms lose the incentive to reduce their markups for customer base accumulation.

2.2 Financing Constraints

Markups. Firms produce differentiated goods using capital, which is rented at the rental rate $R = r + \delta$, where r is the risk-free rate and δ is the capital depreciation rate.[4] Because there is no risk in firm production, the rental rate is derived based on the risk-free rate and is the same for all firms.

Each firm uses an AK production technology. Over $[t, t + \mathrm{d}t]$, firm i produces a flow of goods $Y_{i,t}$ with intensity

$$Y_{i,t} = AK_{i,t}, \tag{2.6}$$

where $K_{i,t}$ is the amount of capital rented by firm i at t, and the rental cost is $RK_{i,t}\mathrm{d}t$ over $[t, t + \mathrm{d}t]$. Given productivity A, the marginal cost of producing one unit of goods is R/A. The firm's markup $\Lambda_{i,t}$ is defined as the price-to-marginal-cost ratio:

$$\Lambda_{i,t} = \frac{P_{i,t}}{R/A}. \tag{2.7}$$

According to equation (2.4), the industry's markup index Λ_t can be written as follows:

$$\Lambda_t = \left[\int_0^1 \left(\frac{M_{i,t}}{M_t}\right) \Lambda_{i,t}^{1-\eta} \mathrm{d}i\right]^{1/(1-\eta)}. \tag{2.8}$$

The markup index aggregation has the same functional form as the price index aggregation, since firms' markups are proportional to their price levels and the CES aggregator is homogeneous of degree one.

Cash flows shocks. Firms face idiosyncratic operating cash-flow shocks, modeled as $\sigma M_{i,t}\mathrm{d}Z_{i,t}$ over $[t, t + \mathrm{d}t]$, where $Z_{i,t}$ is a standard Brownian motion. Therefore, firm i's operating profit $\mathrm{d}O_{i,t}$ over $[t, t + \mathrm{d}t]$ is given by

$$\mathrm{d}O_{i,t} = (P_{i,t} - R/A)\,\Pi_{i,t}\mathrm{d}t + \sigma M_{i,t}\mathrm{d}Z_{i,t}, \tag{2.9}$$

where $\Pi_{i,t} = \min(Y_{i,t}, C_{i,t})$ is firm i's sales, which cannot exceed its production output $Y_{i,t}$ or demand $C_{i,t}$ as in Gourio and Rudanko (2014) and Dou et al. (2019).

In equilibrium, the firm would never produce more than the demand $C_{i,t}$ because production has positive marginal cost R/A and the goods are immediately perishable. At the same time, the price of goods $P_{i,t}$ must be set above the marginal cost. Therefore, the

[4] Similar modeling approaches have been adopted in the macroeconomics literature (e.g., Jorgenson, 1963; Hall and Jorgenson, 1969; Buera and Shin, 2013; Moll, 2014) and in the corporate theory literature (e.g., Rampini and Viswanathan, 2013).

market-clearing condition is $Y_{i,t} = C_{i,t}$ in equilibrium and the optimal amount of capital rented by firm i is $K_{i,t} = C_{i,t}/A$.

By substituting the market-clearing condition and equation (2.4) into equation (2.9), firm i's operating profit $\mathrm{d}O_{i,t}$ over $[t, t + \mathrm{d}t]$ is given by:

$$\mathrm{d}O_{i,t} = (P_{i,t} - R/A)\left(\frac{P_{i,t}}{P_t}\right)^{-\eta} P_t^{-\epsilon} M_{i,t}\mathrm{d}t + \sigma M_{i,t}\mathrm{d}Z_{i,t}. \tag{2.10}$$

External financing costs and corporate liquidity. We assume that firms have access to the equity market but not the corporate debt or loan market.[5] Let $\mathrm{d}D_{i,t}$ denote the net payout of the firm, with $\mathrm{d}D_{i,t} > 0$ representing dividend payout and $\mathrm{d}D_{i,t} < 0$ representing equity financing. Equity financing is costly as captured by a fixed cost γ proportional to firm size (characterized by $M_{i,t}$) and a variable cost φ proportional to the amount of equity issuance $\mathrm{d}D_{i,t}$ if $\mathrm{d}D_{i,t} < 0$. Thus, the financing cost is $\mathrm{d}X_{i,t} = (\gamma M_{i,t} - \varphi \mathrm{d}D_{i,t})\mathbb{1}_{\mathrm{d}D_{i,t}<0}$.[6] The key idea is that external funds are not perfect substitutes for internal liquid funds.

The financing cost motivates firms to hoard cash $W_{i,t}$ on balance sheets. Holding cash is costly due to the agency costs associated with free cash in the firm or tax distortions.[7] We assume that the return on cash is the interest rate r minus a carrying cost $\lambda > 0$, the existence of which implies that the firm would pay out dividends when cash holdings are high. In our model, cash holdings $W_{i,t}$ capture all internal liquid funds held by the firm. The firm's cash holdings $W_{i,t}$ evolve according to

$$\mathrm{d}W_{i,t} = \mathrm{d}O_{i,t} + (r - \lambda)W_{i,t}\mathrm{d}t - \mathrm{d}D_{i,t}. \tag{2.11}$$

2.3 Equilibrium

It is helpful to highlight two key features of the model before fully characterizing the equilibrium. First, in our model, firm i's shareholder value is homogeneous of degree one in terms of its customer base $M_{i,t}$. This is because both the firm's operating profits $\mathrm{d}O_{i,t}$ and fixed financing costs $\mathrm{d}X_{i,t}$ are proportional to its customer base $M_{i,t}$. Define firm i's customer base share as $m_{i,t} \equiv M_{i,t}/M_t$ and its cash ratio as $w_{i,t} \equiv W_{i,t}/M_{i,t}$. At each point

[5] This assumption is innocuous for our purpose since we only need the endogenous time-varying marginal value of corporate liquidity. The simplification captures the main idea of our theory while maintaining tractability.

[6] The modeling of fixed and variable equity financing costs follows the literature (e.g., Gomes, 2001; Riddick and Whited, 2009; Gomes and Schmid, 2010; Bolton, Chen and Wang, 2011; Eisfeldt and Muir, 2016; Belo, Lin and Yang, 2019; Dou et al., 2019).

[7] An example of tax distortion is that the interest earned by the firm on its cash holdings is taxed at the corporate tax rate, which generally exceeds the personal tax rate on interest income (e.g., Graham, 2000; Faulkender and Wang, 2006; Riddick and Whited, 2009).

in time t, the state of the industry is characterized by the joint distribution $\phi_t(m, w)$ across all firms in the industry. Because of the homogeneity property, we can characterize the state of the industry using the *share of customer base held by firms with cash ratio* w, defined by[8]

$$\theta_t(w) \equiv \int_0^\infty m\phi_t(m, w)\mathrm{d}m. \tag{2.12}$$

As in Moll (2014), $\theta_t(w)$ satisfies that $\int_{\mathcal{A}_t} \theta_t(w)\mathrm{d}w = 1$, where $\mathcal{A}_t$ is the support of the density function $\theta_t(w)$ in equilibrium. Thus, for each firm i, the value function can be rewritten as

$$V(W_{i,t}, M_{i,t}, \theta_t) \equiv v(w_{i,t}, \theta_t)M_{i,t}. \tag{2.13}$$

Second, as shown in equation (2.13), the share density function θ_t is an aggregate state variable capturing the industry dynamics. We emphasize that each firm i needs to track the dynamics of θ_t to optimally choose its product price $P_{i,t}$ (or markup $\Lambda_{i,t}$) and financial policy $\mathrm{d}D_{i,t}$. The industry's price index P_t is determined by the market-clearing condition and the demand curve (2.1) at the industry level. In equilibrium, the industry's price index P_t is given by equation (2.4), which can be rewritten as:

$$P_t \equiv P(\theta_t) = \left[\int_{\mathcal{A}_t} \theta_t(w)P(w, \theta_t)^{1-\eta}\mathrm{d}w\right]^{\frac{1}{1-\eta}}, \tag{2.14}$$

where $P(\theta_t)$ is the industry's price index depending on the share density θ_t, and $P(w, \theta_t)$ is the firm-level price depending on the firm-specific cash ratio w and the share density θ_t. To maximize shareholder value, firms need to know how the industry's price index P_t evolves in the future. According to equation (2.14), the current level of the industry's price index P_t does not suffice to fully capture the evolution of the price index in the future; rather, the current share density θ_t does. Therefore, each firm i needs to track the dynamics of the share density θ_t, as an infinite-dimensional aggregate state variable.

We now characterize the equilibrium. Firm i chooses its product price $P_{i,t}$ and makes financing/payout decisions $\mathrm{d}D_{i,t}$ to maximize its shareholder value $v(w_{i,t}, \theta_t)M_{i,t}$. Optimization problems can be formulated by Hamilton-Jacobi-Bellman (HJB) equations:

$$rv(w_{i,t}, \theta_t)M_{i,t}\mathrm{d}t = \max_{P_{i,t}, \mathrm{d}D_{i,t}} \mathrm{d}D_{i,t} - \mathrm{d}X_{i,t} + \mathbb{E}_t\left[\mathrm{d}\left(v(w_{i,t}, \theta_t)M_{i,t}\right)\right], \tag{2.15}$$

[8]Our normalization follows the insight of Moll (2014) who introduces "the share of wealth held by productivity-type z" to characterize the state of the economy. In his model, entrepreneurs' value is homogeneous of degree one in terms of their wealth because of the constant-returns-to-scale production technology and the log utility.

subject to the evolution of the customer base $M_{i,t}$, the cash ratio $w_{i,t}$, and the share density θ_t. We elaborate the evolution of the three state variables below.

Combining equations (2.4) and (2.5), the evolution of $M_{i,t}$ is given by

$$\frac{\mathrm{d}M_{i,t}}{M_{i,t}} = \beta \left[\frac{P_{i,t}}{P(\theta_t)}\right]^{-\eta} P(\theta_t)^{-\epsilon}\mathrm{d}t - \rho \mathrm{d}t. \tag{2.16}$$

Therefore, the evolution of firm i's customer base share is

$$\frac{\mathrm{d}m_{i,t}}{m_{i,t}} = \beta \left[P_{i,t}^{-\eta} - \int_{\mathcal{A}_t} P(w,\theta_t)^{-\eta}\theta_t(w)\mathrm{d}w\right] P(\theta_t)^{\eta-\epsilon}\mathrm{d}t. \tag{2.17}$$

Next, we characterize the evolution of the cash ratio $w_{i,t}$. We first need to figure out the firm's optimal financial decisions characterized by the decision boundaries of the cash ratio as in Bolton, Chen and Wang (2011). Specifically, the firm pursues external financing ($\mathrm{d}D_{i,t} < 0$) when its cash ratio $w_{i,t}$ is below the optimal equity issuance boundary $\underline{w}(\theta_t)$ due to the fixed financing cost. Similar to Bolton, Chen and Wang (2011), the optimal issuance boundary is $\underline{w}(\theta_t) = 0$. Conditional on issuing equity, the firm replenishes its cash ratio to some optimal level $w^*(\theta_t) > 0$ due to the variable financing cost. The firm pays out dividend ($\mathrm{d}D_{i,t} \geq 0$) when its cash ratio $w_{i,t}$ is above the optimal payout boundary $\overline{w}(\theta_t)$. Thus, the support of the share distribution θ_t is $A_t = [0, \overline{w}(\theta_t)]$. We present the conditions that determine firms' optimal financing and payout decisions in Online Appendix D. We solve the model in both steady states and transitions. The numerical algorithm is detailed in Online Appendix E.1.

The evolution of firm i's cash ratio $w_{i,t}$ is as follows. When firm i is in the external financing region (i.e., $w_{i,t} \leq 0$), the change in its cash ratio over $[t, t+\mathrm{d}t]$ is

$$\mathrm{d}w_{i,t} = w^*(\theta_t) - w_{i,t}; \tag{2.18}$$

when firm i is in the payout region (i.e., $w_{i,t} > \overline{w}(\theta_t)$), the change in its cash ratio over $[t, t+\mathrm{d}t]$ is

$$\mathrm{d}w_{i,t} = \overline{w}(\theta_t) - w_{i,t}; \tag{2.19}$$

when firm i is in the internal liquidity-hoarding region (i.e., $0 < w_{i,t} \leq \overline{w}(\theta_t)$), the change in its cash ratio over $[t, t+\mathrm{d}t]$ is

$$\mathrm{d}w_{i,t} = \left[(r-\lambda+\rho)\, w_{i,t} + (P_{i,t} - R/A - \beta w_{i,t})\, P_{i,t}^{-\eta} P(\theta_t)^{\eta-\epsilon}\right]\mathrm{d}t + \sigma \mathrm{d}Z_{i,t}. \tag{2.20}$$

Finally, we characterize the evolution of the share density θ_t. To better understand its evolution, it is conceptually helpful to use a discrete-time approximation similar to that used by Hopenhayn (1992) and Miao (2005). The following equation describes the evolution of θ_t for any interval $B \subseteq \mathcal{A}_{t+\mathrm{d}t}$:

$$\int_0^{\overline{w}(\theta_{t+\mathrm{d}t})} \mathbf{1}_{\{w\in B\}}\theta_{t+\mathrm{d}t}(w)\mathrm{d}w = \int_0^{\overline{w}(\theta_t)} \mathbb{Q}_{t,t+\mathrm{d}t}(B|w)\theta_t(w)\mathrm{d}w + \left[\beta P(\theta_t)^{\eta-\epsilon}\zeta(B,\theta_t) + \underline{e}_t\mathbf{1}_{\{w^*(\theta_t)\in B\}} + \overline{e}_t\mathbf{1}_{\{\overline{w}(\theta_t)\in B\}}\right]\mathrm{d}t, \quad (2.21)$$

where $\mathbf{1}_{\{w\in B\}}$ is an indicator function which equals to one if and only if $w \in B$, and

$$\zeta(B,\theta_t) \equiv \int_0^{\overline{w}(\theta_t)} \left[P(w,\theta_t)^{-\eta} - \int_0^{\overline{w}(\theta_t)} P(w',\theta_t)^{-\eta}\theta_t(w')\mathrm{d}w'\right]\mathbb{Q}_{t,t+dt}(B|w)\theta_t(w)\mathrm{d}w. \quad (2.22)$$

The derivation of equation (2.21) is shown in Online Appendix A.4. The first term in the right-hand side of equation (2.21) captures the mass of firms that does not issue equity or pay out dividends over $[t, t+\mathrm{d}t]$ and their cash ratios lie in the set B at time $t+\mathrm{d}t$. The quantity $\mathbb{Q}_{t,t+\mathrm{d}t}(B|w)$ is the conditional probability of $w_{i,t+\mathrm{d}t} \in B$ conditioning on $w_{i,t} = w$, according to the evolution equation in the internal liquidity-hoarding region (2.20). The second term, $\beta P(\theta_t)^{\eta-\epsilon}\zeta(B,\theta_t)\mathrm{d}t$, captures the impact of the evolution of m_t given by equation (2.17). The third term $\underline{e}_t\mathbf{1}_{\{w^*(\theta_t)\in B\}}\mathrm{d}t$ captures the mass of firms that issues equity over $[t, t+\mathrm{d}t]$ and their cash ratios lie in the set B at time $t+\mathrm{d}t$. In particular, the term $\underline{e}_t\mathrm{d}t$ captures the measure of firms hitting the optimal equity issuance boundary $\underline{w}(\theta_t) = 0$ over $[t, t+\mathrm{d}t]$ and conducts external financing, which replenishes their cash ratios to the level $w^*(\theta_t)$ at $t+\mathrm{d}t$.[9] The fourth term $\overline{e}_t\mathbf{1}_{\{\overline{w}(\theta_t)\in B\}}\mathrm{d}t$ captures the mass of firms that pays out dividends over $[t, t+\mathrm{d}t]$ and their cash ratios lie in the set B at time $t+\mathrm{d}t$. In particular, the term $\overline{e}_t\mathrm{d}t$ captures the measure of firms hitting the optimal payout boundary $\overline{w}(\theta_t)$ over $[t, t+\mathrm{d}t]$ and pays out dividends, which reduces their cash ratios to the level $\overline{w}(\theta_t)$ at $t+\mathrm{d}t$.

2.4 Discussions on the Model Assumptions

Monopolistic competition versus oligopoly. Our model focuses on industries with monopolistic competition. This assumption is mainly for tractability. The main point of our paper is to highlight the inter-temporal tradeoff in setting markups in the presence of external financing costs. In oligopoly industries, firms internalize the impact of their own prices as well as the impact of their competitors' prices on the industry's price index. The rich strategic interaction among firms may result in multiple equilibria. For example, the literature on dynamic real-option models analyzes how firms interact in making investment

[9]It is essentially the same as the "reinjection" after exit with an intensity $\underline{e}_t$ of firms (e.g., Gabaix et al., 2016).

decisions under oligopolistic competition. Grenadier (2002) develops a dynamic real-option model and shows that firms' competitive interactions drastically erode the value of the option to wait, making them more likely to invest. In a duopoly setup, Bustamante (2015) analytically characterizes the leader-follower equilibrium and the clustering equilibrium. Bustamante (2015) shows that in the leader-follower equilibrium, one firm (i.e., the leader) adopts a preemption strategy to invest first, whereas the other firm (i.e., the follower) invests thereafter; in the clustering equilibrium, both firms invest simultaneously.[10] Moreover, firms may also form implicit collusion in oligopoly industries (e.g., Green and Porter, 1984; Rotemberg and Saloner, 1986; Fershtman and Pakes, 2000; Dou, Ji and Wu, 2020).

Entry and exit. Our model does not consider firms' dynamic entries and exits. This assumption is mainly for tractability. In the literature, Bustamante and Donangelo (2017) analyze the interesting interaction between competition, the threat of entry, and firms' exposure to systematic risks. Corhay, Kung and Schmid (2017) develop a model where markups vary because of the time-varying threat of firm entry in oligopoly industries. They show that when concentration is high, markups are more sensitive to entry risk. Our paper focuses on investigating the interaction between corporate liquidity and markup decisions. This differentiates our paper from the above papers which study the impact of entries and exits in models without corporate liquidity.

Operating cash-flow shocks. We model idiosyncratic operating cash-flow shocks in equation (2.9) as being proportional to the firm's customer base $M_{i,t}$. In equilibrium, a firm's customer base $M_{i,t}$ captures its sales (or firm size). Thus, our assumption essentially means that idiosyncratic operating cash-flow shocks are proportional to firm size. The modeling specification of idiosyncratic shocks proportional to firm size is commonly adopted in the asset pricing and macroeconomics literature (e.g., DeMarzo and Sannikov, 2006; Bloom, 2009; Bolton, Chen and Wang, 2011; DeMarzo et al., 2012). The purpose of this modeling specification is to ensure that firms cannot grow out of the exposure to idiosyncratic risks, and that the model is consistent with the empirical fact that the idiosyncratic component of the change in a firm's sales is roughly proportional to the firm's size. Technically, assuming that shocks to firms' operating profits are proportional to $M_{i,t}$ also affords tractability. Under this assumption, the cash ratio $w_{i,t} = W_{i,t}/M_{i,t}$ is a state variable for firm i and the firm value is homogeneous in $M_{i,t}$.

[10] The preemption strategy is also shown to be relevant in other settings. For example, Bustamante (2012) shows that when firms with good investment prospects are scarce, they may choose to go public earlier than other firms to signal the type of investment prospects they have.

3 Theoretical Results

In this section, we present the main results of the paper. We first study how financial constraints and a sticky customer base affect firms' markups both in an industry with monopolistic competition and in a monopoly industry. We then study how markups, which reflect the intensity of product market competition, affect firms' financial decisions.

3.1 Markup Dynamics

A firm's markup is crucially related to its financial condition and customer base. Let $\nu_{i,t}$ and $\mu_{i,t}$ be the marginal value of corporate liquidity (i.e., the Lagrangian multiplier of the evolution of cash holdings) and the marginal value of customer base (i.e., the Lagrangian multiplier of the evolution of customer base). We characterize how $\Lambda_{i,t}$ is driven by $\nu_{i,t}$ and $\mu_{i,t}$ below.

Proposition 3.1. *Firm i's markup $\Lambda_{i,t}$ is determined by the marginal value of corporate liquidity and the marginal value of customer base as follows:*

$$\Lambda_{i,t} = \frac{\eta}{\eta - 1}\left(1 - \Omega_{i,t}\right), \tag{3.1}$$

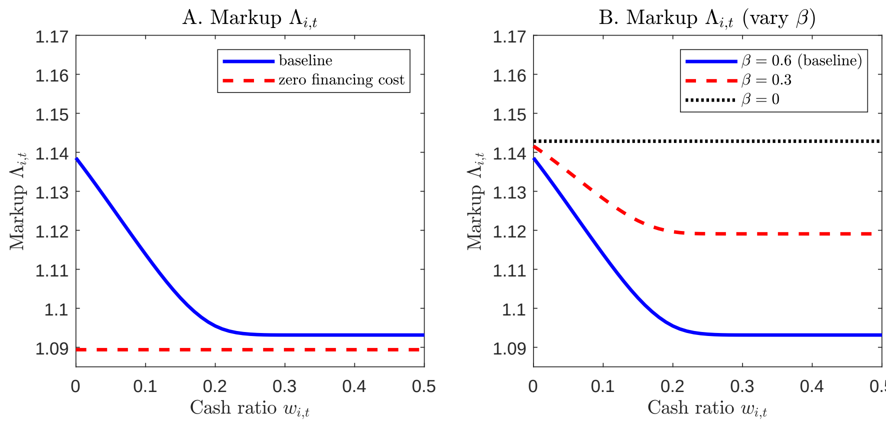
where the markup wedge $\Omega_{i,t}$ is defined as

$$\Omega_{i,t} \equiv \frac{\beta A}{R}\frac{\mu_{i,t}}{\nu_{i,t}} \geq 0. \tag{3.2}$$

In equilibrium, the markup wedge $\Omega_{i,t}$ can be viewed as a "sufficient statistic" that summarizes the impacts of financial constraints and customer base on markups.

Proof. See Online Appendix A.1. □

The equilibrium relation (3.1) connects markups $\Lambda_{i,t}$ with the marginal value of corporate liquidity $\nu_{i,t}$ and the marginal value of customer base $\mu_{i,t}$. The markup wedge term $\Omega_{i,t}$ is crucial here. Specifically, when the consumer does not have deep habits (i.e., $\beta = 0$), the markup wedge is zero (i.e., $\Omega_{i,t} \equiv 0$), meaning that corporate liquidity and customer base play no role in determining markups. Therefore, the markup is constant and equal to $\eta/(\eta - 1)$, as in standard models of monopolistic competition. When the consumer has deep habits (i.e., $\beta > 0$), however, the markup wedge is positive (i.e., $\Omega_{i,t} > 0$), reflecting that the firm has incentive to set a lower markup to accumulate customer base for higher future profits.



Note: This figure is plotted using the parameter values in Table 1 in Section 4.1.

Figure 1: Relation between markups, financial constraints, and customer base development.

According to equation (3.2), the wedge $\Omega_{i,t}$ depends on both the marginal value of corporate liquidity $\nu_{i,t} \geq 1$ and that of customer base $\mu_{i,t} \geq 0$. A higher marginal value of customer base $\mu_{i,t}$ increases the markup wedge $\Omega_{i,t}$ and thus decreases the equilibrium markup $\Lambda_{i,t}$. Intuitively, a higher $\mu_{i,t}$ motivates the firm to expand its customer base for higher future demand by lowering the markup $\Lambda_{i,t}$. A higher marginal value of corporate liquidity $\nu_{i,t}$ reduces the markup wedge $\Omega_{i,t}$ and thus increases the equilibrium markup $\Lambda_{i,t}$. This is because a higher $\nu_{i,t}$ motivates the firm to harvest current inertial consumers by increasing the markup $\Lambda_{i,t}$.

Further, the term $\mu_{i,t}/\nu_{i,t}$ in markup wedge $\Omega_{i,t}$ implies that financial constraints and customer base jointly determine markups. With a higher $\nu_{i,t}$, the effect of $\mu_{i,t}$ on markups becomes smaller, because the incentive for accumulating a larger customer base is dampened when the firm is liquidity constrained. In turn, when the firm has a stronger motivation for customer base accumulation (i.e., a higher $\mu_{i,t}$), the effect of financial constraints becomes greater. The intuition is that with a better opportunity to develop the customer base (i.e., a higher $\mu_{i,t}$), the firm's desire to maintain corporate liquidity becomes stronger. Thus, the firm increases markups more as the financial constraint becomes tighter and decreases markups more when the financial constraint becomes more relaxed, which is the mechanism emphasized by Gilchrist et al. (2017).

To illustrate the interaction effect of financial constraints and customer base in determining markups, Figure 1 plots a firm's equilibrium markup. The blue solid line in panel A shows that the firm increases its markup $\Lambda_{i,t}$ when its cash ratio $w_{i,t}$ is lower, due to the higher marginal value of corporate liquidity. Intuitively, when the marginal value of corporate liquidity is high, the firm will find it optimal to harvest the current loyal customers by charging a high markup at the cost of reducing the customer base in the long run. In the absence of external financing costs (i.e., $\gamma = \varphi = 0$), the marginal value of corporate liquidity is equal to one (i.e., $\nu_{i,t} \equiv 1$), which is its lowest level; as a result, the firm sets a low and constant markup $\Lambda_{i,t}$ to accumulate a larger customer base (the red dashed line). Panel B plots the relation between the firm's equilibrium markup $\Lambda_{i,t}$ and its cash ratio $w_{i,t}$ for different values of the customer-base-accumulation rate β. A higher β implies a higher marginal value of customer base $\mu_{i,t}$ because customer base grows faster conditional on the same contemporaneous demand (see equation (2.5)). As a result, the negative relationship between the markup $\Lambda_{i,t}$ and the cash ratio $w_{i,t}$ becomes more pronounced when β becomes larger (i.e., the blue solid line is steeper than the red dashed line in Panel B of Figure 1). When $\beta = 0$, the equilibrium markup is higher and flat (the black dotted line) because the firm has no incentive to set lower markups for accumulating customer base.

Monopolistic Competition versus Monopoly. We compare the firm's markup dynamics in the industry with monopolistic competition to those in a monopoly industry with a single firm. The characterization of the monopoly industry is described in Online Appendix D.2. The equilibrium relation of markups, financial constraints, and customer bases in a monopoly industry is given by the Proposition 3.2.

Proposition 3.2. *In a monopoly industry, the monopoly's markup $\Lambda_{i,t}$ satisfies*

$$\Lambda_{i,t} = \frac{\epsilon}{\epsilon - 1}\left(1 - \Omega_{i,t}\right), \quad \textit{where } \Omega_{i,t} \textit{ is defined in equation (3.2).} \tag{3.3}$$

Proof. See Online Appendix A.2. □

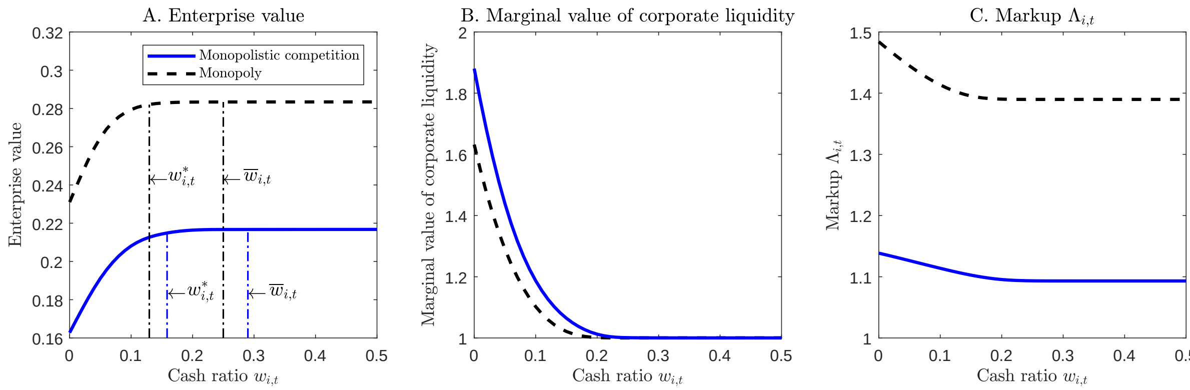
Intuitively, in a monopoly industry, we have $\Lambda_{i,t} = \Lambda_t$ and $M_{i,t} = M_t$ since there is only one firm in the industry. When $\beta = 0$, the markup is constant and equal to $\epsilon/(\epsilon - 1)$, as implied directly by the isoelastic industry demand curve (2.1). When $\beta > 0$, the markup wedge is positive (i.e., $\Omega_{i,t} > 0$), implying that the firm set a lower markup to accumulate customer base for future profits.

The following proposition compares markups in the two industries.

Proposition 3.3. *Given $\nu_{i,t}$ and $\mu_{i,t}$, firm i's markup $\Lambda_{i,t}$ is higher and more sensitive to its condition $\mu_{i,t}/\nu_{i,t}$ in a monopoly industry than in an industry with monopolistic competition.*

Proof. See Online Appendix A.3. □

In Figure 2, we compare the solutions of the firm's enterprise value, financing decisions, payout decisions, and the marginal value of corporate liquidity in the baseline monopolistic competitive industry with those in a monopoly industry.



Note: This figure is plotted using the parameter values in Table 1 in Section 4.1.

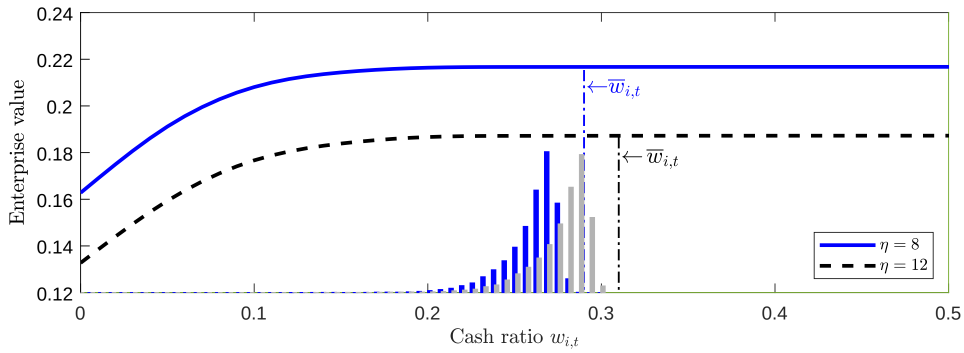
Figure 2: Comparing the industry with monopolistic competition and a monopoly industry.

The key difference between a monopoly industry and a monopolistic competitive industry is that the former has a higher markup, and thus the firm in a monopoly industry receives higher cash flows per unit of customer base. Panel A shows that the firm in a monopoly industry has a higher enterprise value (the black dashed line) than that in a monopolistic competitive industry (the blue solid line). The firm in a monopoly industry is less liquidity constrained due to the higher cash flows, as indicated by the lower marginal value of corporate liquidity in panel B. As a result, the firm in a monopoly industry issues less equity (i.e., lower $w^*_{i,t}$) and is more likely to pay out dividends (i.e., lower $\overline{w}_{i,t}$) than that in the industry with monopolistic competition.

Panel C shows that the firm in a monopoly industry sets a much higher markup and it starts to raise markups when the cash ratio $w_{i,t}$ drops below 0.18 (the black dashed line). By contrast, the firm in the monopolistic competitive industry starts to raise markups when the cash ratio $w_{i,t}$ drops below 0.21 (the blue solid line) because it is more liquidity constrained. Moreover, the markup of a monopoly industry is more sensitive to the cash ratio $w_{i,t}$ than that of a monopolistic competitive industry.

3.2 Financial Policies

We have analyzed how financial constraints affect firms' markups. Conversely, markups also affect firms' financial decisions as they directly determine cash flows. We now explore how lower markups, as caused by an increase in the degree of product market competition, affect firms' cash holdings and payout decisions. In our model, one way to capture increased competitive threats facing all firms is by considering a higher elasticity of substitution η, which means that goods produced within the same industry become more substitutable. As a result, firms set lower markups and receive less cash flows.



Note: This figure is plotted using the parameter values in Table 1 in Section 4.1.

Figure 3: Impact of product market threats on payout and cash holdings.

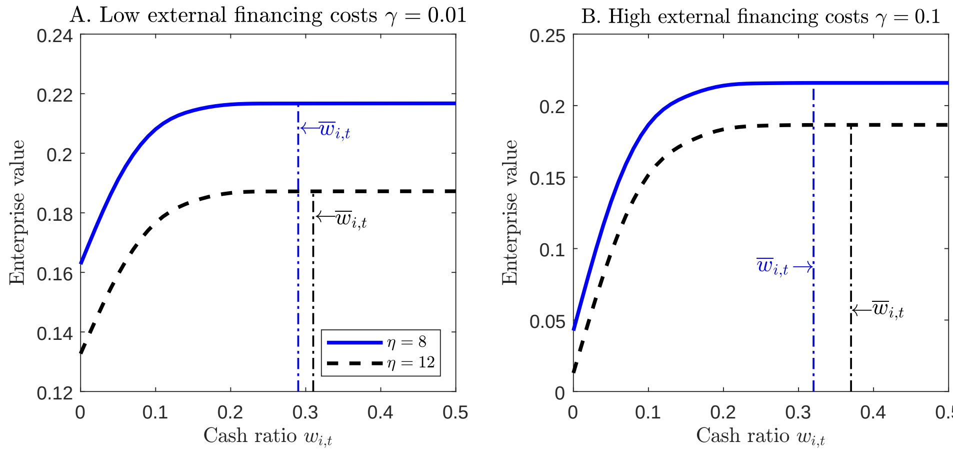
Figure 3 shows that increasing η from our baseline value 8 to 12 reduces a firm's enterprise value per unit of customer base, $v_t(w_{i,t}) - w_{i,t}$ (moving from the blue solid line to the black dashed line). Importantly, the firm's payout boundary $\overline{w}_{i,t}$ shifts to the right (moving from the vertical blue dash-dotted line to the vertical black dash-dotted line). This implies that the firm will increase retained earnings and become less likely to pay out dividends when facing greater product market threats. Intuitively, when the competition in the product market intensifies, firms will reduce their markups, resulting in lower cash flows. The lower cash flows increase the likelihood that firms are liquidity constrained, which motivates these firms to adopt more conservative financial policies. In the stationary equilibrium, the endogenous distribution of cash holdings shifts to the right when η is higher (moving from the blue bars to the light grey bars).

We further study how firms' payout decisions respond to product market threats in the presence of high external financing costs. Comparing panels A and B of Figure 4, it is shown that firms in both industries with $\eta = 8$ and $\eta = 12$ increase their payout boundaries $\overline{w}_{i,t}$ when the fixed financing cost is higher, i.e., γ increases from 0.01 in panel A to 0.1 in panel B. Importantly, the difference in payout boundaries between the two firms is larger with a higher γ in panel B. Thus, our model predicts that firms' payout policies become more sensitive to product market threats when external financing costs are high.

3.3 Summary of Model Predictions

Our model has two sets of testable theoretical predictions: one set is about the impact of financial constraints and customer base on firms' markup dynamics, and the other is about the impact of industry competition on firms' financial decisions.

As for the impact of financial constraints and customer base on markup dynamics, our model makes several predictions: (i) firms increase their markups when they become more



Note: This figure is plotted using the parameter values in Table 1 in Section 4.1.

Figure 4: Impact of product market threats on payout with high external financing costs.

liquidity constrained (see panel A of Figure 1). Supporting evidence has been offered by the literature. For example, Chevalier and Scharfstein (1996) find that during regional and macroeconomic recessions, more financially constrained supermarket chains raise their prices relative to less financially constrained chains. In a recent effort, Gilchrist et al. (2017) provide cross-sectional empirical support using product-level price data during the 2007 – 2009 financial crisis; (ii) firms' markups are more sensitive to their financial conditions when there is a better opportunity to develop the customer base (see panel B of Figure 1); (iii) firms' markups are less sensitive to the marginal value of customer base when they are more liquidity constrained (see panel B of Figure 1); and (iv) firms' markups are higher and more sensitive to changes in financial conditions and in opportunities of customer base development in the industries with less competitive market structure (see Proposition 3.3). Testing the predictions above requires firm-level data on product markups, which is beyond the scope of this paper. In fact, how to measure markups remains one of the few most challenging empirical research questions in the macroeconomics and industrial organization literature. In Section 4.2, we use our calibrated model to study the markup dynamics during the 2007 – 2009 financial crisis documented by Gilchrist et al. (2017).

As for the impact of industry competition on financial decisions, our model gives the following testable predictions: (i) firms become less likely to pay out dividends and hold more cash (or keep more net income as cash holdings) on their balance sheets when the product market becomes more competitive (see Figure 3); and (ii) the relationship in (i) is more pronounced when external financing costs are higher (see Figure 4). These predictions are consistent with the evidence in the literature. For example, Hoberg, Phillips and Prabhala (2014) show that fluidity, as a measure of product market threats, decreases firm propensity to make payouts and increases the cash held by firms, especially for firms with less access to financial market. Morellec, Nikolov and Zucchi (2014) find that equity issuance and cash holdings are positively associated with various measures of product market competition. Based on innovation proximity measures (Jaffe, 1986) of competition intensity, Lyandres and Palazzo (2016) find that financially constrained firms hold more cash when expected competition intensity in the product market increases. By applying a difference-in-differences analysis on the contraction in the supply of credit in 1989, they further show that the association between expected competition intensity and cash holdings is more significant among the firms headquartered in the northeastern part of the U.S., a region more exposed to the collapse of the junk bond market in 1989. While the evidence in the literature is mainly at the firm level, we provide industry-level evidence in Section 4.3.

4 Empirical and Quantitative Analyses

In this section, we first calibrate the model to evaluate the quantitative implications of financial constraints for markup dynamics. Next, we provide evidence to support the model's predictions about the impact of industry competition on financial decisions.

4.1 Calibration

We calibrate the model based on U.S. public firms from Compustat. Some parameters are determined using external information without simulating the model (see panel A of Table 1). The remaining parameters are calibrated internally from moment matching (see panel B of Table 1).

Externally Determined Parameters. We set the physical capital's depreciation rate to $\delta = 10\%$ and the risk-free rate to $r = 6\%$. We set $\rho = 0.52$ following the calibration of Ravn, Schmitt-Grohe and Uribe (2006). We fix the variable cost of financing at $\varphi = 6\%$ based on the estimates reported by Altinkilic and Hansen (2000). Following Bolton, Chen and Wang (2011), we set the fixed financing cost to $\gamma = 1\%$ of the firm size and the cash-carrying cost to $\lambda = 1\%$. We set the within-industry elasticity of substitution to $\eta = 8$ and the industry's price elasticity of demand to $\epsilon = 3$, which are broadly consistent with empirical estimates (e.g., Atkeson and Burstein, 2008).

Internally Calibrated Parameters. The remaining parameters are calibrated by matching relevant moments. We simulate the industry for 100 years according to the computed policy functions. The first 80 years are dropped as burn-in. We then compute the average

Table 1: Calibration and parameter choice.

Panel A: Externally determined parameters					
Parameter	Symbol	Value	Parameter	Symbol	Value
Physical capital depreciation rate	δ	0.1	Risk-free rate	r	0.06
Industry's price elasticity of demand	ϵ	3	Within-industry elasticity of substitution	η	8
Variable financing cost	φ	0.06	Cash-carrying cost	λ	0.01
Fixed financing cost	γ	0.01	Customer base depreciation rate	ρ	0.52

Panel B: Internally calibrated parameters					
Parameter	Symbol	Value	Moments	Data	Model
Productivity of technology	A	0.12	Average cash-to-sales ratio (%)	67.4	60.3
Volatility of cash flow shocks	σ	0.07	Volatility of net profit margin (%)	11.3	13.7
Customer base accumulation rate	β	0.6	Average net profit margin (%)	8.9	8.6

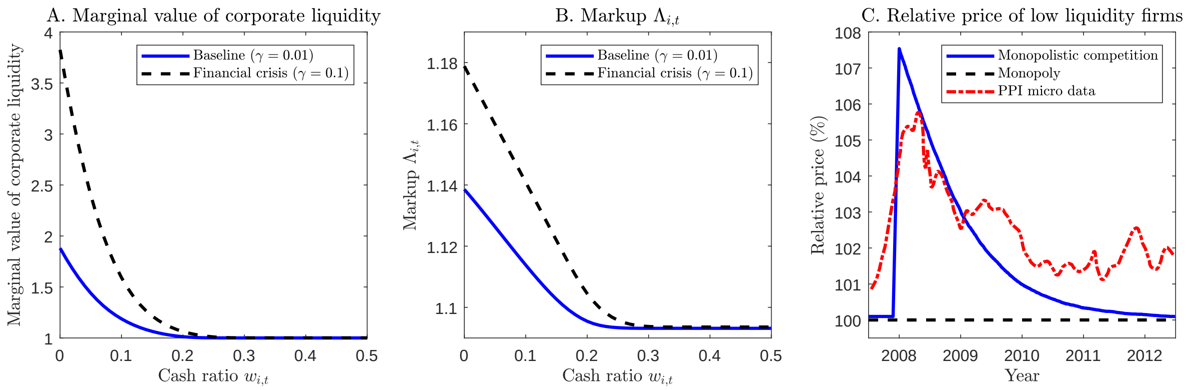
Note: In panel B, the moments are constructed based on Compustat data from 1988 to 2017. We construct the net profit margin for firm i at year t as $(\text{Sales}_{i,t} - \text{COGS}_{i,t} - \text{SG\&A}_{i,t} - \text{Interest}_{i,t} - \text{Tax}_{i,t})/\text{Sales}_{i,t}$. When constructing the model moments, we simulate the industry for 100 years with an 80-year burn-in period. We then compute the model-implied moments similar to the data for a cross-section of 5,000 firms. For each moment, the table reports the average over 1,000 simulations.

model-implied moments in the cross-section of 5,000 firms across 1,000 simulations and adjust parameters until these moments are in line with their values in the data. The mean and standard errors of moments in both data and model are reported in panel B of Table 1.

We choose the moments that are informative about the model's parameters. In particular, we set the productivity of firm technology to $A = 0.12$ to match the average cash-to-sales ratio. The volatility of idiosyncratic cash flow shocks is set to $\sigma = 0.07$ to match the volatility of net profit margin. Our estimate from the data is consistent with the number reported by Eberly, Rebelo and Vincent (2009). The parameter β determines the overall incentive to invest in customer base. A higher β implies that firms have more incentive to set lower markups to accumulate customer base. Measuring markups in the data is difficult because marginal costs are not observable (see Blanchard, 2009; Eichenbaum, Jaimovich and Rebelo, 2011). Loecker and Eeckhout (2019) and Anderson, Rebelo and Wong (2018) argue that average profit margins can be considered as good proxies for product markups. In our model, a firm's profit margin, i.e., $(P_{i,t} - R/A)/P_{i,t}$, is positively associated with its markup $\Lambda_{i,t}$; moreover, the profit margin directly determines its cash flows and retained earnings, the two key variables related to the main mechanism. Therefore, we set $\beta = 0.6$ to match the average net profit margin.

4.2 Markup Dynamics during the Financial Crisis

We now study the quantitative and empirical relevance of our calibrated model's main mechanism for markup dynamics. Specifically, we test whether the model can quantitatively explain the markup dynamics observed during the 2007 – 2009 financial crisis, a period



Note: This figure is plotted using the parameter values in Table 1 in Section 4.1. In panel C, the red dash-dotted line refers to the PPI micro data. We follow Gilchrist et al. (2017, panel A of Figure 3) and plot the cumulative weighted-average industry-adjusted inflation rates for low liquidity firms. When constructing model-implied relative price dynamics, we mimic the empirical exercise in data by focusing on low liquidity firms. In particular, we consider an unexpected financial shock that hits the steady state of our baseline calibration in the fourth quarter of 2007 (t_0). We model the financial shock by increasing the fixed financing cost to $\gamma = 0.1$, which leads to an annualized external finance premium of 20% on average. For the baseline industry with monopolistic competition, we simulate 50,000 firms and sort them based on their cash holdings at time $t \geq t_0$. The blue solid line plots the average price of the low liquidity firms (the 25,000 firms whose cash holdings are below the median value) relative to the industry's price index at any point in time $t \geq t_0$. For the monopoly industry (the black dashed line), we plot the price of the monopolist relative to the industry's price index, which is equal to the monopolist's price.

Figure 5: Markups and external finance premium during a financial crisis.

of high external financing costs during which the commercial paper market froze, credit spreads widened dramatically, equity prices plunged, and asset price volatility soared. Based on PPI micro data, Gilchrist et al. (2017) document that liquidity-constrained firms significantly increased their prices relative to the industry average, whereas their unconstrained counterparts cut prices relatively. Following the calibration of Gilchrist et al. (2017), we simulate the financial crisis in the model by setting the fixed financing cost to $\gamma = 0.1$, which implies an annualized external finance premium of $\mathbb{E}[\xi_{i,t}] = 20\%$, where $\xi_{i,t} = \partial V_{i,t}/\partial W_{i,t} - 1$.

Panel A of Figure 5 compares the marginal value of corporate liquidity in our baseline calibration (the blue solid line) and the one during the financial crisis (the black dashed line). The firm's marginal value of corporate liquidity $\partial V_{i,t}/\partial W_{i,t}$ is higher when its cash ratio $w_{i,t}$ is lower, especially during the financial crisis. Panel B shows that the firm raises its markup $\Lambda_{i,t}$ when it becomes more liquidity constrained. The negative relationship between financial condition and markups is more pronounced during the financial crisis (the black dashed line).

In panel C, we replicate the main exercise of Gilchrist et al. (2017) to check whether the model can quantitatively explain the markup dynamics of liquidity-constrained firms during the financial crisis. The blue solid line shows that the low liquidity firms substantially raise their markup relative to the industry's price index, and the magnitude is comparable to that in the data (the red dash-dotted line). For comparison, we also simulate a monopoly industry with one single firm. In the monopoly industry, the price of the low liquidity firm relative to the industry's price index is a constant (and equal to one) because there is only one firm in the industry by definition (the black dashed line).

4.3 Payout Policies and Cash Holdings

Our model predicts that the average industry-level payout frequency is lower and cash holdings are higher when firms within the industry face greater product market threats (see Figure 3). Moreover, firms' payout policies become more sensitive to product market threats during the period of high external financing costs (see Figure 4). These predictions are consistent with the firm-level evidence in the literature (e.g., Hoberg, Phillips and Prabhala, 2014; Morellec, Nikolov and Zucchi, 2014; Lyandres and Palazzo, 2016). We now test these implications at the industry level based on the product fluidity measure of Hoberg, Phillips and Prabhala (2014).

Fluidity is a measure of product market threats derived from firms' business descriptions in 10-K filings. The firm faces a greater fluidity if its competitors generate products more similar to its own products. Thus, the weighted fluidity at the industry level intuitively captures the change in the elasticity of substitution among goods produced in the same industry. We construct the industry-level fluidity measure for each FIC-300 industry (see Online Appendix B for data and summary statistics). Table 2 shows that industries with greater fluidity are associated with fewer share repurchases and higher cash holdings, suggesting that firms in such industries adopt more conservative financial policies. Our results also hold at the firm level (see Online Appendix B.2), and are in line with the findings of Hoberg, Phillips and Prabhala (2014) based on a shorter sample period. These empirical findings are consistent with the model's implication in Figure 3. To formally show our model's prediction, we simulate a sample of 300 industries for 100 years with the first 80 years dropped as burn-in. The simulated industries are exogenously specified to have different levels of within-industry elasticity of substitution η, ranging from 5 to 12. We estimate model-implied coefficients by regressing industries' yearly payout frequencies and average cash holdings on their ηs. Table 3 shows that on average, industries with higher within-industry elasticity η pay out less frequently and have more cash holdings.

We further study the interaction effect between product market threats and external financing costs. We introduce a financial crisis dummy that equals one for years 2008 and 2009, and zero otherwise. Columns (1) and (2) of Table 4 show that the coefficient on the interaction term of the industry's local product fluidity and the financial crisis dummy is negative and statistically significant. This indicates that the negative effect of product market threats on share repurchases is more significant during periods of high external financing

Table 2: Industry-level repurchases, cash holdings and product fluidity.

	Repurchases$_{i,t}$		Cash holdings$_{i,t}$/assets$_{i,t}$	
	(1)	(2)	(3)	(4)
Local product fluidity$_{i,t}$	-0.045^{***}	-0.040^{***}	0.019^{***}	0.020^{***}
	[0.012]	[0.012]	[0.004]	[0.004]
Self-product fluidity$_{i,t}$	0.000	0.003	0.007^{**}	0.007^{**}
	[0.008]	[0.008]	[0.003]	[0.003]
HHI$_{i,t}$	-0.023^{*}	-0.023^{*}	0.001	0.0003
	[0.012]	[0.012]	[0.005]	[0.005]
Total risk$_{i,t}$	-0.069^{***}	-0.061^{***}	0.009	0.01
	[0.014]	[0.014]	[0.007]	[0.007]
Log firm age$_{i,t}$	0.009	-0.002	0.001	0.0002
	[0.010]	[0.011]	[0.004]	[0.004]
Market-to-book$_{i,t}$	0.012	0.011	0.036^{***}	0.037^{***}
	[0.010]	[0.010]	[0.006]	[0.007]
Asset growth$_{i,t}$	-0.019^{*}	-0.020^{*}	-0.004^{**}	-0.004^{**}
	[0.010]	[0.010]	[0.002]	[0.002]
Income/assets$_{i,t}$	0.018^{*}	0.005	-0.017^{***}	-0.018^{***}
	[0.010]	[0.014]	[0.004]	[0.006]
NYSE size percentile$_{i,t}$	0.106^{***}	0.105^{***}	-0.015^{**}	-0.015^{**}
	[0.015]	[0.015]	[0.007]	[0.007]
R&D/sales$_{i,t}$		0.036^{***}		0.007^{***}
		[0.012]		[0.002]
Negative earnings$_{i,t}$		-0.025^{***}		-0.006^{**}
		[0.009]		[0.003]
Retained earnings/assets$_{i,t}$		0.022^{*}		0.004
		[0.012]		[0.007]
3-Year sales growth$_{i,t}$		-0.032^{***}		-0.010^{***}
		[0.008]		[0.004]
R-squared$_{i,t}$	0.211	0.216	0.181	0.185
Observations	4,568	4,537	4,634	4,601

Note: In columns (1) and (2), the dependent variable is the industry-level share repurchases; and in columns (3) and (4), the dependent variable is the industry-level cash holdings. Variable construction is described in Online Appendix B. All specifications control for time fixed effects. The sample spans the period from 1998 to 2017. We include t-statistics in brackets. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Standard errors are clustered by FIC-300 industry.

costs, as implied by our model (see Figure 4). In columns (3) and (4), we further consider the change in retained earnings as a fraction of net income as the dependent variable. The coefficient on the interaction term of the industry's local product fluidity and the financial crisis dummy is positive and statistically significant. This indicates that in industries where firms face greater product market threats, a larger fraction of net income is held as retained

Table 3: Impact of η on payout and cash holdings in model.

	Payout$_{i,t}$	Cash holdings$_{i,t}$
Coefficient on η_i	-0.014	0.038
	$[-0.016, -0.011]$	$[0.035, 0.041]$
Constant	0.183	0.230
	$[0.165, 0.201]$	$[0.228, 0.232]$
R-squared	0.054	0.46
	$[0.043, 0.076]$	$[0.39, 0.53]$
Observations	6,000	6,000

Note: We run the simulation 1,000 times. The 5th and 95th estimated percentiles of the simulated distribution of regression coefficients are reported in brackets.

earnings during the financial crisis, which is consistent with the low share repurchases in these industries.

5 Conclusion

We develop an industry equilibrium model of monopolistic competition to understand how product markups are determined in the presence of external financing costs and customer base. In the model, firms optimally conduct external financing and compete with each other by setting markups. Markups are optimally determined based on the intertemporal tradeoff between setting a higher markup to harvest profits from the existing customer base and setting a lower markup to develop customer base for future profits.

We derive an analytical representation for markups in terms of the marginal value of corporate liquidity and the marginal value of customer base. Firms facing greater product market competition charge lower markups which are less responsive to the changes in their financial conditions and in their opportunities of customer base development. Moreover, firms facing greater product market competition adopt more conservative financial policies such as paying out less dividends and holding more cash and other liquid assets.

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Table 4: Repurchases, retained earnings, and product fluidity during the financial crisis.

	Repurchases$_{i,t}$		$(\text{RE}_{i,t+1} - \text{RE}_{i,t})$/net income$_{i,t+1}$	
	(1)	(2)	(3)	(4)
Local product fluidity$_{i,t}$ × Crisis$_t$	−0.033**	−0.024*	0.053*	0.059**
	[0.013]	[0.013]	[0.030]	[0.029]
Local product fluidity$_{i,t}$	−0.024**	−0.020*	0.029*	0.030*
	[0.011]	[0.011]	[0.017]	[0.017]
Financial crisis dummy$_t$	−0.142***	−0.121***	−0.055	−0.074
	[0.040]	[0.037]	[0.061]	[0.064]
Self-product fluidity$_{i,t}$	−0.005	0.000	−0.014	−0.011
	[0.008]	[0.008]	[0.011]	[0.012]
HHI$_{i,t}$	−0.019**	−0.026***	0.005	0.008
	[0.009]	[0.004]	[0.017]	[0.016]
Total risk$_{i,t}$	−0.054***	−0.062***	0.049**	0.058**
	[0.019]	[0.014]	[0.023]	[0.025]
Log firm age$_{i,t}$	0.011	−0.001	−0.056***	−0.052***
	[0.010]	[0.011]	[0.018]	[0.018]
Market-to-book$_{i,t}$	0.014	0.011	0.020	0.014
	[0.011]	[0.011]	[0.017]	[0.017]
Asset growth$_{i,t}$	−0.021**	−0.021**	0.037***	0.022*
	[0.010]	[0.010]	[0.012]	[0.012]
Income/assets$_{i,t}$	0.013	−0.003	−0.011	−0.024
	[0.011]	[0.014]	[0.016]	[0.016]
NYSE size percentile$_{i,t}$	0.119***	0.111***	−0.053**	−0.053**
	[0.015]	[0.014]	[0.022]	[0.022]
R&D/sales$_{i,t}$		0.066***	−0.044***	−0.042***
		[0.016]	[0.015]	[0.015]
Negative earnings$_{i,t}$		−0.028***		−0.008
		[0.010]		[0.018]
Retained earnings/assets$_{i,t}$		0.023**		0.019
		[0.011]		[0.017]
3-Year sales growth$_{i,t}$		−0.033***		0.045***
		[0.008]		[0.014]
R-squared		0.21		0.124
Observations		4,537		3,918

Note: In columns (1) and (2), the dependent variable is the industry-level share repurchases; and in columns (3) and (4), the dependent variable is the industry-level change in retained earnings as a fraction of net income. Variable construction is described in Online Appendix B. All specifications control for time fixed effects. The sample spans the period from 1998 to 2017. We include t-statistics in brackets. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Standard errors are clustered by FIC-300 industry.

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Online Appendix for "External Financing and Customer Capital: A Financial Theory of Markups"

A Proofs

A.1 Proof of Proposition 3.1

Substituting equation (2.4) into equation (2.5), we obtain the evolution of customer base as follows:

$$\mathrm{d}M_{i,t} = \beta \left(\frac{P_{i,t}}{P_t}\right)^{-\eta} P_t^{-\epsilon} M_{i,t}\mathrm{d}t - \rho M_{i,t}\mathrm{d}t. \tag{A.1}$$

Taking derivative with respect to $P_{i,t}$ on both sides of (A.1), we obtain

$$\frac{\partial}{\partial P_{i,t}}\mathbb{E}_t\left[\mathrm{d}M_{i,t}\right] = -\beta\eta P_{i,t}^{-\eta-1} P_t^{\eta-\epsilon} M_{i,t}\mathrm{d}t. \tag{A.2}$$

Substituting equation (2.9) into equation (2.11), we obtain

$$\mathrm{d}W_{i,t} = \left(P_{i,t} - \frac{R}{A}\right) P_{i,t}^{-\eta} P_t^{\eta-\epsilon} M_{i,t}\mathrm{d}t + \sigma M_{i,t}\mathrm{d}Z_{i,t} + (r-\lambda)W_{i,t}\mathrm{d}t - \mathrm{d}D_{i,t}. \tag{A.3}$$

Taking derivative with respect to $P_{i,t}$ on both sides of (A.3), we obtain

$$\frac{\partial}{\partial P_{i,t}}\mathbb{E}_t\left[\mathrm{d}W_{i,t}\right] = \left[P_{i,t}^{-\eta} P_t^{\eta-\epsilon} - \left(P_{i,t} - \frac{R}{A}\right)\eta P_{i,t}^{-\eta-1} P_t^{\eta-\epsilon}\right] M_{i,t}\mathrm{d}t. \tag{A.4}$$

Given the Lagrangian multipliers $\mu_{i,t}$ and $\nu_{i,t}$, the optimality condition with respect to $P_{i,t}$ is

$$\mu_{i,t}\frac{\partial\mathbb{E}_t\left[\mathrm{d}M_{i,t}\right]}{\partial P_{i,t}} + \nu_{i,t}\frac{\partial\mathbb{E}_t\left[\mathrm{d}W_{i,t}\right]}{\partial P_{i,t}} = 0, \tag{A.5}$$

which leads to

$$P_{i,t} = \frac{\eta}{\eta-1}\frac{R}{A} - \frac{\beta\eta}{\eta-1}\frac{\mu_{i,t}}{\nu_{i,t}}. \tag{A.6}$$

Define the markup wedge $\Omega_{i,t}$ as

$$\Omega_{i,t} = \frac{\beta A}{R}\frac{\nu_{i,t}}{\mu_{i,t}}. \tag{A.7}$$

Using the definition of markups (2.7) and substituting equation (A.7) into equation (A.6), we have

$$\Lambda_{i,t} = \frac{\eta}{\eta - 1} \left(1 - \Omega_{i,t}\right). \tag{A.8}$$

A.2 Proof of Proposition 3.2

In the monopoly industry, we have $P_{i,t} = P_t$. Thus equation (A.1) becomes:

$$\mathrm{d}M_{i,t} = \beta P_{i,t}^{-\epsilon} M_{i,t} \mathrm{d}t - \rho M_{i,t} \mathrm{d}t. \tag{A.9}$$

Taking derivative with respect to P_t on both sides of (A.1), we obtain

$$\frac{\partial}{\partial P_{i,t}} \mathbb{E}_t \left[\mathrm{d}M_{i,t}\right] = -\beta \epsilon P_{i,t}^{-\epsilon-1} M_{i,t} \mathrm{d}t. \tag{A.10}$$

Equation (A.3) becomes

$$\mathrm{d}W_{i,t} = \left(P_{i,t} - \frac{R}{A}\right) P_{i,t}^{-\epsilon} M_{i,t} \mathrm{d}t + \sigma M_{i,t} \mathrm{d}Z_{i,t} + (r - \lambda) W_{i,t} \mathrm{d}t - \mathrm{d}D_{i,t}. \tag{A.11}$$

Taking derivative with respect to $P_{i,t}$ on both sides of (A.11), we obtain

$$\frac{\partial}{\partial P_{i,t}} \mathbb{E}_t \left[\mathrm{d}W_{i,t}\right] = \left[P_{i,t}^{-\epsilon} - \left(P_{i,t} - \frac{R}{A}\right) \epsilon P_{i,t}^{-\epsilon-1}\right] M_{i,t} \mathrm{d}t. \tag{A.12}$$

Given the Lagrangian multipliers $\mu_{i,t}$ and $\nu_{i,t}$, the optimality condition with respect to $P_{i,t}$ is

$$\mu_{i,t} \frac{\partial \mathbb{E}_t \left[\mathrm{d}M_{i,t}\right]}{\partial P_{i,t}} + \nu_{i,t} \frac{\partial \mathbb{E}_t \left[\mathrm{d}W_{i,t}\right]}{\partial P_{i,t}} = 0, \tag{A.13}$$

It follows that

$$\Lambda_{i,t} = \frac{\eta}{\eta - 1}(1 - \Omega_{i,t}) + \frac{\eta - \epsilon}{\eta - 1}(\Lambda_{i,t} - 1 + \Omega_{i,t}). \tag{A.14}$$

Rearranging terms yields

$$\Lambda_{i,t} = \frac{\epsilon}{\epsilon - 1}(1 - \Omega_{i,t}), \tag{A.15}$$

where $\Omega_{i,t}$ is given by equation (3.2).

A.3 Proof of Proposition 3.3

It follows directly from $\eta > \epsilon > 1$ that the markup in the monopoly industry is higher. Let $q_{i,t} = \mu_{i,t}/\nu_{i,t}$ be the firm-level conditions summarizing the interaction of financial constraints and customer base. In the industry with monopolistic competition, we have

$$\frac{\partial \Lambda_{i,t}}{\partial q_{i,t}} = -\frac{\eta}{\eta - 1}\frac{\partial \Omega_{i,t}}{\partial q_{i,t}} = -\frac{\eta}{\eta - 1}\frac{\beta A}{R}. \tag{A.16}$$

In the monopoly industry, we have

$$\frac{\partial \Lambda_{i,t}}{\partial q_{i,t}} = -\frac{\epsilon}{\epsilon - 1}\frac{\partial \Omega_{i,t}}{\partial q_{i,t}} = -\frac{\epsilon}{\epsilon - 1}\frac{\beta A}{R}. \tag{A.17}$$

Because $\eta > \epsilon > 1$, we have that the value of $\frac{\partial \Lambda_{i,t}}{\partial q_{i,t}}$ is more negative in the monopoly industry.

A.4 Evolution of Share Density

$$
\begin{aligned}
&\int_0^{\overline{w}(\theta_{t+\mathrm{d}t})} \mathbf{1}_{\{w\in B\}}\theta_{t+\mathrm{d}t}(w)\mathrm{d}w \\
=&\mathbb{E}\left[\mathbf{1}_{\{w_{t+\mathrm{d}t}\in B\}}m_{t+\mathrm{d}t}\right] \\
=&\mathbb{E}\left\{\mathbb{E}\left[\mathbf{1}_{\{w_{t+\mathrm{d}t}\in B\}}m_{t+\mathrm{d}t}|w_t,m_t\right]\right\} \\
=&\int_0^\infty\int_0^{\overline{w}(\theta_t)}\left[\int_0^\infty\int_0^{\overline{w}(\theta_{t+\mathrm{d}t})}\mathbf{1}_{\{w_{t+\mathrm{d}t}\in B\}}m_{t+\mathrm{d}t}q(m_{t+\mathrm{d}t},w_{t+\mathrm{d}t}|m_t,w_t)\mathrm{d}m_{t+\mathrm{d}t}\mathrm{d}w_{t+\mathrm{d}t}\right]\phi_t(m_t,w_t)\mathrm{d}m_t\mathrm{d}w_t \\
&\qquad+\underline{e}_t\mathbf{1}_{\{w^*(\theta_t)\in B\}}\mathrm{d}t+\overline{e}_t\mathbf{1}_{\{\overline{w}(\theta_t)\in B\}}\mathrm{d}t \\
=&\int_0^\infty\int_0^{\overline{w}(\theta_t)}\left[\int_0^\infty\int_0^{\overline{w}(\theta_{t+\mathrm{d}t})}\mathbf{1}_{\{w_{t+\mathrm{d}t}\in B\}}m_{t+\mathrm{d}t}q_w(w_{t+\mathrm{d}t}|m_t,w_t)q_m(m_{t+\mathrm{d}t}|m_t,w_t)\mathrm{d}m_{t+\mathrm{d}t}\mathrm{d}w_{t+\mathrm{d}t}\right]\phi_t(m_t,w_t)\mathrm{d}m_t\mathrm{d}w_t \\
&\qquad+\underline{e}_t\mathbf{1}_{\{w^*(\theta_t)\in B\}}\mathrm{d}t+\overline{e}_t\mathbf{1}_{\{\overline{w}(\theta_t)\in B\}}\mathrm{d}t \\
=&\int_0^\infty\int_0^{\overline{w}(\theta_t)}\left[\int_0^\infty\int_0^{\overline{w}(\theta_{t+\mathrm{d}t})}\mathbf{1}_{\{w_{t+\mathrm{d}t}\in B\}}\frac{m_t+\mathrm{d}m_t}{m_t}q_w(w_{t+\mathrm{d}t}|w_t)q_m(m_{t+\mathrm{d}t}|m_t,w_t)\mathrm{d}m_{t+\mathrm{d}t}\mathrm{d}w_{t+\mathrm{d}t}\right]m_t\phi_t(m_t,w_t)\mathrm{d}m_t\mathrm{d}w_t \\
&\qquad+\underline{e}_t\mathbf{1}_{\{w^*(\theta_t)\in B\}}\mathrm{d}t+\overline{e}_t\mathbf{1}_{\{\overline{w}(\theta_t)\in B\}}\mathrm{d}t \\
=&\int_0^\infty\int_0^{\overline{w}(\theta_t)}\left[\int_0^\infty\int_0^{\overline{w}(\theta_{t+\mathrm{d}t})}\mathbf{1}_{\{w_{t+\mathrm{d}t}\in B\}}q_w(w_{t+\mathrm{d}t}|w_t)q_m(m_{t+\mathrm{d}t}|m_t,w_t)\mathrm{d}m_{t+\mathrm{d}t}\mathrm{d}w_{t+\mathrm{d}t}\right]m_t\phi_t(m_t,w_t)\mathrm{d}m_t\mathrm{d}w_t \\
&+\int_0^\infty\int_0^{\overline{w}(\theta_t)}\left\{\int_0^\infty\int_0^{\overline{w}(\theta_{t+\mathrm{d}t})}\mathbf{1}_{\{w_{t+\mathrm{d}t}\in B\}}\beta\left[P(w_t,\theta_t)^{-\eta}-\int_0^{\overline{w}(\theta_t)}P(w,\theta_t)^{-\eta}\theta_t(w)\mathrm{d}w\right]P(\theta_t)^{\eta-\epsilon}\mathrm{d}t\right. \\
&\qquad\left.q_w(w_{t+\mathrm{d}t}|w_t)q_m(m_{t+\mathrm{d}t}|m_t,w_t)\mathrm{d}m_{t+\mathrm{d}t}\mathrm{d}w_{t+\mathrm{d}t}\right\}m_t\phi_t(m_t,w_t)\mathrm{d}m_t\mathrm{d}w_t \\
&\qquad+\underline{e}_t\mathbf{1}_{\{w^*(\theta_t)\in B\}}\mathrm{d}t+\overline{e}_t\mathbf{1}_{\{\overline{w}(\theta_t)\in B\}}\mathrm{d}t \\
=&\int_0^{\overline{w}(\theta_t)}\left[\int_0^{\overline{w}(\theta_{t+\mathrm{d}t})}\mathbf{1}_{\{w_{t+\mathrm{d}t}\in B\}}q(w_{t+\mathrm{d}t}|w_t)\mathrm{d}w_{t+\mathrm{d}t}\right]\theta_t(w_t)\mathrm{d}w_t \\
&+\int_0^{\overline{w}(\theta_t)}\left[\int_0^{\overline{w}(\theta_{t+\mathrm{d}t})}\mathbf{1}_{\{w_{t+dt}\in B\}}q_w(w_{t+\mathrm{d}t}|w_t)\mathrm{d}w_{t+\mathrm{d}t}\right]\beta\left[P(w_t,\theta_t)^{-\eta}-\int_0^{\overline{w}(\theta_t)}P(w,\theta_t)^{-\eta}\theta_t(w)\mathrm{d}w\right]P(\theta_t)^{\eta-\epsilon}\mathrm{d}t\theta_t(w_t)\mathrm{d}w_t \\
&\qquad+\underline{e}_t\mathbf{1}_{\{w^*(\theta_t)\in B\}}\mathrm{d}t+\overline{e}_t\mathbf{1}_{\{\overline{w}(\theta_t)\in B\}}\mathrm{d}t \\
&=\int_0^{\overline{w}(\theta_t)}\mathbb{Q}_{t,t+\mathrm{d}t}(B|w)\theta_t(w)\mathrm{d}w \\
&+\beta P(\theta_t)^{\eta-\epsilon}\left[\int_0^{\overline{w}(\theta_t)}P(w,\theta_t)^{-\eta}\mathbb{Q}_{t,t+\mathrm{d}t}(B|w)\theta_t(w)\mathrm{d}w-\int_0^{\overline{w}(\theta_t)}P(w,\theta_t)^{-\eta}\theta_t(w)\mathrm{d}w\int_0^{\overline{w}(\theta_t)}\mathbb{Q}_{t,t+\mathrm{d}t}(B|w)\theta_t(w)\mathrm{d}w\right]\mathrm{d}t \\
&\qquad+\underline{e}_t\mathbf{1}_{\{w^*(\theta_t)\in B\}}\mathrm{d}t+\overline{e}_t\mathbf{1}_{\{\overline{w}(\theta_t)\in B\}}\mathrm{d}t \\
&=\int_0^{\overline{w}(\theta_t)}\mathbb{Q}_{t,t+\mathrm{d}t}(B|w)\theta_t(w)\mathrm{d}w+\beta P(\theta_t)^{\eta-\epsilon}\int_0^{\overline{w}(\theta_t)}\left[P(w,\theta_t)^{-\eta}-\int_0^{\overline{w}(\theta_t)}P(w',\theta_t)^{-\eta}\theta_t(w')\mathrm{d}w'\right]\mathbb{Q}_{t,t+dt}(B|w)\theta_t(w)\mathrm{d}w \\
&\qquad+\underline{e}_t\mathbf{1}_{\{w^*(\theta_t)\in B\}}\mathrm{d}t+\overline{e}_t\mathbf{1}_{\{\overline{w}(\theta_t)\in B\}}\mathrm{d}t,
\end{aligned}
$$

where $q(m_{t+\mathrm{d}t},w_{t+\mathrm{d}t}|m_t,w_t)$ is the joint transition density from (m_t,w_t) to $(m_{t+\mathrm{d}t},w_{t+\mathrm{d}t})$; $q_m(m_{t+\mathrm{d}t}|m_t,w_t)$ is the marginal transition density from (m_t,w_t) to $m_{t+\mathrm{d}t}$; and $q_w(w_{t+\mathrm{d}t}|m_t,w_t)$ is the marginal transition density from (m_t,w_t) to $w_{t+\mathrm{d}t}$. We have $q_w(w_{t+\mathrm{d}t}|m_t,w_t)=q_w(w_{t+\mathrm{d}t}|w_t)$ because the evolution of w_t is independent from m_t according to equation (2.20).

B Data and Supplementary Results

B.1 Data and Summary Statistics

We construct our Compustat-CRSP sample following Hoberg and Prabhala (2009) and Hoberg, Phillips and Prabhala (2014). We obtain the fluidity measures from Hoberg's website. Our sample spans the period from 1998 to 2017, which is chosen based on the availability of fluidity measures.

Sample Selection We select the sample following Hoberg and Prabhala (2009). The Compustat sample for calendar year t includes those firms with fiscal year-ends in t that have the following data variables: total assets, stock price, and shares outstanding at the end of the fiscal year, income before extraordinary items, interest expense, dividends per share by ex date, preferred dividends, and one of preferred stock liquidating value, preferred stock redemption value, and preferred stock carrying value. Firms must also have preferred stock par value and one of stockholder's equity, liabilities, and common equity. Total assets must be available in years t and $t-1$. The other items must be available in year t. We exclude firms with book equity below $250,000 or assets below $500,000. We require firms in the Compustat sample to have common shares (CRSP share codes of 10 and 11) listed on NYSE, AMEX, or NASDAQ. A firm must have market equity data (price and shares outstanding) for December of year t to be in the CRSP sample for that year. We exclude utilities (SIC codes 4900 – 4949) and financial firms (SIC codes 6000 – 6999) from both Compustat and CRSP samples.

Variable Construction Firm-level variables are constructed as follows (Compustat data items in parentheses):

Equity repurchaser: A firm is a repurchaser in calendar year t if its repurchase variable is positive in the fiscal year that ends in year t. The repurchase variable is the purchase of common and preferred stock (115) minus the reduction in the value of any preferred stock outstanding (56).

Cash holdings/assets: Cash and short-term investments (1) divided by assets (6).

Change in retained earnings/Net income: Change in retained earnings (36) from year t to year $t+1$ divided by net income (177) in year $t+1$. We focus on firm-year observations with positive net income.

Local product market fluidity: Obtained from Hoberg-Phillips data library.

Self product fluidity: Obtained from Hoberg-Phillips data library.

HHI: Obtained from Hoberg-Phillips data library. HHI is constructed based on Text-based Network Industry Classifications (TNIC) (see Hoberg and Phillips, 2016).

Total risk: The standard deviation of the firm's daily stock returns from CRSP in a calendar year.

Firm age: Firm age is year minus the date on which the firm first listed on a stock market, which is the IPO date from Compustat. If the IPO date is missing, we use the first date on which the firm has return record in any listing vintage in CRSP.

Book equity: Stockholder's equity (216) minus preferred stock plus balance sheet deferred taxes and investment tax credit (35) minus post retirement asset (330). If data item 216 is not available, it is replaced by either common equity (60) plus preferred stock par value (130), or assets(6) minus liabilities (181). Preferred stock is preferred stock liquidating value (10) (or preferred stock redemption value (56), or preferred stock par value (130)).

Table B.1: Summary statistics.

Variable	N	Mean	SD	Minimum	Median	Maximum
Equity repurchaser	51,348	0.490	0.500	0.000	0.000	1.000
Cash holdings/assets	56,121	0.202	0.232	0.000	0.107	0.943
Local product market fluidity	56,125	6.533	3.405	1.377	5.840	17.147
Self product fluidity	55,748	18.322	14.402	1.399	14.223	73.698
HHI	56,125	0.315	0.283	0.031	0.202	1.000
Total risk	56,124	0.038	0.022	0.010	0.032	0.125
Market-to-book	56,125	1.968	1.547	0.544	1.452	9.725
Asset growth	56,125	0.126	0.373	−0.448	0.049	1.714
Income/assets	56,125	−0.010	0.254	−1.293	0.064	0.305
NYSE size percentile	56,125	0.282	0.292	0.000	0.167	0.978
Log firm age	56,105	2.581	0.845	0.782	2.641	4.395
Negative earnings dummy	56,125	0.363	0.481	0.000	0.000	1.000
R&D/sales	55,913	0.661	3.255	0.000	0.003	21.747
Retained earnings/assets	56,051	−0.488	1.920	−11.891	0.089	0.970
Retained earnings change/net income	48,140	0.826	1.372	−6.759	0.998	7.211
3-year sales growth	49,632	0.274	0.736	−2.177	0.208	3.869
ln(book assets)	56,125	5.881	2.060	1.708	5.818	10.870
R&D/assets	56,125	0.059	0.117	0.000	0.003	0.679

Market equity: Fiscal year closing price (199) times shares outstanding (25).

Market-to-book ratio: Book assets (6) minus book equity plus market equity divided by book assets (6).

Asset growth: Percentage growth in assets (6) from year $t-1$ to year t.

Income/assets: Income is constructed from earnings before extraordinary items (18) plus interest expense (15) plus income statement deferred taxes (50) divided by assets (6).

NYSE size percentile: NYSE market capitalization percentile, i.e., the fraction of NYSE firms having equal or smaller capitalization than firm i in year t.

3-year sales growth: Percentage growth in sales (12) from year $t-3$ to year t.

R&D/sales: Research and development expense (46) divided by sales (12).

Negative earnings: We follow the definition of DeAngelo, DeAngelo and Skinner (1992) and (Hoberg, Phillips and Prabhala, 2014). A firm's negative earnings dummy is one if earnings before extraordinary items (18) plus extraordinary items and discontinued operations (48) is negative.

Table B.1 presents the summary statistics of firm-level variables, which are broadly consistent with the sample of Hoberg, Phillips and Prabhala (2014).

Table B.2: Firm-level repurchases, cash holdings and product fluidity.

	Repurchases$_{i,t}$		Cash holdings$_{i,t}$/assets$_{i,t}$	
	(1)	(2)	(3)	(4)
Local product fluidity$_{i,t}$	-0.032^{***}	-0.020^{***}	0.058^{***}	0.039^{***}
	[0.005]	[0.005]	[0.003]	[0.003]
Self-product fluidity$_{i,t}$	0.007^{**}	0.006	0.004^{***}	0.006^{***}
	[0.003]	[0.003]	[0.001]	[0.001]
HHI$_{i,t}$	-0.012^{***}	-0.011^{***}	-0.003	-0.004^{*}
	[0.004]	[0.004]	[0.002]	[0.002]
Total risk$_{i,t}$	-0.073^{***}	-0.075^{***}	-0.012^{***}	-0.012^{***}
	[0.004]	[0.005]	[0.002]	[0.002]
Log firm age$_{i,t}$	0.028^{***}	0.008	-0.007^{***}	-0.008^{***}
	[0.004]	[0.005]	[0.002]	[0.002]
Market-to-book$_{i,t}$	-0.009^{**}	-0.001	0.075^{***}	0.073^{***}
	[0.004]	[0.005]	[0.002]	[0.002]
Asset growth$_{i,t}$	-0.045^{***}	-0.047^{***}	0.009^{***}	0.008^{***}
	[0.003]	[0.003]	[0.001]	[0.001]
Income/assets$_{i,t}$	0.038^{***}	0.008^{**}	-0.060^{***}	-0.020^{***}
	[0.004]	[0.006]	[0.002]	[0.003]
NYSE size percentile$_{i,t}$	0.101^{***}	0.094^{***}	-0.034^{***}	-0.028^{***}
	[0.005]	[0.005]	[0.002]	[0.002]
R&D/sales$_{i,t}$		-0.006		0.046^{***}
		[0.005]		[0.002]
Negative earnings$_{i,t}$		-0.049^{***}		0.001
		[0.004]		[0.002]
Retained earnings/assets$_{i,t}$		0.021^{***}		-0.024^{***}
		[0.005]		[0.003]
3-Year sales growth$_{i,t}$		-0.022^{***}		-0.012^{***}
		[0.003]		[0.002]
R-squared	0.144	0.146	0.384	0.400
Observations	55,596	48,556	55,592	48,552

Note: In columns (1) and (2), the dependent variable is the firm-level share repurchases; and in columns (3) and (4), the dependent variable is the firm-level cash-to-asset ratio. Variable construction is described in Appendix B. All specifications control for industry and time fixed effects. The sample spans the period from 1998 to 2017. We include standard errors in brackets. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Standard errors are clustered by firm.

B.2 Empirical Results at the Firm Level

Our empirical results also hold at the firm level. Table B.2 shows that firms facing greater product market threats are associated with fewer share repurchases and higher cash balance. Table B.3 shows that the coefficient on the interaction term of local product fluidity and the financial crisis dummy is significantly negative for share repurchases (columns 1 and 2) and significantly positive for the change in retained earnings as a fraction of net income (columns 3 and 4).

Table B.3: Firm-level repurchases, retained earnings, and product fluidity during the financial crisis.

	Repurchases$_{i,t}$		$(\text{RE}_{i,t+1}$ - $\text{RE}_{i,t})$/net income$_{i,t+1}$	
	(1)	(2)	(3)	(4)
Local product fluidity$_{i,t}$ × Crisis$_t$	-0.008^{*}	-0.014^{**}	0.040^{*}	0.024^{***}
	[0.005]	[0.005]	[0.021]	[0.009]
Local product fluidity$_{i,t}$	-0.046^{***}	-0.032^{***}	0.013^{**}	0.01
	[0.004]	[0.005]	[0.006]	[0.006]
Financial crisis dummy$_t$	-0.066^{***}	-0.068^{***}	-0.091^{***}	-0.102^{***}
	[0.014]	[0.015]	[0.021]	[0.022]
Self-product fluidity$_{i,t}$	-0.002	-0.001	-0.012^{***}	-0.008^{*}
	[0.003]	[0.003]	[0.004]	[0.004]
HHI$_{i,t}$	-0.012^{***}	-0.011^{***}	-0.011^{**}	-0.008
	[0.004]	[0.004]	[0.005]	[0.005]
Total risk$_{i,t}$	-0.065^{***}	-0.061^{***}	0.066^{***}	0.066^{***}
	[0.005]	[0.006]	[0.006]	[0.007]
Log firm age$_{i,t}$	0.035^{**}	0.017^{**}	-0.055^{***}	-0.047^{***}
	[0.004]	[0.005]	[0.005]	[0.006]
Market-to-book$_{i,t}$	-0.023^{***}	-0.017^{**}	-0.003	-0.01
	[0.003]	[0.004]	[0.006]	[0.007]
Asset growth$_{i,t}$	-0.025^{***}	-0.025^{**}	0.047^{***}	0.026^{***}
	[0.009]	[0.013]	[0.004]	[0.004]
Income/assets$_{i,t}$	0.021^{***}	0.010^{**}	0.006	-0.007
	[0.004]	[0.004]	[0.005]	[0.006]
NYSE size percentile$_{i,t}$	0.105^{***}	0.096^{***}	-0.030^{***}	-0.029^{**}
	[0.005]	[0.005]	[0.007]	[0.007]
R&D/sales$_{i,t}$		-0.018^{***}	-0.005	-0.015
		[0.003]	[0.006]	[0.013]
Negative earnings$_{i,t}$		-0.054^{***}		-0.014
		[0.004]		[0.013]
Retained earnings/assets$_{i,t}$		0.016^{***}		-0.013^{**}
		[0.004]		[0.006]
3-Year sales growth$_{i,t}$		-0.028^{***}		0.052^{***}
		[0.003]		[0.005]
R-squared	0.144	0.146	0.089	0.095
Observations	55,596	48,556	30,923	28,666

Note: In columns (1) and (2), the dependent variable is the firm-level share repurchases; and in columns (3) and (4), the dependent variable is the firm-level change in retained earnings as a fraction of net income. Variable construction is described in Appendix B. All specifications control for industry and time fixed effects. The sample spans the period from 1998 to 2017. We include standard errors in brackets. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Standard errors are clustered by firm.

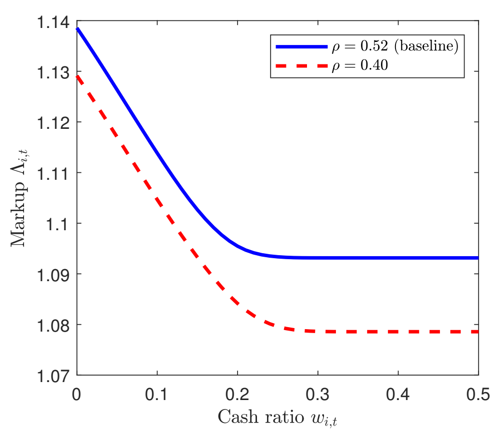
B.3 Industry-Level Variables

For each FIC-300 industry, we construct industry-level variables by taking the average of the top four firms (ranked by sales) weighted by sales. Regarding industry-level HHI, we consider both the sales-weighted firm-level HHI and the HHI calculated based on the sum of the squares of the market shares of the top four firms' in the industry, where the market share of each firm is defined as the sales of the firm divided by the total sales of the top four firms in the industry. Our empirical results are robust to both definitions of HHI.

C Discussions on Model Ingredients

In this appendix section, we discuss the role played by the parameter ρ governing the depreciation rate of customer base.

In Figure C.1, the black dashed line shows that a lower depreciation rate implies a lower markup for any cash ratio $w_{i,t}$. Intuitively, customer base becomes stickier when the depreciation rate is lower, and this creates more incentive for firms to accumulate customer base by setting a lower markup. Moreover, comparing the black dashed line and the blue solid line, we can see that the decrease in markups due to a lower ρ is smaller when the firm is more liquidity constrained (i.e., lower $w_{i,t}$). In other words, the sensitivity of the firm's markups with respect to its financial condition increases when the depreciation rate of customer base is lower. This is consistent with the implication of Proposition 3.1 because a lower ρ implies that the marginal value of customer base is higher (i.e., higher $\mu_{i,t}$), which makes markups more responsive to the firm's financial conditions. Thus, our model implies that the negative relationship between markups and financial constraints is more significant in industries with a stickier customer base.



Note: This figure is plotted using the parameter values in Table 1 in Section 4.1.

Figure C.1: Markups and the depreciation rate of customer base.

D Model Solution

We solve the model in both steady states and transitions. In steady states, the share density $\theta_t(w)$ is a time-invariant density function $\overline{\theta}(w)$, implying a constant price index $\overline{P}$ according to equation (2.14). The constant price index $\overline{P}$ summarizes all the information contained in the steady-state density function $\overline{\theta}(w)$ for firm i to solve the optimization problem (2.15). Thus, the HJB equation (2.15) in steady states can be rewritten as

$$rv(w_{i,t};\overline{P})M_{i,t}\mathrm{d}t = \max_{P_{i,t},\mathrm{d}D_{i,t}} \mathrm{d}D_{i,t} - \mathrm{d}X_{i,t} + \mathbb{E}_t\left[\mathrm{d}\left(v(w_{i,t};\overline{P})M_{i,t}\right)\right], \tag{D.1}$$

subject to the evolution of customer base $M_{i,t}$ and cash ratio $w_{i,t}$, given by

$$\frac{\mathrm{d}M_{i,t}}{M_{i,t}} = \beta\left(\frac{P_{i,t}}{\overline{P}}\right)^{-\eta}\overline{P}^{-\epsilon}\mathrm{d}t - \rho\mathrm{d}t, \tag{D.2}$$

$$\mathrm{d}w_{i,t} = \left[(r-\lambda+\rho)\,w_{i,t} + \left(P_{i,t} - \frac{R}{A} - \beta w_{i,t}\right)\left(\frac{P_{i,t}}{\overline{P}}\right)^{-\eta}\overline{P}^{-\epsilon}\right]\mathrm{d}t - \frac{\mathrm{d}D_{i,t}}{M_{i,t}} + \sigma\mathrm{d}Z_{i,t}, \tag{D.3}$$

Our numerical algorithm is described in detail in Online Appendix E.1.3. In a nutshell, we guess the steady-state price index $\overline{P}$ and solve a generic firm i's problem (D.1). Then, we simulate a large number of firms based on the optimal policy functions and the law of motions (D.2) – (D.3) to obtain the steady-state share density $\overline{\theta}(w)$, based on which we calculate the implied price index $\overline{P}'$ according to equation (2.14). We iterate the above steps until $\overline{P} = \overline{P}'$.

In transitions, because the model does not have aggregate shocks, the path of price index $\{P_s\}_{s\geq t}$ is deterministic and summarizes all the information that firm i needs to know to solve the HJB equation (2.15) at t. In other words, given the path of price index $\{P_s\}_{s\geq t}$, we can solve firm i's problem without tracking the evolution of the share density $\theta_s(w)$ for $s \geq t$. Thus, the HJB equation (2.15) in transitions can be rewritten as

$$rv(w_{i,t};\{P_s\}_{s\geq t})M_{i,t}\mathrm{d}t = \max_{P_{i,t},\mathrm{d}D_{i,t}} \mathrm{d}D_{i,t} - \mathrm{d}X_{i,t} + \mathbb{E}_t\left[\mathrm{d}\left(v(w_{i,t};\{P_s\}_{s\geq t})M_{i,t}\right)\right], \tag{D.4}$$

subject to the evolution of customer base $M_{i,t}$ and cash ratio $w_{i,t}$, given by

$$\frac{\mathrm{d}M_{i,t}}{M_{i,t}} = \beta\left(\frac{P_{i,t}}{P_t}\right)^{-\eta}P_t^{-\epsilon}\mathrm{d}t - \rho\mathrm{d}t, \tag{D.5}$$

$$\mathrm{d}w_{i,t} = \left[(r-\lambda+\rho)\,w_{i,t} + \left(P_{i,t} - \frac{R}{A} - \beta w_{i,t}\right)\left(\frac{P_{i,t}}{P_t}\right)^{-\eta}P_t^{-\epsilon}\mathrm{d}t\right]\mathrm{d}t - \frac{\mathrm{d}D_{i,t}}{M_{i,t}} + \sigma\mathrm{d}Z_{i,t}, \tag{D.6}$$

Our numerical algorithm is described in detail in Online Appendix E.1.4. In a nutshell, we guess the price index P_t for all $t \in [0, T]$, where T is sufficiently large to ensure that the industry reaches the steady state. Then, we solve a generic firm i's problem (D.1) for all $t \in [0, T]$ using backward induction, given that the firm's value at T is equal to its steady-state value. Finally, we simulate a large number of firms based on the optimal policy functions and the law of motions (D.5) – (D.6) to obtain the share density $\theta_t(w)$ for all $t \in [0, T]$, based on which we calculate the implied price index P_t' according to equation (2.14) for all $t \in [0, T]$. We iterate the above steps until $P_t = P_t'$ for all $t \in [0, T]$.

D.1 External Financing and Payout Boundaries

The firm makes the optimal financing decisions and markup-setting decisions together. Because financing decisions are binary, we can characterize firm i's financing choice by the optimal decision boundaries and regions: (1) an external financing region ($w_{i,t} < \underline{w}(\theta_t)$), within which the firm pursues external financing ($\mathrm{d}D_{i,t} < 0$); (2) an internal liquidity-hoarding region ($\underline{w}(\theta_t) \leq w_{i,t} \leq \overline{w}(\theta_t)$), within which the firm keeps net profits as cash holdings ($dD_{i,t} = 0$); and (3) a payout region ($w_{i,t} > \overline{w}(\theta_t)$), within which the firm chooses to pay out dividend ($dD_{i,t} > 0$). The decision boundaries $\underline{w}(\theta_t)$ and $\overline{w}(\theta_t)$ are the financing boundary and the payout boundary, respectively.

Intuitively, when exogenous cash flow shocks drive the cash ratio $w_{i,t}$ gradually to some low level $\underline{w}(\theta_t)$ such that the current financing costs and shareholders' gain from issuing equity are equal, the firm would issue equity. Although the firm can issue equity any time, it is optimal for the firm to raise equity only when it runs out of cash, which means the external financing boundary $\underline{w}(\theta_t) \equiv 0$.[11] Because holding cash is costly, the firm chooses to pay out cash when exogenous positive cash flow shocks drive the cash ratio $w_{i,t}$ beyond some high level $\overline{w}(\theta_t)$.

When the firm lies in the external financing region ($w_{i,t} \leq \underline{w}(\theta_t)$), the optimal financing amount is endogenously determined. Let $w^*(\theta_t)$ be the optimal issuance ratio. The value-matching condition for $w^*(\theta_t)$ is, for any $w_{i,t} \leq \underline{w}(\theta_t)$,

$$v(w_{i,t}, \theta_t) = v(w^*(\theta_t), \theta_t) - \gamma - (1 + \varphi)[w^*(\theta_t) - w_{i,t}]. \tag{D.7}$$

The left-hand side of equation (D.7) is the firm's value right before equity issuance. The right-hand side is the firm's value right after equity issuance minus both the fixed and the variable financing costs for issuance ratio $w^*(\theta_t) - w_{i,t}$. The first-order optimality condition for the optimal issuance ratio leads to the smooth pasting condition (e.g., Dixit, 1993):

$$\left.\frac{\partial v(w_{i,t}, \theta_t)}{\partial w_{i,t}}\right|_{w_{i,t}=w^*(\theta_t)} = 1 + \varphi. \tag{D.8}$$

Intuitively, equation (D.8) states that the marginal value of the last dollar raised by the firm must equal one plus the marginal cost of external financing φ.

The firm starts to pay out cash when the marginal value of cash that it holds is less than the marginal value of cash that shareholders hold, which is one. Thus, the value-matching condition gives the following boundary condition:

$$\left.\frac{\partial v(w_{i,t}, \theta_t)}{\partial w_{i,t}}\right|_{w_{i,t}=\overline{w}(\theta_t)} = 1. \tag{D.9}$$

The payout region is characterized by $w_{i,t} > \overline{w}(\theta_t)$. Whenever the cash ratio is above the boundary, paying out the extra cash $w_{i,t} - \overline{w}(\theta_t)$ in a lump-sum manner and reducing its cash ratio back to $\overline{w}(\theta_t)$ is optimal. Thus, the firm's value in the payout region has the following form:

$$v(w_{i,t}, \theta_t) = v(\overline{w}(\theta_t)) + w_{i,t} - \overline{w}(\theta_t), \quad \text{for } w_{i,t} \geq \overline{w}(\theta_t). \tag{D.10}$$

Moreover, the first-order condition for minimizing the firm's marginal value of cash over constant payout boundaries leads to the super contact condition (see Dumas, 1991):

$$\left.\frac{\partial^2 v(w_{i,t}, \theta_t)}{\partial w_{i,t}^2}\right|_{w_{i,t}=\overline{w}(\theta_t)} = 0. \tag{D.11}$$

Within the internal liquidity-hoarding region, $dD_{i,t} = dX_{i,t} = 0$, thus the HJB equation (2.15) for the firm

[11] Financing costs always have smaller present values for three reasons when they are paid later in the future, as long as the firm has positive liquidity hoarding. First, cash within the firm earns a lower interest rate $r - \lambda$ due to the holding cost from shareholders' perspective. Second, the firm's expenses can be covered by immediate financing. Third, the risk-free rate is a positive constant.

is simplified as

$$rv(w_{i,t},\theta_t)M_{i,t}\mathrm{d}t = \max_{P_{i,t}} \mathbb{E}_t\left[\mathrm{d}\left(v(w_{i,t},\theta_t)M_{i,t}\right)\right], \tag{D.12}$$

subject to the evolution of customer base $M_{i,t}$ (equation (2.16)), the evolution of cash ratio $w_{i,t}$ (equation (2.20)), and the evolution of the share distribution $\theta_t(w)$.

D.2 Monopoly Industry

In a monopoly industry, there is only one firm, indexed by i, facing the industry's demand (2.1). The firm's customer base evolves according to

$$\mathrm{d}M_{i,t} = \beta C_{i,t}\mathrm{d}t - \rho M_{i,t}\mathrm{d}t. \tag{D.13}$$

Substituting equation (2.1) into equation (D.13), we obtain

$$\mathrm{d}M_{i,t} = \beta P_{i,t}^{-\epsilon} M_{i,t}\mathrm{d}t - \rho M_{i,t}\mathrm{d}t. \tag{D.14}$$

Substituting equation (2.9) into equation (2.11), we obtain

$$\mathrm{d}W_{i,t} = \left(P_{i,t} - \frac{R}{A}\right) P_{i,t}^{-\epsilon} M_{i,t}\mathrm{d}t + \sigma M_{i,t}\mathrm{d}Z_{i,t} + (r-\lambda)W_{i,t}\mathrm{d}t - \mathrm{d}D_{i,t}. \tag{D.15}$$

The firm's value function is linear in its customer base $M_{i,t}$, thus we have $V_{i,t} \equiv v(w_{i,t})M_{i,t}$. The optimal financing decisions of firm i are characterized by two decision boundaries, similar to the firm in the industry with monopolistic competition. Within the internal liquidity-hoarding region, $\mathrm{d}D_{i,t} = \mathrm{d}X_{i,t} = 0$, thus the HJB equation is

$$rv(w_{i,t})M_{i,t}\mathrm{d}t = \max_{P_{i,t}} \mathbb{E}_t\left[\mathrm{d}\left(v(w_{i,t})M_{i,t}\right)\right], \tag{D.16}$$

subject to the evolution of customer base (D.14) and the evolution of cash ratio $w_{i,t}$

$$\mathrm{d}w_{i,t} = \left(P_{i,t} - \frac{R}{A}\right) P_{i,t}^{-\epsilon}\mathrm{d}t + \sigma\mathrm{d}Z_{i,t} + \left(r - \lambda - \frac{\mathrm{d}M_{i,t}}{M_{i,t}}\right) w_{i,t}\mathrm{d}t. \tag{D.17}$$

E Numerical Algorithm

In this appendix, we detail the numerical algorithm used to solve the model. In Section E.1, we present the algorithm for solving the equilibrium of our baseline industry with monopolistic competition. In Section E.2, we present the algorithm for solving the equilibrium of a monopoly industry.

E.1 Baseline Industry with Monopolistic Competition

In this appendix section, we describe the recursive formulation for a firm's problem in the industry with monopolistic competition. In subsection E.1.1, we begin by presenting both the original and the normalized recursive formulation in the steady state. Then, in subsection E.1.2 we present the algorithm for solving the transitional dynamics after an unexpected aggregate financial shock. Finally, in subsections E.1.3 and E.1.4, we present the algorithms for searching for the equilibrium industry-level price indices in the steady state and along the transition path.

E.1.1 Steady State

In the steady state, the industry's markup index is constant in the absence of aggregate shocks. Denote by Λ the steady-state markup index. Given the constant markup index, we can solve each atomistic firm's problem separately. For clarity, below we first present the firm's original recursive problem in terms of cash holdings and customer base. Then we present the firm's normalized recursive problem in terms of cash ratios and customer base share.

Recursive Formulation for the Original Problem. A generic firm i solves the following recursive problem:

$$V(W_{i,t}, M_{i,t}) = \max_{\Lambda_{i,t}, \Delta D_{i,t}} \Delta D_{i,t} - (\gamma M_{i,t} - \varphi \Delta D_{i,t})\, \mathbb{1}_{\Delta D_{i,t}<0} + e^{-r\Delta t}\mathbb{E}_t \left[V(W_{i,t+\Delta t}, M_{i,t+\Delta t}) \right],$$

subject to the evolution of the customer base

$$M_{i,t+\Delta t} = M_{i,t} + \beta \left(\frac{\Lambda_{i,t}}{\Lambda}\right)^{-\eta} \left(\frac{\Lambda R}{A}\right)^{-\epsilon} M_{i,t}\Delta t - \rho M_{i,t}\Delta t,$$

and the evolution of cash holdings

$$W_{i,t+\Delta t} = [1 + (r-\lambda)\Delta t] W_{i,t} + (\Lambda_{i,t} - 1)\frac{R}{A}\left(\frac{\Lambda_{i,t}}{\Lambda}\right)^{-\eta} \left(\frac{\Lambda R}{A}\right)^{-\epsilon} M_{i,t}\Delta t + \sigma M_{i,t}\Delta Z_{i,t} - \Delta D_{i,t}.$$

Recursive Formulation for the Normalized Problem. The value function $V(W_{i,t}, M_{i,t})$ is linear in $M_{i,t}$. Thus, we normalize the firm's cash holdings, value, and net payout by $M_{i,t}$. Let

$$w_{i,t} = W_{i,t}/M_{i,t}, \tag{E.1}$$

$$v(w_{i,t}) = V(W_{i,t}, M_{i,t})/M_{i,t}, \tag{E.2}$$

$$\Delta d_{i,t} = \Delta D_{i,t}/M_{i,t}. \tag{E.3}$$

A generic firm i solves the following normalized recursive problem:

$$\begin{aligned} v(w_{i,t}) = &\max_{\Lambda_{i,t}, \Delta d_{i,t}} \Delta d_{i,t} - (\gamma - \varphi \Delta d_{i,t}) \mathbb{1}_{\Delta d_{i,t}<0} \\ &+ e^{-r\Delta t} \left[1 + \beta \left(\frac{\Lambda_{i,t}}{\Lambda}\right)^{-\eta} \left(\frac{\Lambda R}{A}\right)^{-\epsilon} \Delta t - \rho \Delta t \right] \mathbb{E}_t \left[v(w_{i,t+\Delta t}) \right], \end{aligned} \tag{E.4}$$

subject to the evolution of the cash ratio

$$\begin{aligned} &\left[1 + \beta \left(\frac{\Lambda_{i,t}}{\Lambda}\right)^{-\eta} \left(\frac{\Lambda R}{A}\right)^{-\epsilon} \Delta t - \rho \Delta t \right] w_{i,t+\Delta t} \\ = &[1 + (r-\lambda)\Delta t] w_{i,t} + (\Lambda_{i,t} - 1)\, \frac{R}{A} \left(\frac{\Lambda_{i,t}}{\Lambda}\right)^{-\eta} \left(\frac{\Lambda R}{A}\right)^{-\epsilon} \Delta t + \sigma \Delta Z_{i,t} - \Delta d_{i,t}. \end{aligned} \tag{E.5}$$

E.1.2 Transitional Dynamics

During transitions, the industry's markup index is time t dependent, denoted by Λ_t. Thus, the value function and policy function also depend on time t. We make it clear by adding a subscript t for the notation of value and policy functions.

At time t, a generic firm i solves the following normalized recursive problem:

$$\begin{aligned} v_t(w_{i,t}) = &\max_{\Lambda_{i,t},\Delta d_{i,t}} \Delta d_{i,t} - (\gamma - \varphi \Delta d_{i,t}) \mathbb{1}_{\Delta d_{i,t}<0} \\ &+ e^{-r\Delta t} \left[1 + \beta \left(\frac{\Lambda_{i,t}}{\Lambda_t} \right)^{-\eta} \left(\frac{\Lambda_t R}{A} \right)^{-\epsilon} \Delta t - \rho \Delta t \right] \mathbb{E}_t \left[v_{t+\Delta t}(w_{i,t+\Delta t}) \right], \end{aligned} \tag{E.6}$$

subject to the evolution of the cash ratio

$$\begin{aligned} &\left[1 + \beta \left(\frac{\Lambda_{i,t}}{\Lambda_t} \right)^{-\eta} \left(\frac{\Lambda_t R}{A} \right)^{-\epsilon} \Delta t - \rho \Delta t \right] w_{i,t+\Delta t} \\ =&[1 + (r - \lambda)\Delta t] w_{i,t} + (\Lambda_{i,t} - 1) \frac{R}{A} \left(\frac{\Lambda_{i,t}}{\Lambda_t} \right)^{-\eta} \left(\frac{\Lambda_t R}{A} \right)^{-\epsilon} \Delta t + \sigma \Delta Z_{i,t} - \Delta d_{i,t}. \end{aligned} \tag{E.7}$$

E.1.3 Searching for the Steady State

In this appendix, we describe the algorithm for finding the steady-state markup index Λ.

Solving problem (E.4), we obtain a generic firm's optimal policy functions as a function of firm state $w_{i,t}$ and the industry's state Λ, i.e. $\Lambda(w_{i,t};\Lambda)$ and $\Delta d(w_{i,t};\Lambda)$. We also obtain the growth rate of customer base over a short period Δt:

$$g(w_{i,t};\Lambda) = 1 + \beta \left(\frac{\Lambda(w_{i,t};\Lambda)}{\Lambda} \right)^{-\eta} \left(\frac{\Lambda R}{A} \right)^{-\epsilon} \Delta t - \rho \Delta t. \tag{E.8}$$

We then perform forward simulation to compute the implied equilibrium markup index $\hat{\Lambda}$. We iterate until $|\Lambda - \hat{\Lambda}| < 10^{-6}$. The forward simulation proceeds in the following steps:

1. Start with a sufficiently large number of firms, say $n = 50,000$, and an arbitrary initial distribution of cash holdings $W_{i,0}$ and the customer base $M_{i,0}$. For each firm i, compute the initial cash ratio $w_{i,0} = W_{i,0}/M_{i,0}$.
2. For time $t \geq 0$ and each firm i, use the optimal policy functions $\Lambda(w_{i,t};\Lambda)$ and $\Delta d(w_{i,t};\Lambda)$ to compute $w_{i,t+\Delta t}$ according to equation (E.5). Use the optimal policy function $\Lambda(w_{i,t};\Lambda)$ to compute $g(w_{i,t};\Lambda)$, and the evolution of $M_{i,t}$ according to $M_{i,t+\Delta t} = M_{i,t} g(w_{i,t};\Lambda)$.
3. Calculate each firm i's customer base share according to $m_{i,t} = \frac{M_{i,t}}{\sum_{j=1}^{n} M_{j,t}}$. Repeat step 2 for a sufficiently long time T to ensure that the economy reaches the steady state, in which the joint distribution of the cash ratio $w_{i,T}$ and customer base share $m_{i,T}$ is stationary. We choose 50 years, so that $T = 50/\Delta t = 18,250$ (given $\Delta t = 1/365$).
4. Calculate the industry's markup index:

$$\hat{\Lambda} = \left(\sum_{i=1}^{n} m_{i,T} \Lambda(w_{i,T};\Lambda)^{1-\eta} \right)^{\frac{1}{1-\eta}}. \tag{E.9}$$

5. If $|\Lambda - \hat{\Lambda}| \geq 10^{-6}$, set Λ to $0.5\Lambda + 0.5\hat{\Lambda}$. Repeat the algorithm from step 1.

E.1.4 Searching for the Transition Path

In this appendix, we describe the algorithm for finding the markup index $\{\Lambda_t\}_{t=0}^{\infty}$ along the transition path after an aggregate financial shock at $t = 0$ (panel C of Figure 5).

Our numerical algorithm uses forward simulation and backward induction to solve for the value functions along the transition path. Moreover, we use the bi-section search algorithm to solve for the equilibrium values of $\{\Lambda_t\}_{t=0}^{\infty}$. We allow for a sufficiently long time to ensure that the industry converges to the new steady state, say 50 years or $T = 50/\Delta t = 18,250$ (given $\Delta t = 1/365$).

1. Use the algorithm in Online Appendix E.1.3 to obtain the industry's markup index in the steady state before the aggregate financial shock, denoted by Λ_0, and that in the steady state after the aggregate financial shock, denoted by Λ_T.

2. Start with a sufficiently large number of firms, say $n = 50,000$. Each firm i draws the initial cash ratio $w_{i,0}$ and the initial customer base share $m_{i,0}$ from the steady-state distribution of w and m before the aggregate financial shock.

3. Guess the values of $\{\Lambda_t\}_{t=0}^{T}$ along the transition path. Then starting from T, solve problem (E.6) using backward induction to obtain the optimal policy functions of firm i:

$$\left\{\Lambda_t(w_{i,t}; \{\Lambda_t\}_{t=0}^{\infty}), \Delta d_t(w_{i,t}; \{\Lambda_t\}_{t=0}^{\infty})\right\}_{t=0}^{T}. \tag{E.10}$$

   The growth rate of firm i's customer base at time t is

$$g_t(w_{i,t}; \Lambda_t) = 1 + \beta \left(\frac{\Lambda_t(w_{i,t}; \{\Lambda_t\}_{t=0}^{\infty})}{\Lambda_t}\right)^{-\eta} \left(\frac{\Lambda_t R}{A}\right)^{-\epsilon} \Delta t - \rho \Delta t. \tag{E.11}$$

4. For each firm i, starting from $t = 0$, use the optimal policy functions and growth rates to forward simulate and obtain $\{w_{i,t}, m_{i,t}\}_{t=1}^{T}$.

5. Calculate the markup index along the transition path $t \in (0, T)$:

$$\hat{\Lambda}_t = \left(\sum_{i=1}^{n} m_{i,t} \Lambda_t(w_{i,t}; \{\Lambda_t\}_{t=0}^{\infty})^{1-\eta}\right)^{\frac{1}{1-\eta}}. \tag{E.12}$$

6. If $\max_{t\in[0,T]} |\Lambda_t - \hat{\Lambda}_t| \geq 10^{-3}$, set Λ_t to $0.5\Lambda_t + 0.5\hat{\Lambda}_t$ for $t \in (0, T)$. Repeat the algorithm from step 3.

E.2 Monopoly Industry

In this appendix section, we describe the recursive formulation for the single firm's problem in the monopoly industry. For clarity, below we first present the firm's original recursive problem in terms of cash holdings and customer base. Then we present the firm's normalized recursive problem in terms of cash ratios and customer base share.

Recursive Formulation for the Original Problem. The single firm i solves the following recursive problem:

$$V(W_{i,t}, M_{i,t}) = \max_{\Lambda_{i,t}, \Delta D_{i,t}} \Delta D_{i,t} - (\gamma M_{i,t} - \varphi \Delta D_{i,t}) \mathbb{1}_{\Delta D_{i,t}<0} + e^{-r\Delta t} \mathbb{E}_t \left[V(W_{i,t+\Delta t}, M_{i,t+\Delta t})\right],$$

subject to the evolution of the customer base

$$M_{i,t+\Delta t} = M_{i,t} + \beta \left(\frac{\Lambda_{i,t} R}{A} \right)^{-\epsilon} M_{i,t} \Delta t - \rho M_{i,t} \Delta t, \tag{E.13}$$

and the evolution of cash holdings

$$W_{i,t+\Delta t} = [1 + (r - \lambda)\Delta t] W_{i,t} + (\Lambda_{i,t} - 1) \frac{R}{A} \left(\frac{\Lambda_{i,t} R}{A} \right)^{-\epsilon} M_{i,t} \Delta t + \sigma M_{i,t} \Delta Z_{i,t} - \Delta D_{i,t}. \tag{E.14}$$

Recursive Formulation for the Normalized Problem. The value function $V(W_{i,t}, M_{i,t})$ is linear in $M_{i,t}$. Thus, we normalize the firm's cash holdings, value, and net payout by $M_{i,t}$. Let

$$w_{i,t} = W_{i,t} / M_{i,t}, \tag{E.15}$$

$$v(w_{i,t}) = V(W_{i,t}, M_{i,t}) / M_{i,t}, \tag{E.16}$$

$$\Delta d_{i,t} = \Delta D_{i,t} / M_{i,t}. \tag{E.17}$$

The single firm i solves the following normalized recursive problem:

$$v(w_{i,t}) = \max_{\Lambda_{i,t}, \Delta d_{i,t}} \Delta d_{i,t} - (\gamma - \varphi \Delta d_{i,t}) \mathbb{1}_{\Delta d_{i,t} < 0} + e^{-r\Delta t} \left[1 + \beta \left(\frac{\Lambda_{i,t} R}{A} \right)^{-\epsilon} \Delta t - \rho \Delta t \right] \mathbb{E}_t \left[v(w_{i,t+\Delta t}) \right], \tag{E.18}$$

subject to the evolution of the cash ratio

$$\begin{aligned} & \left[1 + \beta \left(\frac{\Lambda_{i,t} R}{A} \right)^{-\epsilon} \Delta t - \rho \Delta t \right] w_{i,t+\Delta t} \\ = & [1 + (r - \lambda)\Delta t] w_{i,t} + (\Lambda_{i,t} - 1) \frac{R}{A} \left(\frac{\Lambda_{i,t} R}{A} \right)^{-\epsilon} \Delta t + \sigma \Delta Z_{i,t} - \Delta d_{i,t}. \end{aligned} \tag{E.19}$$