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Oligopolistic Competition, Price Rigidity, and Monetary Policy

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Abstract

This study investigates how strategic and heterogeneous price setting influences the real effect of monetary policy. Japanese data show that firms with larger market shares exhibit more frequent and larger price changes than those with smaller market shares. We then construct an oligopolistic competition model with sticky prices and asymmetry in terms of competitiveness and price stickiness, which shows that a positive cross superelasticity of demand generates dynamic strategic complementarity, resulting in decreased price adjustments and an amplified real effect of monetary policy. Whether a highly competitive firm sets its price more sluggishly and strategically than a less competitive firm depends on the shape of the demand system, and the empirical results derived from the Japanese data support Hotelling's model rather than the constant elasticity of substitution preferences model. Dynamic strategic complementarity and asymmetry in price stickiness can substantially enhance the real effect of monetary policy.

JEL Classification Number: D43, E31, E52, L11

Keywords: strategic complementarity; price stickiness; real rigidity; competition

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1 Introduction

The COVID-19 pandemic has resulted in a resurgence of inflation, which some policymakers and scholars attribute to a surge in firms' markups.[1] The upward trajectory of market oligopoly and markups over the past few decades may have contributed to the inflationary upswing. In contrast, Japan's inflation has remained low relative to other countries, with firms frequently attributing this phenomenon to the presence of other firms with inflexible pricing policies. These findings underscore the importance of considering *strategic* price setting in an oligopolistic market, yet macroeconomic analyses in this area are limited due to the predominance of monopolistic competition in macroeconomic models, despite strategic complementarity in price setting being a major source of real rigidity (Romer 2001, Woodford 2003). Furthermore, while markups are increasing, their development is not uniform across firms, and heterogeneity, such as the emergence of superstar firms, cannot be ignored.

The main objective of this study is to analyze the influence of strategic price setting in heterogeneous oligopolistic markets on the effects of monetary policy. Our model departs from standard monopolistic competition models and incorporates the strategic pricing behavior of heterogeneous and oligopolistic firms. The model captures both the constant elasticity of substitution (CES) preferences model and Hotelling's (1929) address model in the demand system. Firms optimally determine their prices under Calvo-type price stickiness, taking into account the effect of their prices on competitors' prices in future periods.[2] Moreover, we extend Ueda's (2023) model by introducing heterogeneity in terms of firms' competitiveness and price stickiness.

This study analytically obtains an approximated closed-form solution for the steady-state price and policy function on pricing. We demonstrate that dynamic strategic complementarity arises when the cross superelasticity of demand is positive, which means that a firm's own demand elasticity increases in absolute size when its competitor sets a lower price. This dynamic strategic complementarity generates sluggishness in price

[1] See, for example, Brainard (2023), Arce, Hahn, and Koester (2023), Glover, Mustre-del-Rio and von Ende-Becker (2023), Weber and Wasner (2023). Critical perspectives on the subject are presented by Aoki, Hogen, and Takatomi (2023) and Reserve Bank of Australia (2023).

[2] Our model does not examine how the competitive environment affects the frequency of price changes, as we assume Calvo-type price stickiness. The industrial organization literature provides ample contributions in this regard, as discussed by Fershtman and Kamien (1987), Maskin and Tirole (1988), Tirole (1988), Slade (1999), Bhaskar (2002), and Chen, Korpeoglu, and Spear (2017).

adjustment and amplifies the real effect of monetary policy. The degree to which a highly competitive firm sets its price more sluggishly and strategically than a less competitive firm depends on the shape of the demand system. Specifically, as a firm becomes more competitive, the cross superelasticity increases in the CES preferences model, while it decreases in Hotelling's address model. This implies that the pricing of a large firm is more sluggish than that of a small firm in the former model, while it is relatively less sluggish in the latter model. Our empirical results for Japan are thus consistent with the predictions of Hotelling's model. We also show that the choice between CES preferences and Hotelling's models has no impact on the analysis when firms are symmetric and shocks are small, but it matters when firms are asymmetric. Thus, our results indicate that assuming CES preferences, as is common in macroeconomic models, may lead to incorrect policy implications in the presence of firm heterogeneity, such as the effect of monetary policy and optimal policy design.

Further, we find that the real effect of monetary policy is significantly amplified because of the increase in real rigidity caused by strategic pricing as well as asymmetric price rigidity. While asymmetric competitiveness has a negligible impact on the overall effect of monetary policy, asymmetric price rigidity raises real rigidity through strategic complementarity. A firm with low nominal price rigidity has to pay closer attention to its competitor with high nominal price rigidity, which raises real rigidity at the macro level and amplifies the impact of monetary policy on the real economy.

The secondary objective of this study is to conduct empirical research on firms' pricing behavior in heterogeneous oligopolistic markets, which constitutes the motivation of our theoretical model. Specifically, we present empirical evidence of heterogeneous complementarity in price setting using data taken from a survey of firms, news on price revisions, and scanner data from supermarkets. The empirical analysis reveals that firms (and products) with larger market shares exhibit earlier, more frequent and larger price changes than those with smaller market shares.

Theoretically, the most relevant studies are Atkeson and Burstein (2008), Wang and Werning (2022), and Ueda (2023). Atkeson and Burstein (2008) incorporate firm asymmetry into a static Cournot-type quantity competition model and find a result that is opposite to our empirical findings but not necessarily inconsistent with our model, namely, that a firm with low market share passes through costs more than a firm with high market share. Similarly, Wang and Werning (2022) as well as Faia (2012) and Mongey (2017) all construct models to investigate monetary policy under oligopolistic competition and sticky prices. This study contributes to this stream of the literature by deriving a simple closed-form solution for dynamic strategic complementarity, albeit an approximation. Our study also investigates how structural parameters such as demand elasticity and price stickiness shape dynamic strategic complementarity. In particular, we assess how firm asymmetry affects dynamic strategic complementarity. Although Wang and Werning (2022) also consider firm heterogeneity, their model does not focus on whether a large firm has greater dynamic strategic complementarity than a small firm. Rather, they calibrate the model to match the empirical results reported by Amiti, Itskhoki, and Konings (2019). Additionally, our model features a stochastic monetary policy shock, while Wang and Werning (2022) assume a one-time shock.

Further, this study contributes to the body of previous research on the source of real rigidity. Since the effects of monetary policy on the real economy are too small to be explained when a model is calibrated based on the size of menu costs and frequency of price revisions observed in micro data, real rigidity is called for (Ball and Romer 1990, Romer 2001, Woodford 2003). Leading hypotheses include real wage rigidity (Blanchard and Gali 2007), round-about production structure (Basu 1995), and nonconstant elasticity of substitution (e.g., kinked demand, as in Kimball 1995). Strategic complementarity in price setting has received limited attention in this context despite Woodford (2003) highlighting its significance and Cooper and John (1988) pioneering its incorporation into macroeconomic studies. We extend their work by introducing nominal rigidity to explore the relation between dynamic strategic complementarity and the real effect of monetary policy.

Empirically, our study is related to studies that have provided evidence of strategic complementarities in price setting across a broad range of product categories. Berman, Martin, and Mayer (2012) and Amiti, Itskhoki, and Konings (2019) demonstrate that the pass-through for large firms is lower than that for small firms. This implies that strategic price setting is more likely to be observed for large firms and that small firms are likely to adhere to constant markup pricing in a competitive market. This finding is in stark contrast to our results.[3]By contrast, the empirical studies by Dias, Dias, and Neves

[3]This difference can be attributed to differences in data. While Berman, Martin, and Mayer (2012) and Amiti, Itskhoki, and Konings (2019) use firm/product-level data on French exporters and Belgian manufacturers, respectively, we use mainly product-level data on retailers in Japan. Although their data are highly disaggregated, the product price measured in their study still aggregates product and time. Further, the degree of product classification is coarser (the number of products is around 1,500 in

(2004), Fabiani et al. (2006), and Jonker, Folkertsma, and Blijenberg (2004) find similar results to ours, providing evidence that retail prices in large outlets such as supermarkets and department stores tend to be more flexible than those in smaller retail outlets in Europe. Goldberg and Hellerstein (2011) similarly find that large firms in the United States change prices more frequently and by smaller sizes than small firms, although this pattern is only observed across industries, suggesting that sectoral differences in characteristics other than firm size may explain the heterogeneity in price stickiness.

Evidence of strategic pricing is provided by micro survey and narrative data (e.g., Blinder et al. 1998, Bank of Japan 2000). For instance, Fabiani et al. (2006) find that Eurozone firms facing high competitive pressure review prices more frequently than those firms under less pressure and that 30% of their prices are shaped by competitors' prices. Koga, Yoshino, and Sakata (2020) use the Bank of Japan's Tankan survey to demonstrate that firms with higher market shares are less sensitive to average price changes in the previous quarter in their category in Japan than firms with lower market shares. Pitschner (2020) analyzes narrative data from archived corporate filings and concludes that the pricing of competing firms is an important factor in the pricing decisions of the focal firm. Nonetheless, these studies fail to define the competitive environment accurately or quantify prices.

Empirical research on pricing behavior in oligopolistic markets has focused more extensively on the link between competitive conditions and firms' pricing strategies than on the relationship between a firm's position within a sector (e.g., market share and employment size) and its pricing behavior. For example, Bils and Klenow (2004) use micro price data to estimate the relationship between the frequency of price revisions and the concentration ratio of the top four manufacturers in each category, finding a tendency for the frequency of price revisions to decrease as the degree of oligopoly increases. However, when controlling for whether the goods are raw products, no significant relationship is observed. Gopinath and Itskhoki (2010) examine whether the pass-through of the price of imported goods is affected by the sectoral Herfindahl–Hirschman Index (HHI), concluding that the coefficient is not significant and the results are inconclusive.[4] Mongey

Amiti, Itskhoki, and Konings 2019), meaning that a product price may encapsulate the prices of multiple products. By contrast, in our study, each product brand is assigned a unique code. Furthermore, the data used in their studies are annual, which means that any price changes within a year remain undetected, whereas our data are daily. Finally, the output prices in their data reflect the shipping prices of the exporters or manufacturers, whereas ours represent retail prices.

[4]Gopinath and Itskhoki (2010) conduct a survey and argue that the variable markup channel of real

(2017) finds, using IRI microdata, that the relationship between the frequency of price changes and market concentration is not monotonic. Initially, the former decreases as the latter increases; however, when the market concentration is very high, the frequency of price changes increases with increased market concentration. These inconclusive results are consistent with our finding that the HHI is not robustly linked to firms' pricing behavior.[5] Previous studies have focused on the impact of sectoral oligopoly on sectoral price rigidity, but have overlooked the influence of a firm's position (e.g., market share and employment size) within a sector on its pricing behavior. This study seeks to bridge this gap in the body of knowledge by examining the heterogeneous relationships between each firm's market share and pricing behavior within a product category.

The remainder of this paper is structured as follows. Section 2 presents our estimation results, Section 3 examines our model and simulation results, and Section 4 concludes.

2 Motivating Facts

In this section, we present empirical observations for Japan as a preliminary foundation before formulating an oligopolistic competition model that incorporates both price stickiness and firm asymmetry. First, news on price revisions provides evidence of asymmetry among firms, revealing that larger firms tend to announce their price adjustments earlier than smaller firms. Second, a survey of firms' pricing indicates a strategic approach to price setting. Firms consider their competitors' pricing, which hinders price increases even in the face of rising costs. Third, POS scanner data on retailers show that firms and products with larger market shares exhibit more frequent and larger price changes than those with smaller market shares.

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rigidities is an important feature of the wholesale cost data but not of the retail price data. Our results show that retailer prices differ depending on the competitive environment, which is consistent with the variable markup channel.

[5]By contrast, Vermuelen et al. (2012) argue that a higher degree of competition increases the frequency of price changes by using micro producer price data in the Euro area. Although inflation persistence is not necessarily linked to price stickiness, Kato, Okuda, and Tsuruga (2021) show that the persistence of sectoral inflation decreases as market concentration increases by using US producer prices. See also Alvarez et al. (2006) and Klenow and Malin (2010) for discussions on the determinants of the frequency of price changes. The relationship between the market structure and price flexibility has long been studied, including the seminal works by Berle and Means (1932), Stigler and Kindahl (1970), Domberger (1979), Carlton (1986), and Slade (1991).

2.1 News on Price Revisions

The first dataset used in this study is news on price revisions. We conduct a manual search using Japan's major financial newspaper, Nihon Keizai Shinbun, and food manufacturers' investor relations (IR) materials from 2005 to 2021 to identify their announcements on price revisions. Table 2 presents the dates of the price revisions as well as their announcements. The table only includes instances of price increases, as we found that firms rarely announce price decreases. In fact, we identified only one case of a price decrease announcement, made by a mayonnaise manufacturer in 2009.

The table illustrates that announcements of price revisions typically occur around a quarter before the actual price revisions take place. Furthermore, firms with high market shares tend to make their announcements earlier than firms with low market shares. For example, in fall 2007, the announcement of price increases for instant noodles was first made by the market leader, Nisshin Foods (market share 49%), on September 6, 2007. Price increase announcements followed on September 25, October 3, October 11, and October 19 by the market followers Myojo Foods (7%), Toyo Suisan (18%), Acecook (8%), and Maruka Foods (1%), respectively.

Table 2 also shows that the dates of actual price revisions are often synchronized. In the aforementioned example of price increases for instant noodles in fall 2007, all five manufacturers announced that they would revise their prices on January 1, 2008. Despite the tendency for firms with lower market shares to announce price revisions later than the market leader, the timing of these actual price revisions aligns with that of the market leader.

The anecdote shows that market leaders are often the first to negotiate price increases with retailers. In price negotiations, it is common and feasible for retailers to refuse price increases, because retailers can reduce shelves in their supermarkets for the sale of manufacturer's goods for which the price increase is requested. After reaching an agreement on price increases, the manufacturer announces the price increase. Smaller manufacturers then follow suit by negotiating similar price increases with retailers, which explains the time lag of a couple of weeks between the announcements by market leaders and those by followers.[6]

[6]This evidence highlights the importance of considering the bargaining dynamics between retailers and manufacturers, even though the model that follows does not specifically address this aspect. Further, our model does not distinguish between the timing of actual price revisions and that of price revision announcements.

2.2 Survey of Consumer Goods Manufacturers

The second dataset is compiled from a survey of firms' pricing conducted by the University of Tokyo and Intage Inc., a market research company in Japan. The survey focused on firms' product pricing strategies such as their expectations of price changes, actual price changes in response to yen depreciation, and reasons for keeping prices unchanged. It targeted consumer goods (food, beverages, daily necessities) manufacturers that are customers of Intage and have market shares in their respective product categories within the top 15 rankings. At the beginning of the survey, the University of Tokyo and Intage specified a product category and asked the respondents to indicate their firms' brand with the highest sales value in that category (question 1). Subsequently, when asking about individual price changes, the survey clarified that the price in this case was for the brand provided in their answer to question 1. The survey was mailed in February 2020 and the participants were asked to return it by the end of March 2020. An employee in the corporate planning or product planning department was asked to respond. The survey collected responses from 176 firms in total. The mean number of employees in those firms was 1,057 and their mean market share was 23%. Online Appendix A provides the summarized English translation of the survey and actual questionnaires sent in Japanese as well as the basic statistics of the sample firms.

In the survey, we examine why firms do not raise their prices. When asking firms about their expectation of changes in the shipping prices of their products in five years' time (question 11), 139 of the 176 firms expected price increases of less than 1% annually. We asked these firms the following question: "Why do you expect that shipping prices will increase little compared with the current level or will decrease?" (question 12). Table 1 shows that the low price expectations are not because their production costs did not increase. Competitors' sluggishness in raising prices (row (3) in the table) is one of the main reasons why firms expect small price increases. Of the 110 firms, 63% answered that they expected competitors to keep their prices unchanged (24%and 39% answered "highly applicable" and "applicable," respectively). Two other reasons are important as well, namely, opposition from retailers and a decrease in the sales volume (which can arise from competitors). In Online Appendix A, we also examine another question regarding actual price setting when firms were faced with the one of the largest cost-push shocks, that is, the significant weakening of the Japanese yen from 77 yen to the dollar in 2012 to 125 yen to the dollar in 2015 (question 21). We confirm that competitors are behind the sluggishness of price increases during this period. Further, we find that the number of price changes and total size of price changes tend to increase as their market share rises.

2.3 Scanner Data from Retailers

The third dataset comprises POS scanner data on retailers collected by Nikkei Inc, enabling us to examine the actual prices set by firms, rather than relying on price change news or surveys. News on price revisions suggests that synchronized price changes occur in practice. To explore the presence of any asymmetry in price setting between firms with large market shares and those with small market shares, we leverage the POS scanner data.

These data include the number of units sold and the sales amount (price times the number of units sold) for each product and store on a daily basis. The observation period run from March 1, 1988 to December 31, 2019. The recorded products consist of processed food and daily necessities classified into 218 product categories such as instant cup noodles, tofu, and shampoo. Each product and manufacturer (firm) are identified by the Japanese Article Number (JAN) code and code provided by GS1 Japan. See Online Appendix B for the identification of the products and firms. See also Sudo, Ueda, and Watanabe (2014) and Sudo et al. (2018) for a detailed description of the data.

For each product, store, and month, we calculate the regular price, which is defined as the mode of daily prices in the month (Kehoe and Midrigan 2015, Sudo et al. 2018). We do so only when prices are observable for 14 days or more in the month. We record the frequency of regular price changes when the regular price changes by more than two yen from the previous date. Then, at the firm level, we calculate the sales share of the product category, the frequency of regular price changes, and regular price changes for each firm and year (or month). Furthermore, we calculate the HHI for each product category and year, which is defined as the sum of the squared sales share. The market share and HHI are calculated at either the product or the firm level. See Online Appendix B for more details.

2.3.1 Relationship between the Frequency of Regular Price Changes and Competitive Environment

In this subsection, we investigate the relationship between firms' market competitiveness and price setting behaviors, specifically the frequency of regular price changes. We conduct a regression analysis to examine how the frequency of regular price increases/decreases for each product/firm i is related to its market share as

$$fr_{icy}^{X} = \alpha \log s_{icy} + \gamma HHI_{cy} + d_k + d_c + d_y + \varepsilon_{icy}, \tag{1}$$

where fr_{icy}^{X} and s_{icy} represent the frequency of regular price changes (X represents the direction of the change $\{+, -\}$) and the sales share of product/firm i in product category c in year y, respectively. We include the firm, category, and period fixed effects by adding three dummy variables, namely, d_k, d_c, and d_y, where the time subscript y takes an integer from 1 to 31 (each representing the year $1988 + y$). In the firm-level regression, i equals k. Including both the firm and the category fixed effects in the product-level regression is possible because many firms sell products in more than one product category. Both s_{icy} and HHI_{cy} capture market competitiveness, but they serve different purposes: the former is product/firm specific and captures the market position, while the latter captures the competitive environment for the category to which a firm belongs. In a near-monopoly environment, both s and HHI are high (close to one) if the product/firm is monopolistic. However, in this environment, s is almost zero for products/firms except for monopolistic ones.

Table 3 presents the estimation results. The coefficient of market share, α, is positive and significant. This suggests that as the market share of a product or firm increases, the frequency of regular price changes also increases. The coefficient 0.01 indicates that when market share increases by 0.1 (i.e., 10%), the frequency of regular price changes increases by 0.001 at a monthly frequency, which translates into an approximate increase of 1.2% at an annual frequency. Online Appendix B presents the results of running a regression for each product category, confirming that the frequency of regular price changes tends to increase, as market share is high for the majority of product categories.

The positive coefficient of α in the firm-level regression is consistent with the results of the menu cost model presented by Midrigan (2011), who posits that multi-product firms face economies of scope, as they are more likely to produce a greater number of products; therefore, their frequency of price changes increases. However, the positive coefficient of α in the product-level regression cannot be explained by this model.

The coefficient of the HHI, γ, tends to be negative in the firm-level regression, while it is positive and significant in the product-level regression. The negative γ at the firm level suggests that the frequency of regular price changes increases as the market becomes less concentrated (more perfectly competitive) at the firm level. Conversely, the positive γ at the product level suggests that the frequency of regular price changes increases as the market becomes more concentrated at the product level.

These mixed and inconclusive results of the relationship between the HHI and pricing are in line with those of previous empirical studies. For example, Gopinath and Itskhoki (2010) investigate the effect of the sectoral HHI on the pass-through of imported goods prices and find that the coefficient is not statistically significant and inconclusive. Mongey (2017) finds that the relation between the frequency of price changes and market concentration is not monotonic. The frequency decreases as market concentration increases, but when market concentration is very high, the frequency increases again. These findings highlight the complexity of the relationship between market concentration and pricing behavior and the need for further research in this area.

2.3.2 Price Responses to Aggregate Shocks

In our previous analysis, we demonstrated the higher frequency of price changes among large firms. However, this finding does not necessarily imply a disparity in pricing reaction functions to costs between large and small firms because this could be attributed to idiosyncratic factors such as greater volatility in costs for large firms than their smaller counterparts. In this subsection, we examine the responsiveness of firms' output prices to aggregate shocks, specifically at the product category level, and explore the dependence of these pricing responses on market share.

We undertake the following two steps to analyze the data. In the first step, we identify instances of considerable price changes within each product category. Specifically, we compute the month-to-month Tornqvist regular price change π_{icm} for each firm $i \in \Omega_c$ belonging to product category c in month m relative to previous month $m-1$ (see Online Appendix B for the detailed calculations). To identify considerable aggregate shocks, we compute category-level aggregated price change π_{cm} and designate events where π_{cm} exceeds a predetermined threshold (θ) in either a positive or a negative direction. The selection of θ is arbitrary. In the second step, we employ the following regression for cases in which π_{cm} exceeds the threshold (θ) in the respective direction:

$$\pi_{icm}^{annual} = \alpha \log s_{icm} + \gamma HHI_{cy} + d_i + d_c + d_m + \varepsilon_{icm}, \tag{2}$$

where y is the year of month m, s_{icm} represents the average market share of firm i in category c in the years of $y-1$ and y, and HHI_{cy} is the HHI of firm sales in year y. We control for the firm, category, and period fixed effects.

The underlying rationale for this estimation stems from the notion that considerable changes in π_{cm} are indicative of substantial aggregate or product category-level shocks. Our investigation focuses on whether large firms exhibit stronger price adjustments than small firms during such events, as evidenced by a positive parameter (α) when θ is positive (e.g., positive cost-push shock). In the event of symmetric price responses between positive and negative shocks, the magnitude of α remains consistent, while the sign of α reverses when θ changes to $-\theta$ (e.g., negative cost-push shock). It is important to note that a positive α for a positive θ can arise due to an idiosyncratic shock, rather than an aggregate shock, if the market share of a single firm is sufficiently large to impact category-level price changes, even if the idiosyncratic shock only affects the large firm. However, it is not evident that a positive α would result for a positive θ, as a large number of small firms could exhibit more aggressive price adjustments to an aggregate shock than their larger counterparts, leading to a negative α. To ensure the robustness of our results, we conduct sensitivity tests using higher values of $|\theta|$, which reduces the influence of granular firms on category-level price changes, albeit at the cost of reducing the number of observations. Furthermore, it is worth mentioning that the Japanese economy has witnessed significant aggregate shocks coinciding with fluctuations in international commodity prices and exchange rates on numerous occasions such as during the global financial crisis in 2008 and the period of Abenomics starting from 2012.[7]

Table 4 presents the estimation results. Coefficient α corresponding to market share exhibits a statistically significant positive relationship when θ is positive at the 5% level; the only exception is the coefficient for the highest value of $\theta = 0.08$ is significant only at

[7] The identified events may be a result of both demand and supply (cost-push) factors. The period from 2007 to 2019 includes the fluctuations in global commodity prices around 2007, the Great East Japan Earthquake in 2011, and the depreciation of the yen under Abenomics from 2012, which can be interpreted as supply shocks. However, aggregate demand shocks and idiosyncratic shocks are also likely to have occurred during this period and pricing decisions may thus differ depending on the source of these shocks.

the 10% level. This positive coefficient suggests that large firms exhibit more pronounced price increases in response to positive aggregate shocks than small firms. Similarly, when negative aggregate shocks occur (i.e., θ is negative), coefficient α tends to be significantly negative. This implies that large firms tend to implement more substantial price decreases than small firms in response to negative aggregate shocks. The estimation results also show that when θ is set to 0.08, coefficient γ is significantly positive, which suggests that greater market concentration is associated with larger price increases during positive aggregate shocks.[8]

3 Theoretical Investigations

The empirical analysis in the previous section suggested that a highly competitive firm tends to change its price more aggressively and frequently, while a less competitive firm changes its price sluggishly.

In this section, we consider the implications of this result on monetary policy. To this end, we construct a model incorporating the strategic pricing behaviors of oligopolistic firms. The model extends that presented by Ueda (2023), who considers price setting by symmetric oligopolistic firms under Calvo-type nominal rigidity, by incorporating firm heterogeneity. Specifically, three types of asymmetry exist: preference (taste b or firm location δ), Calvo-type price stickiness θ, and productivity ϕ. Using the model, we characterize the strategic pricing behavior of asymmetric firms and investigate how this feature changes the nominal and real effects of monetary policy.

3.1 Model Setup

A representative household maximizes the preference given by $U = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log C_t - (L_t + \tau D_t)\right],$ where aggregate consumption C_t equals $\log C = \int_0^1 \log c^j dj$, L_t represents labor supply, and shopping distance D_t is given by $D = \int_0^1 d^j dj$. Here, c^j represents consumption for product line $j \in [0,1]$, parameter $\beta \in (0,1)$ is the subjective discount factor, and

[8] Even in situations in which price changes are driven by aggregate shocks, it is possible that input price (cost) changes differ across firms, given their different cost structures or degrees of bargaining power. However, this potential heterogeneity in input price changes is unlikely to undermine the robustness of our estimation results because large firms possess greater bargaining power in procurement. The Bank of Japan's Tankan survey shows that input prices tend to increase less for large firms than for small firms, as shown in Online Appendix C.

parameter $\tau > 0$ represents the transport cost incurred per unit of distance. Except for Hotelling's address model, one may assume $\tau = 0$ and abstract away D_t.

The budget constraint is $M_t + B_t + P_t C_t \leq M_{t-1} + R_{t-1} B_{t-1} + W_t L_t + \Pi_t + T_t$, where M_t, B_t, P_t, R_t, W_t, Π_t, and T_t represent the money supply, nominal bonds, the aggregate price, the nominal interest rate, nominal wages, dividends from firms, and lump-sum transfers, respectively. We assume that nominal spending must equal the money supply: $P_t C_t = M_t$. The first-order condition yields $W_t = M_t = P_t C_t$.

In each product line $j \in [0, 1]$, there exist n firms denoted by i. When $n = 2$, we denote them as A or B ($i = A, B$). The quantity demanded for firm i's goods in period t, x_t^i, is described by an arbitrary invertible demand system $x_t^i = x^i(p_t^i, p_t^{-i}; M_t) = x^i(p_t^i/M_t, p_t^{-i}/M_t)$, where p_t^i and p_t^{-i} represent the prices set by firm i and its competitors, respectively. Demand invertibility is a mild technical requirement, encompassing the demand system characterized by CES preferences, quasi kinked demand (Kimball 1995), and Hotelling's address model. To produce one unit of a product, firm i requires $1/\phi^i$ unit of labor, which costs W_t, where $\phi^i > 0$ represents firm-specific time-invariant productivity.

The goods market clears as $Y_t (= L_t) = C_t$. Money supply growth is exogenous and given by $\log(M_t/M_{t-1}) = \varepsilon_t = \rho \varepsilon_{t-1} + \mu_t$, where μ_t is an i.i.d. shock to money supply growth. This is the only aggregate uncertainty in the economy. Idiosyncratic uncertainty arises only from Calvo-type price stickiness regarding whether a firm can reset its price. The money supply has a zero growth trend.

We define five types of demand elasticities as follows: own elasticity $\Psi^i \equiv \frac{\partial \log x^i(p^i/M, p^{-i}/M)}{\partial \log(p^i/M)}$, cross elasticity $\Psi^{-i} \equiv \frac{\partial \log x^i(p^i/M, p^{-i}/M)}{\partial \log(p^{-i}/M)}$, and three types of superelasticity (elasticity of elasticity) $\Psi^{i,i} \equiv \frac{\partial \Psi^i}{\partial \log(p^i/M)}$, $\Psi^{-i,-i} \equiv \frac{\partial \Psi^{-i}}{\partial \log(p^{-i}/M)}$, and $\Psi^{i,-i} \equiv \frac{\partial \Psi^{-i}}{\partial \log(p^i/M)} = \frac{\partial \Psi^i}{\partial \log(p^{-i}/M)}$. We name $\Psi^{i,i}$ and $\Psi^{i,-i}$ own superelasticity and cross superelasticity, respectively. Negative own superelasticity suggests that own demand becomes more (less) elastic as own price increases (decreases), while a positive cross superelasticity suggests that own demand becomes more (less) elastic as competitors' prices decrease (increase). The demand elasticities for firm $-i$, which is the competitor of firm i, are defined using an asterisk, such as $\Psi^{-i*} \equiv \frac{\partial \log x^{-i*}(\bar{p}^{-i}/M, p^i/M)}{\partial \log(\bar{p}^{-i}/M)}$.

3.2 Two Special Cases

We discuss the main results in the subsequent discussion and present the detailed derivations in Online Appendix D. Let us first consider two special cases.

CES Oligopolistic Competition We assume $\tau = 0$. In the case of CES preferences, for each product line $j \in [0,1]$, consumption is aggregated following the CES form of aggregation: $c_t^j = \left\{ \sum_{i=1}^n \left(b^i/n\right)^{1/\sigma} \left(x_t^i\right)^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}}$, where $\sum_{i=1}^n \frac{b^i}{n} = 1$. Parameter b^i captures consumers' taste for the good produced by firm i. A high b^i implies the high competitiveness of firm i.

We obtain

$$\Psi^i = -\sigma + \frac{b^i}{n}(\sigma-1)(p^i/P)^{1-\sigma} < 0,$$

$$\Psi^{-i} = \frac{b^{-i}}{n}(\sigma-1)(p^{-i}/P)^{1-\sigma} > 0,$$

$$\Psi^{i,i} = -\left\{1 - \frac{b^i}{n}(p^i/P)^{1-\sigma}\right\}\left\{\frac{b^i}{n}(1-\sigma)^2(p^i/P)^{1-\sigma}\right\} < 0,$$

$$\Psi^{-i,-i} = \frac{b^{-i}}{n}(1-\sigma)^2(p^{-i}/P)^{1-\sigma}\left\{\frac{b^{-i}}{n}(p^{-i}/P)^{1-\sigma} - 1\right\} > 0,$$

$$\Psi^{i,-i} = \left(\frac{1-\sigma}{n}\right)^2 b^i b^{-i}(p^i/P)^{1-\sigma}(p^{-i}/P)^{1-\sigma} > 0.$$

Three remarks are in order. First, when the number of firms is infinite ($n \to \infty$), the demand elasticities become $\Psi^i = -\sigma$ and $\Psi^{-i} = \Psi^{i,i} = \Psi^{-i,-i} = \Psi^{i,-i} = 0$. Thus, no strategic consideration needs to be taken into account. Own elasticity is constant and independent of b^i. Second, an increase in b^i decreases the absolute value of own elasticity $|\Psi^i|$ (less price elastic), increases the cross elasticity Ψ^{-i}, and increases the cross superelasticity $\Psi^{i,-i}$ for firm i. Third, a decrease in p^i relative to P (e.g., due to an increase in firm i's relative productivity) decreases the absolute value of own elasticity $|\Psi^i|$, decreases the cross elasticity Ψ^{-i}, and increases the cross superelasticity $\Psi^{i,-i}$ for firm i when $\sigma > 1$.

The left-hand panel of Figure 1 graphically illustrates the relationships between the absolute value of own demand elasticity $|\Psi^A|$ and competitors' prices p^B based on the CES model. When the number of firms is infinite, the cross superelasticity is zero ($\Psi^{AB} = 0$) and own elasticity is independent of competitors' prices (expressed as the horizontal dashed line in the figure). When the number of firms is finite, we have $\Psi^{AB} > 0$, which suggests that $|\Psi^A|$ decreases with p^B; that is, demand becomes more elastic as the competitor decreases its price. Further, suppose that firm A is more competitive than firm B, which is captured by an increase in b. Then, Ψ^{AB} increases in the CES model; that is, as the red line in the figure demonstrates, the slope of $|\Psi^A|$ increases. In other words, demand becomes even more elastic when the competitor decreases its price or demand elasticity becomes more sensitive to competitors' prices, as a firm becomes more competitive.

Atkeson and Burstein (2008) consider nested CES preferences in which the elasticity of substitution is lower across sectors than within a sector. This implies that a firm with high market share (high b^i) is less price elastic than a firm with low market share (low b^i). Further, the cross superelasticity increases as b^i increases. These responses to b^i are similar to those based on the above non-nested CES preferences.

Hotelling's Address Model and Duopolistic Competition A household comprises an infinite number of consumers who are uniformly located in the interval [0, 1]. In each product line $j \in [0, 1]$, there exist two firms, A and B. These are situated on the horizontal line at [0, δ], respectively, where $\delta \in [1, \infty)$. The firms are symmetric (i.e., equally competitive) if δ equals one, while firm A becomes more competitive than firm B as δ increases.

Hotelling's address model is based on regional location differences, but the interpretation goes beyond that. In particular, the assumption of location where δ exceeds one cannot occur if the location can be chosen. Differences in location represent differences in the attractiveness of products (the degree to which they appeal to different consumers), and a high δ implies that the attractiveness of the product is weaker.

A consumer located at $x \in [0, 1]$ is at a distance x from firm A and $\delta - x$ from firm B. The consumer's net surplus is written as $u^i = \log c^i - \tau d^i = \log M - \log p^i - \tau d^i$, where d^i represents the distance the consumer travels to firm i. Although we call τ the transport cost hereafter, this parameter also represents consumers' choosiness, that is, how much they dislike buying from their less preferred firms.

In this setup, demand is given by $x_t^A = \left(\frac{\delta}{2} - \frac{\log(p_t^A/M_t) - \log(p_t^B/M_t)}{2\tau}\right)\frac{M_t}{p_t^A}$ and $x_t^B = \left(\frac{2-\delta}{2} - \frac{\log(p_t^B/M_t) - \log(p_t^A/M_t)}{2\tau}\right)\frac{M_t}{p_t^B}$. Thus, we obtain $\log x_t^A = \log\left(\frac{\delta}{2} - \frac{\log(p_t^A/M_t) - \log(p_t^B/M_t)}{2\tau}\right) -$

$\log(p_t^A/M_t)$ and

$$\Psi^A = -\frac{1}{\tau}\left(\delta - \frac{\log(p^A) - \log(p^B)}{\tau}\right)^{-1} - 1 < 0,$$

$$\Psi^B = \frac{1}{\tau}\left(\delta - \frac{\log(p^A) - \log(p^B)}{\tau}\right)^{-1} > 0,$$

$$\Psi^{AA} = -\frac{1}{\tau^2}\left(\delta - \frac{\log(p^A) - \log(p^B)}{\tau}\right)^{-2} < 0,$$

$$\Psi^{BB} = -\frac{1}{\tau^2}\left(\delta - \frac{\log(p^A) - \log(p^B)}{\tau}\right)^{-2} < 0,$$

$$\Psi^{AB} = \Psi^{BA} = \frac{1}{\tau^2}\left(\delta - \frac{\log(p^A) - \log(p^B)}{\tau}\right)^{-2} > 0.$$

Three remarks are in order. First, when the two firms are symmetric, the demand elasticities in Hotelling's address model with $\delta = 1$ resemble those in the CES model with $n = 2$ and $b = 1$. Specifically, when $\sigma - 1 = 2/\tau$, all the Ψ values are the same. This identicalness is consistent with that argued by Anderson, de Palma, and Thisse (1992). Second, an increase in δ decreases the absolute value of own elasticity $|\Psi^A|$ (less price elastic), the cross elasticity Ψ^B, and the cross superelasticity Ψ^{AB} for firm A. This response is different from that in the CES model except for own elasticity. Third, a decrease in p^A relative to p^B (e.g., due to an increase in firm A's relative productivity) decreases the absolute value of own elasticity $|\Psi^A|$, the cross elasticity Ψ^B, and the cross superelasticity Ψ^{AB} for firm A. The response of the cross superelasticity is different.

The right-hand panel of Figure 1 graphically illustrates the relationships between the absolute value of own demand elasticity $|\Psi^A|$ and the competitor's price p^B based on Hotelling's model. As in the CES model with finite n, we have $\Psi^{AB} > 0$, which suggests that $|\Psi^A|$ decreases with p^B; that is, demand becomes more elastic as the competitor decreases its price. Further, suppose that firm A is more competitive than firm B, which is captured by an increase in δ. Then, Ψ^{AB} decreases in Hotelling's model, rather than increases as in the CES model. That is, as the red line in the figure demonstrates, the slope of $|\Psi^A|$ decreases. In other words, the demand elasticity becomes less sensitive to the competitor's price as a firm becomes more competitive. This sensitivity change is the opposite to that in the CES model.

3.3 Steady State without Price Stickiness

Before we introduce price stickiness, we consider the steady-state equilibrium. The first-order condition with respect to p_t^i yields

$$\begin{aligned}\frac{\partial \Pi_t^i}{\partial p_t^i} &= \frac{\partial}{\partial p_t^i}\left((p_t^i - W_t/\phi^i)x^i(p_t^i/M_t, p_t^{-i}/M_t)\right)\\ &= x^i(p_t^i/M_t, p_t^{-i}/M_t) + \frac{p_t^i - W_t/\phi^i}{M_t}\frac{\partial x^i}{\partial p_t^i} = 0.\end{aligned}$$

In the steady state with $W = M = 1$, it becomes

$$p^i = \frac{\Psi^i}{\Psi^i + 1}\frac{1}{\phi^i}, \tag{3}$$

which is the same as that under monopolistic competition, although Ψ^i is different. However, the steady-state price changes when we consider price stickiness.

3.4 Pricing under Price Stickiness

We assume Calvo-type price stickiness and the case of $n = 2$ consisting of firms A and B in each product line. Firm i ($i = A, B$) can reset its price with a probability of $1 - \theta_i$, while firm $-i$ can do so with a probability of $1 - \theta_{-i}$. We limit our analysis by assuming that the Markov perfect equilibrium concept applies. Each firm's action (i.e., price setting decision) depends on a state consisting only of the following three variables: its price in the previous period, the competitor's price in the previous period, and a shock to money supply growth. We exclude collusive pricing, although the folk theorem suggests that dynamic setting can generate multiple collusive equilibria.

When firm i has a chance to set its price at t, it sets $\bar{p}_t^i$ to maximize

$$\begin{aligned}\max \sum_{k=0}^{\infty} \theta_i^k \beta^k \mathbb{E}_t &\left[\left(\bar{p}_t^i - W_{t+k}/\phi^i\right)\theta_{-i}^{k+1} x^i(\bar{p}_t^i/M_{t+k}, p_{t-1}^{-i}/M_{t+k})\right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t}\frac{P_t}{P_{t+k}}\\ + \sum_{k=0}^{\infty} \theta_i^k \beta^k \mathbb{E}_t &\left[\left(\bar{p}_t^i - W_{t+k}/\phi^i\right)\sum_{k'=0}^{k}(1-\theta_{-i})\theta_{-i}^{k-k'} x^i(\bar{p}_t^i/M_{t+k}, p_{t+k'}^{-i}/M_{t+k})\right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t}\frac{P_t}{P_{t+k}},\end{aligned} \tag{4}$$

where Λ_t represents the stochastic discount factor given by C_t^{-1}. Solving this optimization problem is more complex than solving a similar problem in a standard New Keynesian model because we have to explicitly consider the path of the prices set by the competitor.

The first-order condition for the optimal $\bar{p}_t^i$ is given by

$$
\begin{aligned}
0 =& \sum_{k=0}^{\infty} \theta_i^k \beta^k \mathbb{E}_t \left[\theta_{-i}^{k+1} x^i(\bar{p}_t^i/M_{t+k}, p_{t-1}^{-i}/M_{t+k})\right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \\
&+ \sum_{k=0}^{\infty} \theta_i^k \beta^k \mathbb{E}_t \left[\sum_{k'=0}^{k} (1-\theta)\theta_{-i}^{k-k'} x^i(\bar{p}_t^i/M_{t+k}, p_{t+k'}^{-i}/M_{t+k})\right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \\
&+ \sum_{k=0}^{\infty} \theta_i^k \beta^k \mathbb{E}_t \left(\bar{p}_t^i - M_{t+k}/\phi^i\right) \left[\theta_{-i}^{k+1} \frac{\partial x^i(\bar{p}_t^i/M_{t+k}, p_{t-1}^{-i}/M_{t+k})}{\partial \bar{p}_t^i}\right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \\
&+ \sum_{k=0}^{\infty} \theta_i^k \beta^k \mathbb{E}_t \left(\bar{p}_t^i - M_{t+k}/\phi^i\right) \left[\sum_{k'=0}^{k} (1-\theta_{-i})\theta_{-i}^{k-k'} \frac{\partial x^i(\bar{p}_t^i/M_{t+k}, p_{t+k'}^{-i}/M_{t+k})}{\partial \bar{p}_t^i}\right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \\
&+ \sum_{k=1}^{\infty} \theta_i^k \beta^k \mathbb{E}_t \left(\bar{p}_t^i - M_{t+k}/\phi^i\right) \left[\sum_{k'=1}^{k} (1-\theta_{-i})\theta_{-i}^{k-k'} \frac{\partial x^i(\bar{p}_t^i/M_{t+k}, p_{t+k'}^{-i}/M_{t+k})}{\partial p_{t+k'}^{-i}} \frac{\partial p_{t+k'}^{-i}}{\partial \bar{p}_t^i}\right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}}.
\end{aligned}
$$

The last term, which is a new element in this oligopolistic competition model, captures the strategic effect. A price-revising firm must consider how its reset price $\bar{p}_t^i$ influences the competitor's price in the future p_{t+k}^{-i}, which, in turn, influences its own optimal price in the current period because the competitor's price changes demand and its elasticities.

Given the Markov perfect equilibrium, the log-linearized optimal reset price is expressed in the following form:

$$\hat{p}_t^A = \Gamma^{AA}\hat{p}_{t-1}^A + \Gamma^{AB}\hat{p}_{t-1}^B + \Gamma^{A\varepsilon}\varepsilon_t, \tag{5}$$

$$\hat{p}_t^B = \Gamma^{BB}\hat{p}_{t-1}^B + \Gamma^{BA}\hat{p}_{t-1}^A + \Gamma^{B\varepsilon}\varepsilon_t, \tag{6}$$

$$\partial \text{log}\bar{p}_{t+k}^B / \partial \text{log}\bar{p}_t^A = \Gamma^{BA} \text{ for } k \geq 1, \tag{7}$$

where $\bar{p}_t^i \equiv pM_t e^{\hat{p}_t^i}$. Equation (6) in the second line indicates the log-linearized optimal reset price set by the competitor, which we denote using an asterisk. The third line shows that from the standpoint of firm i, a marginal change in its reset price ($\partial \text{log}\bar{p}_t^i$) induces the competitor $-i$ to change its price by Γ^{*i-i} from equation (6).

Proposition 1 in Online Appendix D describes the equilibrium, specifically the steady-state prices p^A and p^B and policy functions Γ^{AA}, Γ^{AB}, $\Gamma^{A\varepsilon}$, Γ^{BB}, Γ^{BA}, and $\Gamma^{B\varepsilon}$. Here, we focus on the steady-state prices and dynamic strategic complementarity.

Lemma 1 *Firm A's steady-state price under price stickiness equals*

$$p^A\phi^A = 1 - \left\{1 + \Psi^A + \frac{\theta_A\beta(1-\theta_B)}{1-\theta_A\theta_B\beta}\Psi^B\Gamma^{BA}\right\}^{-1}. \tag{8}$$

This lemma shows that unless Γ^{BA} is zero, the steady state under nominal rigidity differs from that without nominal rigidity given by equation (3). Firms consider the effect of their prices on the competitor's price in the following periods. Specifically, if Γ^{BA} is positive, there is dynamic strategic complementarity. An increase in firm A's price in the current period increases firm B's price in the following periods. This strategic effect increases the steady-state price. The above equation also shows that the steady-state price becomes identical to that in the scenario without nominal rigidity in the limit of $\theta_A \to 0$. Given Γ^{BA}, the steady-state price increases as nominal stickiness θ_A increases.

While the above lemma shows that steady-state price p^A (p^B) is determined by Γ^{BA} (Γ^{AB}), the next lemma shows how Γ^{AB} is determined, although it is in an approximation.

Lemma 2 *Suppose* $p^A \simeq \frac{\Psi^A}{\Psi^A+1}\frac{1}{\phi^A}$ *and that both* $|\mathbb{\Gamma}_{k1}^{BB}|$ *and* $|\mathbb{\Gamma}_{k0}^{BB}|$ *given in Proposition 1 in Online Appendix D are sufficiently small. Then, the degree of dynamic strategic complementarity* Γ^{AB} *satisfies*

$$\Gamma^{AB} = \frac{\theta_B}{1-\theta_A\theta_B\beta}\Psi^{AB} \cdot \left\{\frac{1}{1-\theta_A\beta}\left(\Psi^A(\Psi^A+1) - \Psi^{AA}\right) - (\Psi^{AB} - \Psi^B)\left(\frac{\theta_A\beta}{1-\theta_A\beta} - \frac{\theta_A\theta_B\beta}{1-\theta_A\theta_B\beta}\right)\Gamma^{BA}\right\}^{-1}. \quad (9)$$

Lemma 2 shows that when the cross superelasticity is zero ($\Psi^{AB} = 0$), no dynamic strategic complementarity exists; that is, $\Gamma^{AB} = 0$. Further, the following corollary shows that Γ^{AB} depends on other parameters.

Corollary 1 *Suppose* $\Psi^{AB} > 0$, $\Psi^A(\Psi^A+1) - \Psi^{AA} > 0$, $\Psi^{AB} - \Psi^B > 0$, Γ^{BA} *is positive and not too large,* $|\partial\Gamma^{BA}/\partial\theta_A| \ll 1$, *and* $|\partial\Gamma^{BA}/\partial\theta_B| \ll 1$. *Then, from equation (9), we obtain*

$$\Gamma^{AB} > 0$$
$$\partial\Gamma^{AB}/\partial\Gamma^{BA} > 0$$
$$\partial\Gamma^{AB}/\partial\Psi^{AA} > 0$$
$$\partial\Gamma^{AB}/\partial\Psi^{AB} > 0$$
$$\partial\Gamma^{AB}/\partial\theta_A > 0$$
$$\partial\Gamma^{AB}/\partial\theta_B > 0.$$

Further, when the superelasticity, Ψ^{AA}/Ψ^A *and* Ψ^{AB}/Ψ^A, *is given, we have*

$$\partial\Gamma^{AB}/\partial\Psi^A < 0.$$

In the CES and Hotelling's duopolistic competition models with $\sigma > 3$ or $\tau < 1$, three inequalities, namely, $\Psi^{AB} > 0$, $\Psi^A(\Psi^A+1) - \Psi^{AA} > 0$, and $\Psi^{AB} - \Psi^B > 0$, are likely to hold. Therefore, there is dynamic strategic complementarity, $\Gamma^{AB} > 0$. This corollary also shows that Γ^{AB} is reinforced as dynamic strategic complementarity for the competitor, Γ^{BA}, increases. While own superelasticity Ψ^{AA} is negative, its increase (i.e., a decrease in the absolute value of Ψ^{AA}) strengthens Γ^{AB}. Quasi kinked demand is often interpreted as a decrease in Ψ^{AA}. Thus, this result shows that quasi kinked demand decreases, rather than increases, dynamic strategic complementarity. By contrast, cross superelasticity Ψ^{AB} is positive, and an increase in the cross superelasticity increases dynamic strategic complementarity. That is, as own elasticity is more sensitive to the competitor's price, dynamic strategic complementarity increases. Further, the corollary suggests that dynamic strategic complementarity is amplified as price stickiness θ or the absolute value of own elasticity $|\Psi^A|$ increases.

Figure 2 illustrates the relationships between demand and price. First, when $\Psi^{AA} = 0$, the own demand elasticity of firm A, Ψ^A, is independent of own price p^A; therefore, log demand decreases linearly with log price. Second, suppose $\Psi^{AA} < 0$, which is the case in both the above CES (with finite n) model and Hotelling's model. Then, the curve becomes concave. As own price increases, demand becomes more elastic. The above corollary shows that this decreases, rather than increases, dynamic strategic complementarity Γ^{AB}.

Third, suppose $\Psi^{AA} = 0$ and $\Psi^{AB} > 0$. A positive Ψ^{AB} is again the case in both the CES and Hotelling's models. The corollary shows that a positive Ψ^{AB} generates dynamic strategic complementarity; that is, $\Gamma^{AB} > 0$. To see this, let us consider a decrease in competitor price p^B. As the red line in Figure 2 shows, the slope decreases because $\Psi^{AB} > 0$. In other words, when the competitor decreases its price, demand becomes more elastic. This induces firm A to decrease its price (dynamic strategic complementarity).

Let us consider what happens when a positive money supply growth rate shock occurs given $\Psi^{AB} > 0$. When firm A has a chance to increase its price, it considers the possibility that firm B will not change its price; that is, firm B's real price p_t^B/M_t decreases. Because $\Psi^{AB} > 0$, demand for firm A becomes more elastic, which prevents it from increasing its price aggressively. In other words, nominal price adjustments are staggered, which, in turn, increases the real effect of monetary policy.

Effects of Asymmetry Using this corollary, we next consider how firm asymmetry influences dynamic strategic complementarity. The first asymmetry we consider is in preference (taste b in the CES model or firm location δ in Hotelling's model). As discussed, in the CES model, $|\Psi^A|$ decreases and Ψ^{AB} increases as b for firm A increases.[9] Therefore, from the corollary, Γ^{AB} should increase (decrease) if the effect of Ψ^{AB} dominates (is dominated by) that of $|\Psi^A|$. Suppose that the former dominates the latter.

[9] By contrast, the relative price, p^A/P, increases, which leads to an increase in $|\Psi^A|$ and a decrease in Ψ^{AB} when $\sigma > 1$. This mitigates the changes in $|\Psi^A|$ and Ψ^{AB}.

Then, the more competitive firm is more concerned about the less competitive firm than its competitor is. In other words, a large firm sets its price more sluggishly than a small firm. This is illustrated in the left-hand panel of Figure 1. Demand becomes more elastic (see the steeper slope in the figure) as firm A becomes more competitive than firm B and/or as the competitor decreases its price. This increases dynamic strategic complementarity for firm A.

Next, let us turn to Hotelling's model. As δ increases (i.e., firm A becomes more competitive), both $|\Psi^A|$ and Ψ^{AB} decrease. Therefore, Γ^{AB} decreases unambiguously. This implies that a large firm sets its price less strategically than a small firm, which is the opposite movement to that based on the CES model. The right-hand panel of Figure 1 illustrates that, based on Hotelling's model, an increase in firm A's competitiveness decreases both the level and the slope of $|\Psi^A|$, which makes demand less elastic to a decrease in the competitor's price and, in turn, decreases dynamic strategic complementarity for firm A.

The second asymmetry we consider is in productivity ϕ. An increase in ϕ^A for firm A decreases relative price p^A/P. This leads to an decrease in $|\Psi^A|$ and an increase in Ψ^{AB} in the CES model when $\sigma > 1$, while it decreases both $|\Psi^A|$ and Ψ^{AB} in Hotelling's model. Thus, we again see that price setting differs between the CES and Hotelling's models. However, asymmetry in productivity plays a similar role in price setting to asymmetry in preference.

Third, we consider the effect of asymmetry in price stickiness θ, specifically a mean-preserving change in θ; that is, an increase in θ^A for firm A and a decrease in θ^B for firm B. Because $\partial\Gamma^{AB}/\partial\theta_A > 0$ and $\partial\Gamma^{AB}/\partial\theta_B > 0$, whether this change in θ increases Γ^{AB} is ambiguous. We discuss this issue more in the following subsection.

Atkeson and Burstein (2008) incorporate firm asymmetry in their analysis of price setting and show that a firm with a higher market share passes through changes in costs more than a firm with a lower market share. There are three main differences between their model and ours. First, their model is static, as it is based on flexible rather than sticky prices. They focus on the steady-state markup, not on dynamic strategic complementarity. Second, their model is based on Cournot-type quantity competition rather than price competition. Third, their model does not explicitly incorporate strategic pricing. Unlike in our model, the cross (super)elasticity does not matter for pricing.

3.5 Numerical Illustrations

We numerically solve the policy functions for price setting without resorting to the approximation given in Lemma 2. A time unit is a quarter. We normalize $W = 1$ and set the elasticity of substitution σ to 9, as assumed by Gali (2015), for the CES model with $n = 2$ or transport cost τ at 0.125 for Hotelling's model, so that the two models yield the same demand elasticities and steady-state markups without price stickiness. Benchmark price stickiness is set at $\theta = 0.75$, which implies that price revisions occur once a year. We also use $\rho = 0.85$ and $\beta = 0.99$.

Figure 3 shows steady-state price p and coefficients of the policy function Γ (e.g., Γ^{AB} and $\Gamma^{A\varepsilon}$). The four panels on the left and right are based on the CES and Hotelling's models, respectively and the horizontal axis represents an asymmetry parameter for preferences b and δ. For each panel, the solid line with the circle and blue solid line show p and Γ for firms A and B, respectively. In addition, we show p and Γ based on the CES monopolistic competition model, which corresponds to $n \to \infty$ in the CES model, as the dashed line. We denote Γ^{AA} and Γ^{BB} for firms A and B, respectively as Γ in each top right-hand panel. Similarly, Γ^{AB} and Γ^{BA} are shown as Γ^* in each bottom left-hand panel, while $\Gamma^{A\varepsilon}$ and $\Gamma^{B\varepsilon}$ are shown as Γ^{ε} in each bottom right-hand panel.

When Firms are Symmetric Let us begin with the case under symmetry (i.e., $b = 1$ or $\delta = 1$), which replicates that in Ueda (2023). In this case, the CES and Hotelling's duopolistic competition models yield the same results. The figure shows that both Γ and Γ^* are positive. A firm revises its price upward when its previous price was high (i.e., $\Gamma > 0$) or its competitor's previous price was high (i.e., $\Gamma^* > 0$). Particularly, positive Γ^* implies dynamic strategic complementarity, thereby causing a higher markup in the steady state under sticky prices than that under flexible prices, as illustrated in equation (8).

In the CES monopolistic competition model, both Γ and Γ^* are zero. The policy function does not depend on the prices in the previous period. Firms adjust their prices by simply looking at the current shock, ε_t, which makes Γ^{ε} positive and larger than that in our model. Thus, the aggregate prices in our model are more staggered than those in the CES monopolistic competition model, yielding a larger real effect of monetary policy, as we show below.

We calculate the impulse response functions (IRFs) to a positive money supply growth shock ($\mu_t = 1$ at $t = 1$) for aggregate inflation rate π_t and output $\hat{Y}_t$. The solid line in Figure 4 shows that the strategic complementarity of price setting decreases the effect of monetary policy on inflation, but increases the real effect. The real effect of monetary policy in this model is approximately 50% larger than that in the CES monopolistic competition model, shown as the dashed line.

When Firms are Asymmetric in Terms of Preferences Next, consider the case of asymmetry in terms of preferences. Based on the CES model, we change parameter b. The left-hand panel of Figure 3 shows that as b increases (i.e., firm A becomes more competitive than firm B), the steady-state markup of firms A and B increases and decreases, respectively. Whereas Γ is hardly different between firms A and B, the dynamic strategic complementarity Γ^* differs between firms A and B and the difference increases as b increases. Specifically, Γ^{AB} for firm A increases, while Γ^{BA} for firm B decreases. As firm A becomes more competitive, it becomes more concerned about firm B strategically, whereas firm B becomes less concerned about firm A. Further, the panel of Γ^{ε} shows that firm A responds to the aggregate shock less strongly, while firm B responds more strongly. This result is consistent with the arguments of Atkeson and Burstein (2008) and Wang and Werning (2022).

On the contrary, Hotelling's model yields the opposite result. The right-hand panel of Figure 3 shows that as δ increases (i.e., firm A becomes more competitive), Γ^{AB} for firm A decreases, while Γ^{BA} for firm B increases. As firm A becomes more competitive, it becomes less concerned about firm B, whereas firm B becomes more concerned about firm A. Consequently, firm A responds to the aggregate shock more strongly, while firm B does responds less strongly. Our empirical results are thus consistent with Hotelling's model rather than the CES model.

The next question is the extent to which these asymmetric responses of the two firms change the aggregate implications. The solid line with the asterisk in Figure 4 shows that the IRFs under asymmetry (specifically, when $b = 1.5$ or $\delta = 3$) hardly differ from those under symmetry. Hence, irrespective of the choice between the CES and Hotelling's models, the changes in the pricing responses of the more and the less competitive firms cancel each other out, leading to the heterogeneity in preferences having virtually no effect on the aggregate economy.

When Firms are Asymmetric in Terms of Price Stickiness We next investigate the effects of asymmetry in terms of price stickiness θ. While Carvalho (2006) and Nakamura and Steinsson (2010) argue that the heterogeneity in price stickiness increases the real effect of monetary policy in the non-linear Calvo-type pricing and menu cost models, respectively, it has no real effect when using the log-linearized Calvo-type monopolistic competition model, as we show in Online Appendix D. Here, we demonstrate a different channel through which the heterogeneity in price stickiness increases the real effect of monetary policy through strategic pricing.

In Figure 5, the horizontal axis indicates θ_A for firm A. Price stickiness θ_B for firm B changes following $\theta_B = 2\theta - \theta_A$; hence, aggregate price stickiness θ remains at 0.75, the value in the case of symmetry. The left- and right-hand panels show the CES and Hotelling's models, respectively.

In both models, a decrease in price stickiness θ_A results in a greater degree of dynamic strategic complementarity Γ^{AB} for firm A. As own price stickiness decreases, we assume that the competitor's price stickiness increases; therefore, the competitor's price in the previous period becomes an increasingly important state variable for firm A. Thus, when $\theta_A = 0.6$ and $\theta_B = 0.9$, we find that Γ^{AB} (the black line with the circle) is greater than Γ^{BA} (the blue line).

The next question is again the extent to which such an asymmetric response changes the aggregate implications. Figure 6 shows that when duopolistic firms are asymmetric in terms of θ, the real effect of monetary policy increases and the nominal effect decreases. In the figure, we calculate the IRFs for the following four cases: a monopolistic firm in the standard New Keynesian model, duopolistic firms with asymmetric θ ($\theta_A = 0.6$ and $\theta_B = 0.9$), duopolistic firms with asymmetric preferences ($b = 1.5$ or $\delta = 3$), and duopolistic firms with asymmetries both in b/δ and θ. The case of asymmetric b/δ is almost identical to the case of symmetry, as shown in Figure 4, which indicates that the real effect of monetary policy is approximately 50% larger than that in the monopolistic competition model.

Figure 4 shows that the real effect of monetary policy increases when duopolistic firms are asymmetric in terms of θ. This can be understood for the following two reasons. First, since firm B's price setting is less frequent ($\theta_A = 0.6$ and $\theta_B = 0.9$), even if firm B decreases its degree of dynamic strategic complementarity, its price remains sticky. By contrast, firm A's price setting is frequent. Thus, the effect of the increase in dynamic strategic complementarity Γ^{AB} on its price stickiness is large. Owing to this asymmetry, aggregate price stickiness increases.

Second, the change in the pricing response to the aggregate shock Γ^{ε} is asymmetric. The lower right-hand panel of Figure 5 shows coefficient Γ^{ε}, highlighting that firm A's Γ^{ε} decreases as price stickiness θ_A decreases. This comes from two channels. First, owing to $\rho > 0$, a positive aggregate shock is expected to persist in the future. Lower price stickiness decreases the need for a preemptive price increase today to ensure the continuation of the positive aggregate shock. This channel is present even without strategic behavior; as the dashed line shows, Γ^{ε} increases with θ even for a representative monopolistic firm in the standard New Keynesian model. The second channel is through a change in dynamic strategic complementarity. As discussed above, lower price stickiness for firm A (θ_A) combined with higher price stickiness for the competitor (θ_B) increases the degree of dynamic strategic complementarity Γ^{AB} for firm A. Owing to this enhanced dynamic strategic complementarity, firm A responds less strongly to the aggregate shock, decreasing Γ^{ε}. By contrast, firm B pays little attention to firm A (i.e., small Γ^{BA}) because firm A frequently revises its price. Thus, the gap in Γ^{ε} between firm A and a representative monopolistic firm in the standard New Keynesian model widens as θ_A decreases. This suggests that the strategic pricing effect on Γ^{ε} decreases as θ increases. Therefore, overall, the contribution of firm A with lower price stickiness is greater than that of firm B with higher price stickiness, thereby dampening the change in the aggregate price in response to the aggregate shock and increasing the real effect of monetary policy.[10]

Figure 6 shows that the real effect of monetary policy is further strengthened when two types of asymmetry coexist and the model is based on Hotelling's version. In the simulation, we consider duopolistic firms with asymmetric δ and θ ($\delta = 3$, $\theta_A = 0.6$, and $\theta_B = 0.9$). This approach is motivated by our observations in the empirical analysis that a firm with higher market share (i.e., higher δ) tends to change prices more frequently (i.e., smaller θ) than a firm with lower market share. The figure shows that the real effect is almost three times as large as that in the standard monopolistic competition

[10]The upper left-hand panel of Figure 5 shows that price stickiness influences the steady-state price. As equation (8) shows, the steady-state price is influenced by price stickiness θ_A and dynamic strategic complementarity Γ^*; moreover, Γ^* is influenced by θ_A. On the one hand, lower θ_A decreases the steady-state price. On the other hand, as discussed above, lower θ_A increases Γ^*, which, in turn, increases the steady-state price. Therefore, the effect of price stickiness on the steady-state price is not monotonic. According to the simulation, the steady-state price exhibits a U shape, where an intermediate value of θ^A around 0.7 yields the lowest steady-state price for firm A. The figure also shows that the steady-state price for firm B increases more than that for firm A when $\theta_B > \theta_A$.

model. However, when the model is based on CES preferences, the asymmetry of b hardly changes the real effect of monetary policy—even if the asymmetry of θ is present.

4 Concluding Remarks

This study examined the dynamic and strategic pricing behavior of oligopolistic firms and its implications for monetary policy. In the empirical analysis, we used micro data to show that firms set the prices of their products while keeping an eye on competitors' prices and that firms with higher market share revise their prices more frequently and make larger revisions than those with lower market share. In the theoretical analysis, we constructed a model that explicitly incorporates the pricing of oligopolistic firms and showed that strategic pricing and firm heterogeneity increase the effects of monetary policy on the real economy.

One of the key challenges for the future is better understanding the relationship between manufacturers and retailers. In this study, we focused on the strategic relationship between manufacturers. In practice, however, manufacturers often need to negotiate with retailers in advance to have their products placed on store shelves and their price revision accepted. Furthermore, wholesalers often operate between manufacturers and retailers in the real world. Therefore, investigating the effects of these three relationships on pricing behavior is crucial.

Another direction of future research is to study nominal rigidity. In this study, nominal rigidity is based on the Calvo-type model in which the frequency of price changes is exogenous. As shown in the empirical analysis, large firms (or goods with high market share) revise their prices more frequently than small firms (or goods with low market share). Using the menu cost model would thus be promising to explain both the frequency and the size of price changes, although analytical solutions could be hard to derive.

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Table 1: Reasons for the Expectation of Low Price Increases (Q12)

		1	2	3	4
	No of firms	Highly applicable	Applicable	Not very applicable	Not at all
(1) Costs are not expected to increase much.	139	1.4	3.6	45.3	49.6
(2) Retailers oppose.	138	33.3	46.4	18.1	2.2
(3) Competitors are unlikely to raise their prices.	**139**	**28.1**	**54.0**	**13.7**	**4.3**
(4) Consumers are price sensitive.	139	26.6	54.7	18.0	0.7
(5) Cost-cutting measures can be taken.	139	1.4	11.5	51.8	35.3
(6) Productivity can be improved.	138	2.2	14.5	54.3	29.0
(7) Products can be downsized.	139	1.4	17.3	49.6	31.7
(8) Other	11	72.7	27.3	0.0	0.0

Notes: In the preceding question (Q11), we asked firms, "In five years' time, how do you expect the shipping price of this product to change compared with the current level?" Then, we asked the firms that answered "the increase will be less than 1 percent annually," "Why do you expect that shipping prices will increase little compared with the current level or will decrease?" Reason (1) is "Raw material prices and labor costs are not expected to rise much, so the cost of goods is not expected to rise either. Hence, there is no need to raise shipping prices." Reasons (2) to (7) started with the clause "Raw material and labor costs are expected to rise," followed by (2) "but we will not be able to raise prices because retailers and other distribution firms are opposed to price increases," (3) "but competitors are unlikely to raise their prices, so we will have to match them," (4) "consumers are price sensitive, so we will not be able to pass on the price increases," (5) "but there is no need to raise prices because cost-cutting measures can be taken," (6) "but there is no need to raise prices as this can be handled by increasing productivity," and (7) "but there is no need to raise prices because we can respond by downsizing products (reducing capacity or weight)." The unit is percent except for the number of firms.

Table 2: Dates of Price Increases and Their Announcements

	Date of Price Revision					Date of Price Revision			
Category	Announcement	Revision	Firm	Market share	Category	Announcement	Revision	Firm	Market share
Coffee	09-Dec-2004	01-Mar-2005	UCC	0.387	Instant noodle	29-Sep-2014	01-Jan-2015	Nisshin Foods	0.491
	10-Feb-2005	01-Mar-2005	Key Coffee	0.166		02-Oct-2014	01-Jan-2015	Toyo Suisan	0.175
	28-Apr-2005	01-Jun-2005	Unicafe	0.002		03-Oct-2014	01-Jan-2015	Myojo Foods	0.071
						08-Oct-2014	01-Jan-2015	Sanyo Foods	0.056
Coffee	06-Apr-2006	01-May-2006	UCC	0.387		10-Oct-2014	01-Jan-2015	Acecook	0.083
	26-Apr-2006	01-Jun-2006	Unicafe	0.002		17-Oct-2014	01-Jan-2015	Maruka Foods	0.014
Mayonnaise	08-May-2007	01-Jun-2007	Kewpie	0.683	Pasta	22-Oct-2014	05-Jan-2015	Nisshin Foods	0.433
	29-May-2007	03-Jul-2007	Ajinomoto	0.173		30-Oct-2014	05-Jan-2015	NIPPN	0.085
						31-Oct-2014	05-Jan-2015	Showa Sangyo	0.012
Pasta	01-Oct-2007	15-Nov-2007	Nisshin Foods	0.433		09-Jan-2015	02-Mar-2015	Hagoromo Foods	0.070
	04-Oct-2007	20-Nov-2007	NIPPN	0.085					
	06-Oct-2007	20-Nov-2007	Showa Sangyo	0.012	Pasta	23-Apr-2015	01-Jul-2015	Nisshin Foods	0.433
	22-Oct-2007	01-Dec-2007	Hagoromo Foods	0.070		30-Apr-2015	01-Jul-2015	Showa Sangyo	0.012
						01-May-2015	01-Jul-2015	NIPPN	0.085
Instant noodle	06-Sep-2007	01-Jan-2008	Nisshin Foods	0.491					
	25-Sep-2007	01-Jan-2008	Myojo Foods	0.071	Chocolate	14-May-2015	07-Jul-2015	Meiji	0.227
	03-Oct-2007	01-Jan-2008	Toyo Suisan	0.175		26-May-2015	14-Jul-2015	Morinaga	0.065
	11-Oct-2007	01-Jan-2008	Acecook	0.083		03-Jun-2015	14-Jul-2015	Lotte	0.129
	19-Oct-2007	01-Jan-2008	Maruka Foods	0.014					
					Potato chips	01-Mar-2019	21-May-2019	Calbee	0.463
Pasta	17-Jan-2008	01-Mar-2008	Nisshin Foods	0.433		06-Mar-2019	01-Jun-2019	Koikeya	0.094
	24-Jan-2008	01-Mar-2008	NIPPN	0.085					
	24-Jan-2008	01-Mar-2008	Showa Sangyo	0.012	Instant noodle	05-Feb-2019	01-Jun-2019	Nisshin Foods	0.491
	28-Jan-2008	01-Mar-2008	Hagoromo Foods	0.070		13-Feb-2019	01-Jun-2019	Myojo Foods	0.071
						19-Feb-2019	01-Jun-2019	Toyo Suisan	0.175
Mayonnaise	20-May-2008	23-Jul-2008	Ajinomoto	0.173		27-Feb-2019	01-Jun-2019	Sanyo Foods	0.056
	23-May-2008	01-Aug-2008	Kewpie	0.683		28-Feb-2019	01-Jun-2019	Acecook	0.083
	26-Aug-2008	01-Oct-2008	Okonomi Foods	0.001		05-Mar-2019	01-Jun-2019	Maruka Foods	0.014
Potato chips	08-Sep-2008	03-Nov-2008	Calbee	0.463	Pasta	19-May-2021	01-Jul-2021	Nisshin Foods	0.433
	25-Sep-2008	17-Nov-2008	Koikeya	0.094		26-May-2021	01-Jul-2021	Showa Sangyo	0.012
						17-Jun-2021	01-Sep-2021	NIPPN	0.085
Coffee	27-Dec-2010	01-Mar-2011	Key Coffee	0.166		14-Jul-2021	01-Sep-2021	Hagoromo Foods	0.070
	25-Jan-2011	10-Mar-2011	UCC	0.387					
					Mayonnaise	26-Apr-2021	01-Jul-2021	Kewpie	0.683
Pasta	23-May-2011	01-Jul-2011	Nisshin Foods	0.433		28-Apr-2021	01-Jul-2021	Ajinomoto	0.173
	26-May-2011	01-Jul-2011	Showa Sangyo	0.012		19-May-2021	01-Aug-2021	SSK Foods	0
	27-May-2011	01-Jul-2011	NIPPN	0.085					
					Coffee	08-Jul-2021	01-Sep-2021	UCC	0.387
Mayonnaise	08-May-2013	01-Jul-2013	Kewpie	0.683		06-Aug-2021	01-Oct-2021	Key Coffee	0.166
	20-May-2013	01-Aug-2013	Ajinomoto	0.173					
	22-May-2013	01-Jul-2013	Kenko Mayonnaise	0	Pasta	25-Oct-2021	04-Jan-2022	Nisshin Foods	0.433
	30-May-2013	01-Aug-2013	SSK Foods	0		28-Oct-2021	04-Jan-2022	Showa Sangyo	0.012
						10-Nov-2021	04-Jan-2022	NIPPN	0.085

Sources: Nihon Keizai Shinbun and firms' IR materials. Market share is the average from 2000 to 2019.

Table 3: Relationship between the Frequency of Regular Price Changes and Competitive Environment

	Frequency of regular price changes:					
	Product level			Firm level		
	fr^+	fr^-	$fr^+ - fr^-$	fr^+	fr^-	$fr^+ - fr^-$
Market share	0.010***	0.008***	0.002***	0.008***	0.007***	0.001***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.001)
HHI	0.100***	0.110***	-0.010	-0.007	-0.009*	0.003
	(0.010)	(0.010)	(0.012)	(0.005)	(0.006)	(0.007)
Observations	3,266,770	3,266,770	3,266,770	476,801	476,801	476,801

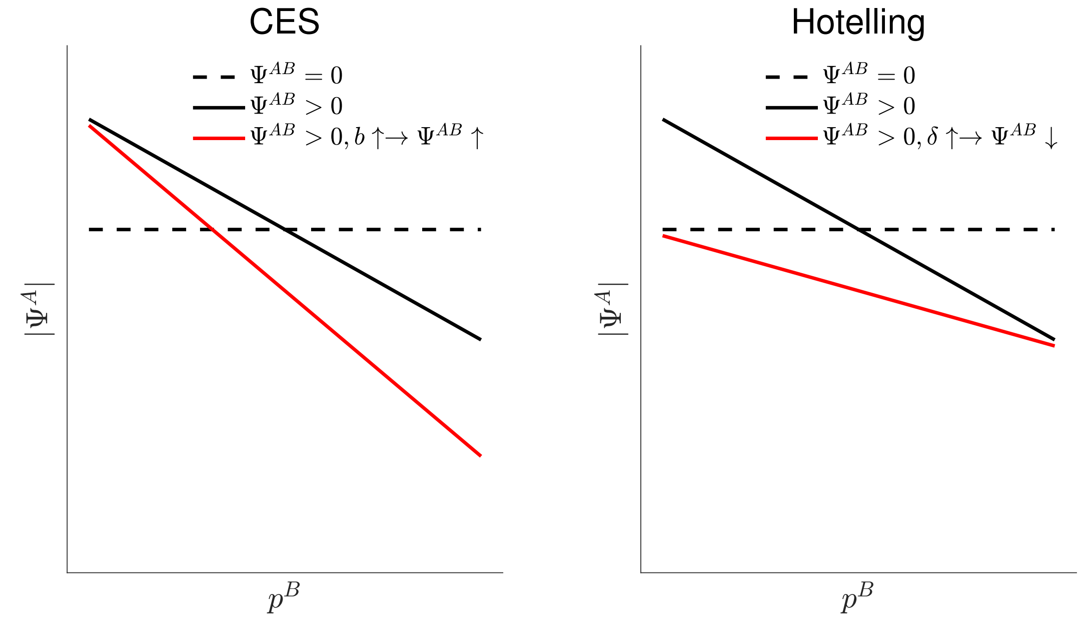
Notes: *p<0.1; **p<0.05; ***p<0.01. The values in parentheses are standard errors.
Dummies: period, firm, category

Table 4: Relationship between Price Changes and Competitive Environment

	Market share		HHI			*Fixed effects*		
θ	Estimate	S.E.	Estimate	S.E.	No. of obs.	categ.	firms	months
0.08	0.002*	(0.001)	-0.100**	(0.037)	1409	19	338	57
0.06	0.003***	(0.0005)	-0.035	(0.281)	2993	31	629	89
0.04	0.004***	(0.001)	0.171	(0.109)	8859	64	1708	125
0.02	0.004***	(0.0003)	0.026	(0.022)	26510	138	4095	154
>0.00	0.001***	(0.0001)	0.003	(0.007)	934908	217	15435	156
<0.00	-0.00005	(0.0001)	0.0003	(0.005)	1184125	217	15750	156
−0.02	-0.003***	(0.001)	-0.044*	(0.026)	21180	111	2914	154
−0.04	-0.004	(0.004)	-0.200***	(0.071)	5417	51	937	121
−0.06	-0.010***	(0.001)	-0.032	(0.068)	1947	21	353	69
−0.08	-0.008*	(0.004)	0.471	(0.323)	907	17	302	47

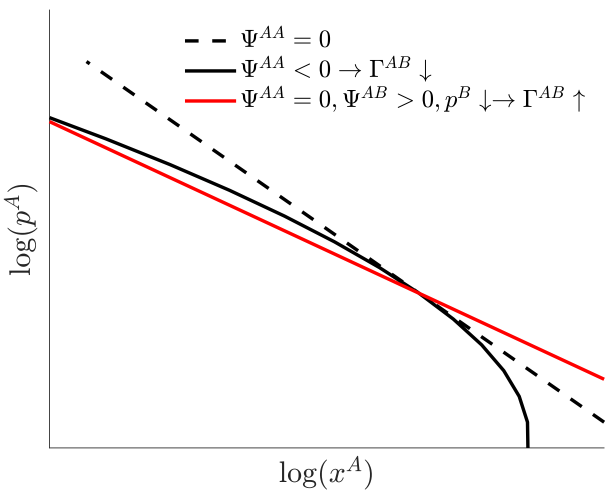
Notes: The events of large aggregate shocks are selected by $\pi_{cm} > \theta$ for a positive θ or $\pi_{cm} < \theta$ for a negative θ. *p<0.1; **p<0.05; ***p<0.01. The figures in parentheses represent robust standard errors clustered at the category level. The number of cateogories, firms, and months are shown in the right-hand three columns.

Figure 1: Own Demand Elasticity under Duopolistic Competition



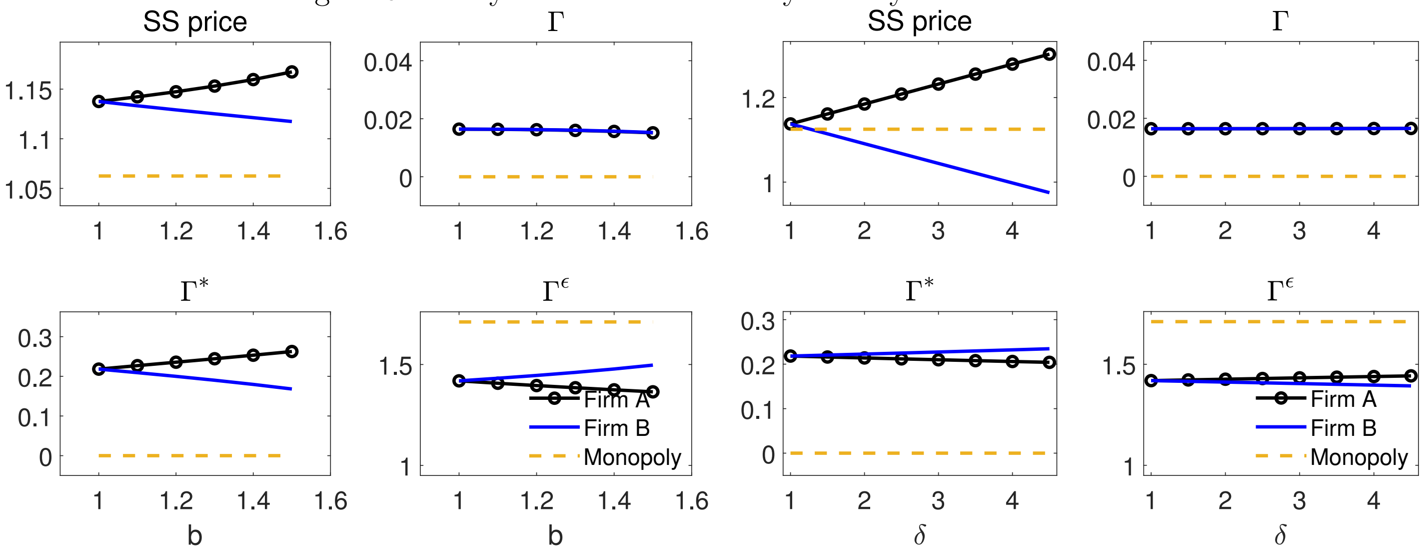
Notes: Own elasticity is given by $\Psi^A \equiv \frac{\partial \log x^A(p^A/M, p^B/M)}{\partial \log(p^A/M)}$, while the cross superelasticity (elasticity of elasticity) is given by $\Psi^{AB} \equiv \frac{\partial \Psi^B}{\partial \log(p^A/M)} = \frac{\partial \Psi^A}{\partial \log(p^B/M)}$. The red line indicates the case in which firm A becomes more competitive than firm B.

Figure 2: Demand under Duopolistic Competition



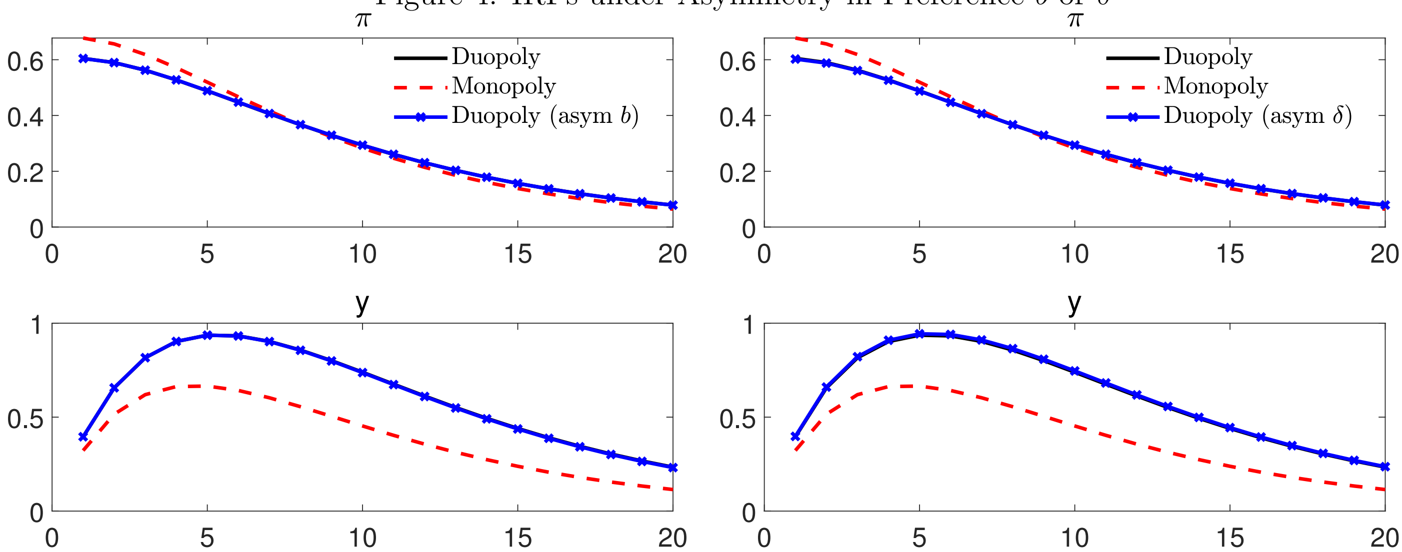
Notes: Own super elasticity is given by $\Psi^{AA} \equiv \frac{\partial \Psi^A}{\partial \log(p^A/M)}$, while the cross superelasticity (elasticity of elasticity) is given by $\Psi^{AB} \equiv \frac{\partial \Psi^B}{\partial \log(p^A/M)} = \frac{\partial \Psi^A}{\partial \log(p^B/M)}$. Coefficient Γ^{AB} represents the degree of dynamic strategic complementarity.

Figure 3: Policy Functions under Asymmetry in Preference b or δ



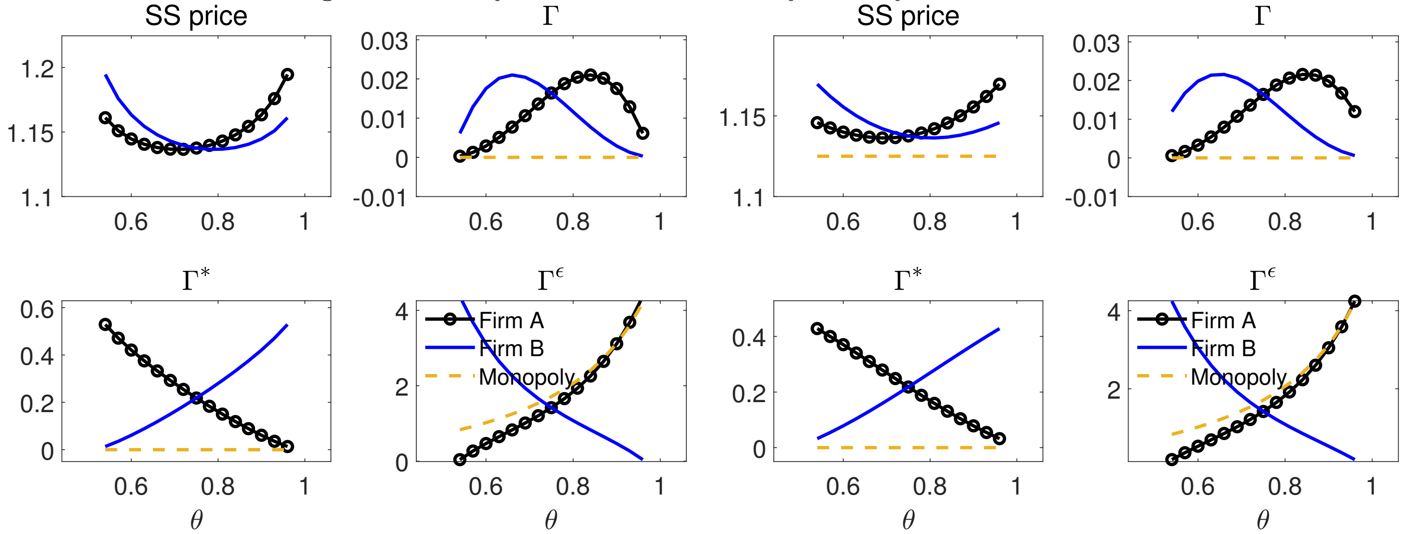
Notes: The figure shows the steady-state (SS) prices and coefficients of the policy functions for the optimal reset price. Denoting the optimal pricing as $\hat{p}_t^i = \Gamma^{ii}\hat{p}_{t-1}^i + \Gamma^{i-i}\hat{p}_{t-1}^{-i} + \Gamma^{i\varepsilon}\varepsilon_t$ for $i = A, B$, we show Γ^{AA} and Γ^{BB} for firms A and B, respectively, as Γ in each top right-hand panel. Similarly, Γ^{AB} and Γ^{BA} are shown as Γ^* in each bottom left-hand panel, while $\Gamma^{A\varepsilon}$ and $\Gamma^{B\varepsilon}$ are shown as Γ^{ε} in each bottom right-hand panel. Left- and right-hand figures are based on the CES and Hotelling's models, respectively. The horizontal axis represents preference b based on the CES model and δ based on Hotelling's model, where a higher b/δ indicates the greater competitiveness of firm A than firm B. The two firms are equally competitive when $b = 1$ or $\delta = 1$.

Figure 4: IRFs under Asymmetry in Preference b or δ



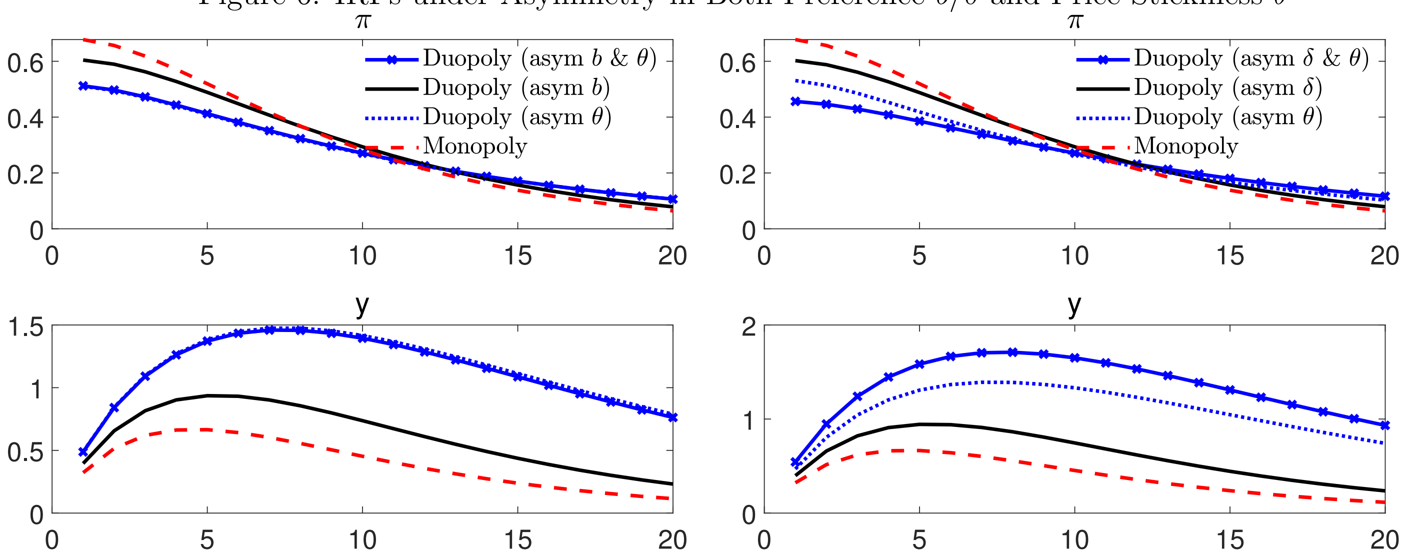
Notes: The figure shows the impulse response functions to a positive shock to money supply growth. The left- and right-hand figures are based on the CES and Hotelling's models, respectively. In the model "Duopoly," the two firms are symmetric. In the model "Duopoly (asym b)," b equals 1.5, while δ equals 3 in the model "Duopoly (asym δ)."

Figure 5: Policy Functions under Asymmetry in Price Stickiness θ



Notes: The figure shows the steady-state (SS) prices and coefficients of the policy functions for the optimal reset price. Denoting optimal pricing as $\hat{p}_t^i = \Gamma^{ii}\hat{p}_{t-1}^i + \Gamma^{i-i}\hat{p}_{t-1}^{-i} + \Gamma^{i\varepsilon}\varepsilon_t$ for $i = A, B$, we show Γ^{AA} and Γ^{BB} for firms A and B, respectively as Γ in each top right-hand panel. Similarly, Γ^{AB} and Γ^{BA} are shown as Γ^* in each bottom left-hand panel, while $\Gamma^{A\varepsilon}$ and $\Gamma^{B\varepsilon}$ are shown as Γ^{ε} in each bottom right-hand panel. The left- and right-hand figures are based on the CES and Hotelling's models, respectively. The horizontal axis represents Calvo-type price stickiness for firm A, θ_A. Price stickiness for firm B is set at $\theta_B = 2\theta - \theta_A$; hence, average price stickiness θ remains at 0.75.

Figure 6: IRFs under Asymmetry in Both Preference b/δ and Price Stickiness θ



Notes: The figure shows the impulse response functions to a positive shock to money supply growth. The left- and right-hand figures are based on the CES and Hotelling's models, respectively. In the model "asym b," b equals 1.5, while δ equals 3 in the model "asym δ." In the model "asym θ," θ_A and θ_B equal 0.6 and 0.9, respectively.