Oligopolistic Competition, Price Rigidity, and Monetary Policy

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Abstract

This paper investigates how strategic price setting influences the real effect of monetary policy. Using a questionnaire survey to consumer-goods manufacturers and scanner data from supermarkets in Japan, we show that price changes by firms with low market share tend to be less frequent, smaller in size, and have smaller correlations with other firms' price changes than those by firms with high market share. Then, we construct a duopolistic competition model to investigate how asymmetry in terms of competitiveness and price stickiness influences firms strategic pricing behavior and aggregate implications on monetary policy. The model shows that the real effect of monetary policy substantially increases by the dynamic strategic complementarity as well as asymmetry in price stickiness.

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1 Introduction

Macroeconomic models often assume monopolistic firms and ignore firms' strategic behaviors when considering pricing and its effects on the aggregate economy. However, in practice, firms face oligopolistic competition and adopt a pricing strategy that takes into account the behavior of rival firms. In Japan, in particular, under the prolonged deflation, firms often say that they cannot raise prices because other firms do not raise their prices even though their costs have risen due to, for example, an increase in the global commodity price and/or the depreciation of Japanese yen caused by the Abenomics policies since the end of 2012. Furthermore, firms are heterogeneous in their competitiveness, which seem to influence their pricing decisions unevenly. Bearing this in mind, this paper asks how pricing behavior depends on the competitive environment in which each firm operates, and how oligopolistic competition and firms' pricing behavior change macroeconomic implications.

The contribution of this paper is mainly twofold. The first contribution is to provide evidence of strategic complementarity in price setting by empirically showing relationships between the competitive environment and pricing behavior using two sets of data. The data are a questionnaire survey of firms and scanner data from supermarkets. Using the data, we show that a firm's price setting has a significant relationship with its sales share in the market. In particular, what is novel compared to previous studies is that we use supermarket micro price data to examine not only the relationship between aggregated competitive environment indices and pricing behavior for each product category, but also the heterogeneous relationship between each firm's market share and pricing behavior within a product category.

Second, given the oligopolistic market and heterogeneity (asymmetry) of firms, we use the model to examine the effects of these factors on monetary policy effects. Particularly, the question we tackle is how a heterogeneity in terms of firms' competitiveness and price rigidity influences firms' pricing decisions in the oligopolistic market and then changes the effect of monetary policy.[1]

The empirical analysis shows that firms' pricing is strategic and associated with the

[1] Another important question would be how the competitive environment affects price rigidity. This question is considered only partially since we take into account the optimal pricing behavior of firms by assuming Calvo-type price stickiness. Theory is ample in the industrial-organization literature. See Fershtman and Kamien (1987), Maskin and Tirole (1988), Tirole (1988), Slade (1999), Bhaskar (2002), and Chen, Korpeoglu, and Spear (2017).

competitive environment in the market. According to the questionnaire survey, among the firms that did not think they would be able to raise their prices in five years' time or did not raise their prices in response to yen depreciation since the end of 2012, nearly 80% or 60%, respectively, of the firms answered that this was because their competitors would keep or kept their prices unchanged. In terms of the relationship between these responses and the competitive environment of the market, the degree of such strategic pricing behavior is found to be significantly related to the number of rivals and the market share, with the sign being positive and negative, respectively. This suggests that uncompetitive firms are concerned about the pricing behavior of their rivals and do not actively revise their prices.

Similar empirical results are observed when analyzing actual prices set by firms using the scanner data. First, we find that firms or products with high market share tend to change their regular prices more frequently than those with low market share. Second, firms with high market share appear to have greater influence on rival firms' pricing than those with low market share. Third, when aggregate shocks occur, firms with high market share tend to increase their prices more frequently and to a greater size than those with low market share. Fourth, these three results are not robustly found when we use the Herfindahl–Hirschman index (HHI) instead of firms' or goods' market share. Depending on whether we measure the competitive environment either firm- or product-level, the HHI has both positive and negative associations with price rigidity.

The model we construct incorporates strategic pricing behaviors of oligopolistic firms. Specifically, the model is a macroeconomic extension of address model based on duopolistic competition, as described by Hotelling (1929), to incorporate price stickiness and monetary policy. In each product line, two firms located in geographically separated places exist and consumers are distributed evenly between them. The firms optimally determine their prices to maximize their present-valued profits under Calvo-type price stickiness. The model is extended from Ueda (2021) to allow for firm heterogeneity in terms of competitiveness and price stickiness.

Our model differs from the standard New Keynesian model in two ways. The first is the competition structure. Our model has two firms, whereas the standard New Keynesian model with monopolistic competition includes infinite firms. Therefore, duopolistic firms in our model must internalize the effect of their price setting on the prices of others. The second is the demand system. Our model is based on a Hotelling-type address model, whereas the standard New Keynesian model is based on CES preferences, which makes demand functions different (see, e.g., Pettengill 1979, Dixit and Stiglitz 1979, Anderson, de Palma, and Thisse 1992).

The results of the theoretical analysis show that when there are asymmetries in terms of competitiveness, large firms do not pay attention to small firms, while on the other hand, small firms pay great attention to the movements of large firms. As a result, prices for large firms will be elastic, while prices for small firms will be rigid. At the aggregate level, the two effects cancel each other, and the impact of asymmetry on the effect of monetary policy is small. However, the asymmetry in price rigidity increases real rigidity through strategic complementarity. A firm with low nominal price rigidity needs to pay a great attention to its rival firm with high nominal price rigidity, which increases real rigidity at the aggregate level and greatly increases the effect of monetary policy on the real economy. Moreover, when combined with asymmetries in goods preferences and productivity, the effect of monetary policy on the real economy is even greater.

This study lies in the class of 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, Woodford 2003). Leading hypotheses include real wage rigidity (Blanchard and Gali 2007), round-about production structure (Basu 1995), nonconstant elasticity of substitution (e.g., kinked demand as in Kimball 1995), and strategic complementarities in price setting. This paper focuses on strategic complementarities in price setting.

Previous micro survey and narrative data show that a competitive environment influences firms' pricing (e.g., Blinder et al. 1997 and Bank of Japan 2000 for the earlier attempts to use survey for the analysis of pricing). Fabiani et al. (2006), through a survey of Eurozone firms, document that firms facing high competitive pressures carry out price reviews more frequently. The prices of around 30% of the firms are shaped by competitors' prices. For Japan, by using the Tankan survey, Koga, Yoshino, and Sakata (2020) find that firms with greater market share are less sensitive to average price changes in the previous quarter in their category. Pitschner (2020) analyzes narrative information from archived corporate filings and finds that the price-setting behavior of competing firms is important in pricing decisions. However, these studies suffer from ambiguity and subjectiveness regarding how to define competitive environment and how to quantify pricing.

Many empirical studies use actual micro price data, which enable us to examine the relationship between competitive environment and firms' pricing behavior more directly (e.g., Bils and Klenow 2004, Gopinath and Itskhoki 2010, Vermuelen et al. 2012, Mongey 2017, and Kato, Okuda, and Tsuruga 2021). Bils and Klenow (2004) estimate the relationship between the frequency of price revisions and the concentration ratio of the top four firms in each category of manufacturing. They observe a tendency for the frequency of price revisions to decrease as the degree of oligopoly increases, but when they control for whether the goods are raw products or not, no significant relationship is observed. Gopinath and Itskhoki (2010) estimate whether the pass-through of the price of imported goods is affected by the sectoral HHI, and conclude that the coefficient is not significant and inconclusive.[2] Using the IRI microdata, Mongey (2017) shows that the relation between the frequency of price changes and the market concentration is not monotonic. The former decreases as the latter increases, but when the market concentration is very high, the former increases as the latter increases. These inconclusive results are consistent our finding that the HHI is not robustly associated with firms' pricing behavior.[3] It should be noted that many previous studies including the ones mentioned above examine the impact of sectoral oligopoly on sectoral price rigidity, but do not look in detail at the impact of a firm's position (e.g., market share and employment size) within a sector on its pricing behavior.

Most related empirical literature is the one that investigates relationships between firms' position and pricing behavior within a sector. Berman, Martin, and Mayer (2012) and Amit, Itskhoki, and Konings (2019) document that the pass-through for large firms is lower than that for small firms, which implies that strategic price setting is observed mostly by large firms and that small firms are approximated by constant markup pricing. This result is opposite to what we find. On the other hand, studies in line with our finding

[2]Gopinath and Itskhoki (2010) also conduct a survey and argue that the variable markup channel of real rigidities is an important feature of the wholesale cost data but not of the retail price data. Our results show that even in the case of retailer prices, there are differences in pricing behavior depending on the competitive environment, which is consistent with variable markup.

[3]By contrast, Vermuelen et al. (2012) argue that a higher degree of competition increases the frequency of price changes by using the 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 sectoral inflation persistence decreases as the market concentration increases by using US producer price. Also see Alvarez et al. (2006) and Klenow and Malin (2010) for the discussion on the determinants of the frequency of price changes. In the industrial-organization literature, the relationship between market structure and price flexibility has been pointed out and tested long before, for example, by Berle and Means (1932), Stigler and Kindahl (1970), Domberger (1979), Carlton (1986), and Slade (1991).

also exist. Dias, Dias, and Neves (2004), Fabiani et al. (2006), Jonker, Folkertsma, and Blijenberg (2004) find that retail prices are more flexible in large outlets, such as supermarkets and department stores, than in smaller retail outlets in Europe. Using US producer price data, Goldberg and Hellerstein (2009) show the pattern that large firms change prices more frequently and by smaller sizes than small firms. Although this pattern is consistent with what we find, it is observed only across industries, so that sectoral differences in other characteristics than firm size may explain the heterogeneity in price stickiness.

Theoretically, similar models are constructed by Faia (2012), Mongey (2017), Wang and Werning (2020), and Ueda (2021) who investigate monetary policy under oligopolistic competition. Wang and Werning (2020) argue that the effect of the number of firms on non-neutrality of money depends on the demand system. The difference between these studies, except for Ueda (2021), is the demand system. Atkeson and Burstein (2008) and Wang and Werning (2020) incorporate firm asymmetry in the analysis of price setting and obtain the results that are opposite to ours in that a firm with a larger market share responds more strongly to a rival firm's price, while the rival firm becomes less responsive. In addition, they do not consider the impact of asymmetry in the frequency of price revisions, which turns out to have a large impact on macroeconomic performance based on our model.

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

2 Empirical Investigations

2.1 Questionnaire Survey to Consumer-Goods Manufacturers

2.1.1 Data Descriptions

The first set of data we use is a questionnaire survey to firms, "Questionnaire Survey on Companys' Product Pricing," conducted by the University of Tokyo and Intage Inc., a market research company in Japan. In this survey, they asked mainly firms' product pricing strategies, such as price change expectations, actual price changes in response to yen depreciation, and reasons for keeping prices unchanged. The survey targets were selected from consumer-goods (food, beverages, daily necessities) manufacturing firms that are customers of Intage Inc. and have the top 15 market shares in their respective product categories. At the beginning of the survey, the University of Tokyo and Intage Inc. specified a product category and asked to indicate a brand name with the largest sales value in the category (question 1). When asking individual price developments, they clarified that price is for the product each firm answered in question 1. The survey form was mailed in February and asked to return it by March 2020. A person in corporate planning or product planning department was asked to answer. See Appendix for the summarized English translation of the questionnaire survey and all of the actual questionnaires that were sent in Japanese. We collected answers from 176 firms in total. The mean of the number of employees is 1,057, while the mean of the market share is 23%. See Appendix for the basic statistics.

2.1.2 Reasons for Price Rigidity

We examine reasons firms do not raise prices. After asking firms expectations on the change in shipping price of their product in five years' time (question 11), we asked the firms that expected price increase by less than 1% annually the following question: "What is the reason why you expect that the level of shipping prices will not increase much compared to the current level, or will decrease? (question 12)"[4] Table 1 shows that the sluggishness of price increase by competitors is one of the main reasons that firms have low price increase expectations. Of 110 firms, 24% and 39% answered that the reason that competitors were expected to keep their prices unchanged was applicable well and applicable, respectively, amount to 63%. Note that again two other reasons are important as well. They are the opposition of retailers and the decrease in sales volume (which can arise from competitors) where answers applicable well and applicable amount to 70% and 84%, respectively.

Next, we examine actual price setting as shown in Table 2, whereas the previous Table 1 concerns expectations on future price change. In the questionnaire survey, we focused on a particular event, in which firms were faced with the one of the largest cost-push shocks in the last decade. The Abe administration that inaugurated at the end of 2002 conducted so-called Abenomics, where one of the three arrows consisted of aggressive monetary policy aiming at achieving 2% inflation target in two years' time. Japanese yen weakened significantly from 77 yen to the dollar in December 2012 to 125 yen to the dollar in June 2015. This depreciation of yen is said to have raised the prices of imported

[4]See Appendix for the distribution of price change expectations.

products and raw materials considerably. However, actual price seems to have increased hardly, falling much short of the inflation target. In the questionnaire survey, we asked firms whether price increase in response to the depreciation of yen between December 2012 and June 2015 was sufficient (question 20) and then asked firms that answered "to some extent, but not sufficiently" or "not at all" the following question: "Why were you not able to fully pass on the weaker yen to shipping prices? (question 21)"

Table 2 shows a similar result to Table 1, illustrating the importance of competitors behind the sluggishness of price increase. Of 139 firms, 28% and 54% answered that this reason was applicable well and applicable, respectively, amount to 82%. Note that two other reasons are important as well. They are the opposition of retailers and price-sensitive consumers, where answers applicable well and applicable amount to 79% and 83%, respectively. From a survey of Eurozone firms, Fabiani et al. (2006) document that the main source of price rigidity is a customer relationship such that a price increase antagonizes customers.

In summary, Tables 1 and 2 show that real rigidity that prevents firms from increasing prices arises from main three reasons: competition with other firms in the same industry, the opposition of retailers, and price-sensitive consumers. In this paper, we focus on the first reason; however, the other two reasons should not be overlooked.

2.1.3 Relationship between Pricing Behavior and the Competitive Environment

We further explore the survey by investigating whether the competitive environment influences the reasons for price rigidity. We run a regression using the answers on three types of reasons, associated with competitors, consumers, and retailers, in question 12 or 21 as a dependent variable. The variable takes 1, 2, 3 or 4, where 1 represents "applicable well" and 4 represents "not at all." As explanatory variables, we use the logarithm of the number of competitors (question 37) and the market share (question 38), which are self reported by firms.

Table 3 shows the estimation results. In Column (1), the coefficient on the number of competitors is negative significantly at the 1% level. This implies that for their price rigidity, firms tend to blame competitor's pricing sluggishness more as the number of competitors increases. In Column (2), the coefficient on the market share is positive significantly at the 5% level. This implies that for their price rigidity, firms tend to blame competitor's pricing sluggishness more as the market share decreases.[5] Columns (3) to (6) show the estimation results when the reason for price rigidity is attributed to consumers or retailers. Except for Column (5), where the coefficient on the number of competitors is negative significantly at the 5% level, no significant coefficient is obtained. Thus, the competitive environment appears to matter pricing behavior through the strategic consideration of competitors' pricing behavior.

This questionnaire survey enables us to observe actual quantitative price setting in response to the depreciation of yen between December 2012 and June 2015. The survey asked firms to answer the actual timing (year and month) and size of shipping price increase(s) (question 19), from which we can calculate the number of price change (frequency) and the cumulated size of price change (size).[6] Table 4 shows the estimation results, where we run a regression for these variables using the logarithm of the number of competitors and the market share as explanatory variables. Column (1) shows that the coefficient on the market share is positive and significant at the 10% level, indicating that the frequency of price change increases as the market share is higher. In Columns (3) and (4), we incorporate the product category fixed effect, considering heterogeneity in price rigidity across product categories. Now in the both columns, the coefficient on the market share is significantly positive at the 5% level. In other words, both the frequency and size of price change increases as the market share is higher. However, we must note that the number of observations is small, far from claiming the robustness of these estimation results. Thus, in the next section, we use the POS scanner data on retailers, thereby substantially increasing the number of observations and enriching our analyses by using actual price data.

2.2 Scanner Data from Retailers

2.2.1 Data Descriptions

The second set of data are retailer-side data, namely, the point-of-sale (POS) scanner data collected by Nikkei Inc. The data include the number of units sold and the sales amount (price times the number of units sold) for each product and shop on a daily basis. The observation period is around thirty years, running from March 1, 1988 to

[5]The correlation between the number of competitors and the market share is negative, but the size of correlation is not high enough to cause multicollinearity. See Appendix.

[6]See Appendix for the distribution of the number, size, and timing of price changes.

December 31, 2019. Products recorded consist of processed food and daily necessities and 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 the code provided by GS1 Japan. See Appendix B for the details on the identification of products and firms. See also Sudo, Ueda, and Watanabe (2014) and Sudo et al. (2018) for a detailed description of the data.

Below we use mainly the following variables. For each product, shop, and date, we calculate the regular price that is defined as the mode price for 42 days before and after the date (Kehoe and Midrigan 2015 and Sudo et al. 2018). The frequency of regular-price changes is recorded when regular price changes more than two yen from the previous date. Then, aggregating from a product to firm level, we calculate a market sales share in 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 squared sales share. Note that the market share and HHI can be calculated based on either product- or firm-level. See Appendix B for the details.

2.2.2 Relationship between the Frequency of Regular-Price Changes and the Competitive Environment

In this subsection, we investigate the relationship between market competitiveness and price setting behaviors, particularly, the frequency of regular-price changes. For each product category j, we regress the frequency of regular-price increase/decrease for each product/firm i on its market share as

$$fr_{ijy}^{X} = \alpha \log s_{ijy} + \sum_{y=1}^{31} \beta_y d_y^{year} + \sum_{k=1}^{K-1} m_k d_k^{firm} + \epsilon_{ijy}, \qquad (1)$$

where, fr_{ijy}^{X} and s_{ijy} 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 j in year y. We include the period and firm fixed effects by adding dummy variables d_y^{year} and d_k^{firm}, where the time subscript y takes an integer from 1 to 31 (each representing the year $1988 + y$) and K denotes the number of firms. In the firm-level regression, i equals k.

Figure 4 shows the result on the above regression at the product/firm level. The curves represent the cumulative distribution, where the vertical axis is the fraction of product categories in which the t-value for the coefficient on the market share, α, takes a value less than or equal to t^* (horizontal axis). The intercepts of the curves at $t^* = 0$ are less than 0.1, which suggests that α is positive for more than 90% of product categories for both regular-price increase and decrease. Furthermore, the curves in the left-hand panels take smaller values than 0.2 at $t^* = 2$, which suggests that α is significantly positive at the 5% level for more than 80% product categories, when we investigate the relationship between market competitiveness and the frequency of regular-price changes at the product level. When we investigate it at the firm level (the right-hand panels), the results are weaker; however, α is significantly positive for the majority of product categories. Comparing regular-price increase and decrease, we find that the frequency of price increase is more strongly associated with a firm's market share than that of price decrease. Additionally, we run the regression by using the frequency of price increase minus that of price decrease for the dependent variable. The figure shows that there is no significant relationship between market competitiveness and the difference in the frequency of regular-price increase and decrease. In sum, the estimation results suggest that the frequency of regular-price changes tends to increase as the market share of the product/firm is large. The market leader, rather than market followers, changes their prices frequently.

We run a similar regression but now by pooling categories:

$$fr_{ijy}^{X} = \alpha \log s_{ijy} + \sum_{y=1}^{31} \beta_y d_y^{year} + \sum_{k=1}^{K-1} m_k d_k^{year} + \sum_{j=1}^{J-1} c_j d_j^{cat} + \gamma HHI_{jy} + \epsilon_{ijy}. \qquad (2)$$

We add new regressors, that is, the HHI for category j and year y, HHI_{jy}, and the category fixed effect d_j^{cat}, where J denotes the number of categories. Although both s_{ijy} and HHI_{jy} capture market competitiveness, they are clearly different. The former is product/firm specific and captures the market position, while latter captures the competitive environment for the category to which a firm belongs. In the environment near monopoly, both s and HHI are high, close to one, if the product/firm is monopolistic. However, in this environment, s is almost zero for the products/firms except for the monopolistic one. We use only top 100 products/firms for each category for the ease of regression. The estimation results hardly change when we use all firms (see Appendix B).

Table 5 shows the estimation results. The sign of coefficient on the market share, α, is positive and significant, except when we use the product-level frequency of price increase minus that of price decrease for the dependent variable. This is consistent with what we observed in Figure 4, suggesting that the frequency of regular-price changes increases as the market share of the product/firm increases.

The coefficient on the HHI, γ, is negative and significant when we run the firm-level regression, although it is positive (but insignificant for price increase) when we run the product-level regression. A negative γ at the firm level suggests that the frequency of regular-price changes increases as the market is less concentrated (more perfectly competitive) at the firm level. By contrast, a positive γ at the product level suggests that the frequency of regular-price changes increases as the market is more concentrated at the product level.

2.2.3 Correlation Structure of Price Changes between a Pair of Firms

In the previous subsection, we reported that a market-leading product/firm tends to change prices more frequently. In this subsection, we investigate whether, by changing price, the market leader influences rivals' prices. To this end, we calculate Spearman's rank correlation for price changes between firm k and l in each product category j and then the fraction of firms with the significant correlation at the 5% level, that is, t-value $t_{kl} > 1.96$ or $t_{kl} < -1.96$, for firm k as $n^+_{jk} = \sum_l 1\{t_{kl} > 1.96\}/\sum_l 1$ and $n^-_{jk} = \sum_l 1\{t_{kl} < -1.96\}/\sum_l 1$.[7] Also, we calculate the mean monthly sales of firm k in category j as $\overline{s}_{jk} = \sum_l s^l_{jk}/\sum_l 1$, where s^l_{jk} represents the mean monthly sales of firm k during the observation period when $s_{jkm} > 0$ and $s_{jlm} > 0$ are satisfied.

Figure 2 shows the relationship between $\overline{s}_{jk}$ and n^+_{jk}/n^-_{jk} across firms for the particular product category of instant cup-noodle. We observe a positive and significant correlation between $\overline{s}_{jk}$ and n^+_{jk}. This implies the possibility that as firm sales are larger, the firm's price has a larger influence on rival firms' prices. Pricing is complementary (significant for n^+_{jk} but not for n^-_{jk}), suggesting that a market leader's price increase is associated with rivals' price increase, not decrease.

Since instant cup-noodle is merely one of product categories, we run the following regression for $n^+_{jk} - n^-_{jk}$ using $\overline{s}_{jk}$ and category dummy d_j:

$$n^+_{jk} - n^-_{jk} = \alpha \log \overline{s}_{jk} + \sum_{j=1}^{J} c_j d_j + \epsilon_{jk}. \tag{3}$$

[7]We use only pairs (k, l) for which the number of observation periods with $s_{jkm} > 0$ and $s_{jlm} > 0$ exceeds 120 months.

Table 6 shows that coefficient α is positive and significant. Moreover, Appendix B provides the estimation results on other product categories than instant cup-noodle, by which we confirm a positive and significant correlation between $\overline{s}_{jk}$ and n^{+}_{jk} for the majority of product categories.

2.2.4 Price Responses to the Aggregate Shock

The above studies suggest that large firms tend to change its price more frequently and have a greater influence on rival firms' pricing than small firms. However, this result may not necessarily imply a difference in their reaction functions to costs. It may arise if costs are idiosyncratic, for example, when costs for large firms are more volatile or change earlier than those for small firms. Thus, in this subsection, we investigate how firms' output prices change in response to aggregate shocks and how price responses depend on firms' market share.

To this end, we do two things. First, we look at a particular product category, i.e., instant cup noodle, and an event around 2007 when global food prices exhibited large swings. The solid line with the cross in the left-hand panel of Figure 3 shows the wheat price based on the Corporate Goods Price Index released by the Bank of Japan from January 2005 to December 2009. Many commodity and energy prices exhibited similar large swings around 2007, so that their effects on food manufactuers' pricing are sizable and the swings can be considered as aggregate shocks, particular, the aggregate cost-push shock around from January 2007 to June 2008.[8] During the period, we calculate the price index for each firm k in product category j in month m as follows:

$$P_{jkm} = \sum_{t=0}^{m} \pi_{jkt}. \tag{4}$$

As explained in Appendix B, we calculate π_{jkt} as the month-to-month Tornqvist regular-price change. The left-hand panel of Figure 3 shows the change in P_{jkm} for the category of instant cup noodle from December 2004.[9] The right-hand panel displays the scatter plot between the market share (average of 2007 and 2008) and the changes in P_{jkm} from January 2007 to June 2008 for each cup-noodle manufacturer firm. The correlation coefficient is significantly positive, which suggests that large firms tend to change their prices to a greater degree in response to the aggregate cost-push shock than small firms.

[8] In Japan, more than 90% of wheat is imported and the imported wheat price sold to user firms is set by the government.

[9] We use only the firms whose inflation rate can be measured in all months of the period.

Second, we extend the previous analysis to other product categories and events. Here, we attempt to identify category-level shocks and estimate how firms adjusted their prices to the shocks. We identify category-level shocks by taking the following steps. First, we calculate the category-level price index for product category j in month m in a similar manner we calculate firm-level π_{jkt}. We use observations from January 2007 to December 2019. Second, we statistically detect the periods of large price changes, $t's$, by the local outlier factor for each category. If t occurs in consecutive months, we record only the first one. Third, we pool the set of $t's$. If period $m = t$ is detected, we calculate the price adjustment for firm k in category j over the next twelve months as $\pi_{jkt} = P_{jkt+11} - P_{jkt-1}$ and pool it in all the detected periods and categories.

We run the following regression for π_{jkt}:

$$\pi_{jkt} = \alpha \log s_{jkt} + \sum_{y=1}^{31} \beta_y d_y^{year} + \sum_{j=1}^{J-1} c_j d_j^{cat} + \gamma HHI_{jy} + \epsilon_{jkt}, \tag{5}$$

where year y is a year for month t, s_{jkt} represents the average market share of firm k in year of $y-1$ and y, and HHI_{jy} is the HHI of firm sales. We control the period and category fixed effect by adding dummy variables d_y^{year} and d_j^{cat}. We separate the regression for the period of price increase from that of price decrease. In addition to π_{jkt}, we also use the frequency of price changes fr_{jkt} for the dependent variable.

Table 7 shows the estimation results in the case of large price increase. The coefficient on the market share, α, is significantly positive in all the four columns. The positive α when we use fr_{jkt} assures the previous estimation result reported in Table 5. Further, the positive α when we use π_{jkt} suggests that large firms tend to make not just more frequent price increase but also greater price increase in response to category-level (positive cost-push or demand) shocks than small firms. By contrast, the coefficient on the HHI, γ, is insignificant at the 5% level when we include the period and category fixed effect. Table 7 shows the estimation results in the case of large price decrease, which are similar to Table 7. Now, coefficient α is significantly negative when we use π_{jkt}, which also suggests that large firms tend to make greater price decrease in response to category-level (negative cost-push or demand) shocks than small firms.

Two reservations are necessary on the identification of category-level shocks. First, the shock we identify is not necessarily aggregate and exogenous, if a granular firm influences the category-level price index. Second, the shock can be both demand and supply (cost-push) shocks. We used observations from January 2007 to December 2019 for the aim of detecting the cases of supply shocks. The period covers when the global commodity prices fluctuated around 2007, the Great East Japan earthquake hits the country in 2011, and the yen exchange rate depreciated under the Abenomics from 2012, which can be more ore less interpreted as supply shocks, but not when the asset market bubble arose in the late 1980s and its collapse fell into the lost decades from the early 1990s. However, this approach is admittedly crude, and pricing decisions should differ depending on the source of shocks.

2.2.5 Changes in Input Prices

Even if the source of price changes is aggregate, different firms may face different degrees of cost changes. However, this possibility likely strengthens, rather than weakens, our estimation results that large firms change their output prices more aggressively than small firms. This is because large firms appear to have stronger bargaining power for procurement. An aggregate positive cost-push shock leads to a smaller cost increase for large firms than for small firms. In Appendix B, we provide evidence to show that input prices for large firms tend to increase less strongly than those for small firms by using the Bank of Japan's Tankan survey.

2.2.6 Timing of Announcements on Price Revisions

Although we have so far analyzed actual price revisions, the timing of actual price revisions is different from the timing of announcements on price revisions. In Japan, food manufacturing firms often publish news releases in which they announce price revisions around a quarter ahead. We manually searched for the news of price revisions by using Japan's major economic newspaper, Nihon Keizai Shinbun, and food manufacturing firms' IR materials from 2005 to 2021.

Table 9 shows the dates of price revisions and their announcements. All the events shown in the table concern price increase.[10] The table shows that the announcement of price revisions occurs approximately a quarter before actual price revisions. Firms with large market share tend to announce early; however, the date of actual price revisions is highly synchronized. According to anecdote, market leaders negotiate with retailers for price increase, and after retailers agree, they can make announcements on price increase.

[10] In constructing this table, we noticed that firms rarely announce price decrease. Actually, we found only one case of price decrease annoucement that was made by a mayonnaise manufacturer in 2009.

After observing this, other firms follow this move by negotiating with retailers for price increase. This evidence likely strengthens our estimation results that large firms change their output prices more aggressively than small firms because what we observe in the scanner data are actual prices, not the dates of announcements.

2.2.7 Comparisons with Previous Studies

Berman, Martin, and Mayer (2012) and Amit, Itskhoki, and Konings (2019) document that the pass-through for large firms is lower than that for small firms, which implies that strategic price setting is observed mostly by large firms. This result is opposite to what we find on the relationship between market share and price changes. The opposing results may be attributed to, firstly, differences in data. Berman, Martin, and Mayer (2012) and Amit, Itskhoki, and Konings (2019) use firm-product level data on French exporters and Belgian manufacturers, respectively, while we use product level data for retailers in Japan. Although their data are highly disaggregated, a product price measured in their study is still aggregated in terms of product and time. The degree of product classification is coarser (the number of products is around 1,500 in Amit, Itskhoki, and Konings 2019), so that a product price may embed the prices of more than one product. By contrast, in our study, each brand of product is assigned a unique code. Further, their data are annual so that price changes within a year are smoothed, while our data are daily. Output prices in their data are shipment prices from exporters or manufacturers, whereas those in our data are retail prices. The second difference is that Amit, Itskhoki, and Konings (2019) identify firms' price responses to changes in competitors' prices by constructing a theoretical model and taking changes in marginal costs into consideration. Third, firm heterogeneity is categorized by whether employee size is large or small in Amit, Itskhoki, and Konings (2019), while we use continuous market share as a proxy for firm/product heterogeneity.

Mixed, inconclusive estimation results regarding the effects of the HHI are are in line with the previous empirical studies. For example, Gopinath and Itskhoki (2010) estimate whether the pass-through of the price of imported goods is affected by the sectoral HHI, and conclude that the coefficient is not significant and inconclusive. Mongey (2017) shows that the relation between the frequency of price changes and the market concentration is not monotonic. The former decreases as the latter increases, but when the market concentration is very high, the former increases as the latter increases.

Fabiani et al. (2006), through a survey of Eurozone firms, document that firms facing high competitive pressures carry out price reviews more frequently. Their result appears consistent with our result based on the firm-level regression if we consider that high competitive pressures imply low HHI. However, it is inconsistent in that high competitive pressures are probably associated with low market share. It should be noted that in their study, competitive pressures are measured by whether firms answer that competitors' prices have a very important effect on their own pricing decisions. Thus, competitive pressures are rather subjective and endogenous and do not separate firm-specific and sectoral variables such as the market share and HHI. Further, category-speficic factors do not seem controlled in their study.

3 Theoretical Investigations

The empirical part of this paper shows that pricing behavior is influenced by competitors' pricing behavior. Specifically, a competitive firm tends to care less about competitors and changes 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 strategic pricing behaviors of oligopolistic firms. The model is based on the seminal address model with duopolistic competition by Hotelling (1929). To this, Calvo-type nominal rigidity is introduced. Furthermore, unlike Ueda (2021), we incorporate firm heterogeneity in terms of competitiveness (δ) and price stickiness (θ). 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

Firms In each product line $j \in [0, 1]$, there exist two firms A and B. They are situated on the horizontal line at [0, δ], respectively, where $\delta \in [1, \infty)$. To produce one unit of product, firm A and B require one unit of labor, which costs nominal wage W_t.[11] Firms are symmetric (i.e., equally competitive) if δ equals one, and firm A is more competitive

[11]In Appendix, we introduce another type of asymmetry that is related to labor productivity to examine the robustness of our results.

than firm B as δ is larger. Firm A and B set output prices p^A and p^B, respectively. No entry or exit is considered.

Household A head of household maximizes the following preference:

$$U = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log C_t - (L_t + \tau D_t)\right],$$

where L_t represents labor supply, and aggregate consumption C_t and shopping distance D_t are given by

$$\log C = \int_0^1 \log c^j dj \tag{6}$$

$$D = \int_0^1 d^j dj. \tag{7}$$

Here, c^j and d^j represent consumption and shopping distance, respectively, for a product line $j \in [0, 1]$. Parameter $\beta \in (0, 1)$ is the subjective discount factor and parameter τ is the transport cost incurred per unit of distance.

The budget constraint is given by

$$M_t + B_t + P_t C_t \le M_{t-1} + R_{t-1} B_{t-1} + W_t L_t + \Pi_t + T_t, \tag{8}$$

where M_t, B_t, P_t, R_t, Π_t, and T_t represent money supply, nominal bonds, aggregate price, nominal interest rate, dividends from firms, and lump-sum transfer, respectively. Furthermore, we assume that nominal spending must be equal to the money supply:

$$P_t C_t = M_t. \tag{9}$$

The first-order conditions lead to

$$\frac{1}{C_t} = \mathbb{E}_t \left[\beta \frac{P_t}{P_{t+1}} R_t \frac{1}{C_{t+1}}\right] \tag{10}$$

$$W_t = M_t = P_t C_t. \tag{11}$$

A household is comprised of an infinite number of consumers who are uniformly located along the interval [0, 1]. A consumer located at $x \in [0, 1]$ is a distance x from firm A and $\delta - x$ from firm B. Because of the unit elasticity in equation (6), a consumer spends M in a nominal term to purchase from either firm A or firm B. Thus, $c = M/p^i$ if the consumer buys from firm $i = A, B$, where p^i represents firm i's price. The consumer's net surplus is written as

$$u^i = \log c^i - \tau d^i = \log M - \log p^i - \tau d^i, \tag{12}$$

where d^i represents the distance the consumer travels to firm i. Although we call τ the transport cost throughout the paper, this parameter also represents a consumer's choosiness, that is, how much he/she dislikes buying from his/her less preferred firm. When τ is high, the consumer is loyal to his/her preferred firm. When τ is low, the consumer cares about the prices sold in the two firms, acting as a bargain hunter.

Goods Market Clearing The goods market is cleared as $Y_t (= L_t^A + L_t^B) = C_t$.

Money Supply Money supply is exogenous and given by

$$\begin{aligned} \log(M_t/M_{t-1}) &= \varepsilon_t \\ &= \rho\varepsilon_{t-1} + \mu_t, \end{aligned} \tag{13}$$

where μ_t is an i.i.d. shock to money supply. Money supply has zero trend growth.

3.2 Steady State without Price Stickiness

Before we introduce price stickiness, we consider the equilibrium in steady state.

Firms' Pricing Denote the prices of firm A and firm B by p^A and p^B, respectively. A consumer will buy from firm A if

$$\log p^A + \tau x \leq \log p^B + \tau(\delta - x). \tag{14}$$

Each consumer purchases the amount of M/p^A if they purchase from firm A. Since the total number of consumers who purchase from firm A cannot exceed one or be negative, firm A's profit is written as

$$\Pi^A(p^A, p^B) = \begin{cases} 0 & \text{if } \frac{\log p^A - \log p^B}{\tau} \geq \delta \\ (p^A - W)\frac{\delta - \frac{\log p^A - \log p^B}{\tau}}{2}\frac{M}{p^A} & \text{if } \delta - 2 < \frac{\log p^A - \log p^B}{\tau} < \delta \\ (p^A - W)\frac{M}{p^A} & \text{if } \frac{\log p^A - \log p^B}{\tau} \leq \delta - 2. \end{cases} \tag{15}$$

Firm B's profit is expressed in a similar manner.

The maximization of firm profit given the rival firm's price yields the steady-state prices p^A and p^B, which satisfy

$$\begin{aligned} p^A + p^B &= 2W(1+\tau) \\ p^A - p^B + 2W(\log p^A - \log p^B) &= 2W(\delta - 1)\tau, \end{aligned} \tag{16}$$

which leads to

$$\begin{aligned}&p^A + W\left\{\log p^A - \log\left(-p^A + 2W(1+\tau)\right)\right\}\\=&W(1+\delta\tau),\end{aligned} \tag{17}$$

$$\begin{aligned}&p^B + W\left\{\log p^B - \log\left(-p^B + 2W(1+\tau)\right)\right\}\\=&W\left\{(1+\tau) - (\delta-1)\tau\right\}.\end{aligned} \tag{18}$$

This shows that higher δ increases p^A and decreases p^B.

Steady-state demand for firm A (i.e., x) is given by $\frac{\delta - \frac{\log p^A - \log p^B}{\tau}}{2}$,which equals $\frac{1}{2} + \frac{p^A - p^B}{4W\tau}$. Thus, higher δ increases demand for firm A and decreases demand for firm B.

When δ equals one, prices are symmetric, that is, $p = p^A = p^B$, which is given by

$$p = (1+\tau)\, W. \tag{19}$$

3.3 Pricing under Price Stickiness

We assume Calvo-type price stickiness. Firms A and B can reset their prices with a probability of $1-\theta_A$ and $1-\theta_B \in (0,1)$, respectively. Specifically, we introduce the following assumption. With the probability of θ_A or θ_B, firms survive in the next period but the price is kept fixed. With the probability of $1-\theta_A$ or $1-\theta_B$, an old firm exits the market and a new firm enters in its place and sets its price. Thus, only a new firm can optimize price. 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 rival firm's price in the previous period, and a shock to money supply. We exclude collusive pricing, although the folk theorem suggests that dynamic setting can generate multiple collusive equilibria.

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

$$\max \sum_{k=0}^{\infty} \theta_A^k \mathbb{E}_t \beta^k \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \left(1 - \frac{W_{t+k}}{\bar{p}_t^A}\right) \left(\frac{\delta - \frac{\log \bar{p}_t^A - \log p_{t+k}^B}{\tau}}{2}\right) \frac{M_{t+k}}{M_t}, \tag{20}$$

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 rival firm. Noting that p_{t+k}^B equals $\bar{p}_{t+k}^B$ with the probability of $1-\theta_B$, $\bar{p}_{t+k-1}^B$ with the probability of $\theta_B(1-\theta_B)$,$\cdots$, $\bar{p}_t^B$ with the probability of $\theta_B^k(1-\theta_B)$, and p_{t-1}^B with the probability of θ_B^{k+1} for $k \geq 0$, we have

$$\max \sum_{k=0}^{\infty} \theta_A^k \beta^k \mathbb{E}_t \left[\left(1 - \frac{M_{t+k}}{\bar{p}_t^A}\right) \theta_B^{k+1} \left(\frac{\delta - \frac{\log \bar{p}_t^A - \log p_{t-1}^B}{\tau}}{2} \right) \right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \frac{M_{t+k}}{M_t}$$
$$+ \sum_{k=0}^{\infty} \theta_A^k \beta^k \mathbb{E}_t \left[\left(1 - \frac{M_{t+k}}{\bar{p}_t^A}\right) \sum_{k'=0}^{k} (1-\theta_B)\theta_B^{k-k'} \left(\frac{\delta - \frac{\log \bar{p}_t^A - \log \bar{p}_{t+k'}^B}{\tau}}{2} \right) \right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \frac{M_{t+k}}{M_t}. \quad (21)$$

Hereafter, we assume $W_0 = M_0 = 1$ in the initial period. The first-order condition for the optimal $\bar{p}_t^A$ is given by

$$0 = \sum_{k=0}^{\infty} \theta_A^k \beta^k \mathbb{E}_t \left(\frac{1}{\bar{p}_t^A}\right)^2 M_{t+k} \left[\theta_B^{k+1} \left(\frac{\delta - \frac{\log \bar{p}_t^A - \log p_{t-1}^B}{\tau}}{2} \right) \right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \frac{M_{t+k}}{M_t}$$
$$+ \sum_{k=0}^{\infty} \theta_A^k \beta^k \mathbb{E}_t \left(\frac{1}{\bar{p}_t^A}\right)^2 M_{t+k} \left[\sum_{k'=0}^{k} (1-\theta_B)\theta_B^{k-k'} \left(\frac{\delta - \frac{\log \bar{p}_t^A - \log \bar{p}_{t+k'}^B}{\tau}}{2} \right) \right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \frac{M_{t+k}}{M_t}$$
$$+ \sum_{k=0}^{\infty} \theta_A^k \beta^k \mathbb{E}_t \left(1 - \frac{M_{t+k}}{\bar{p}_t^A}\right) \left(-\frac{1}{2\tau \bar{p}_t^A}\right) \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \frac{M_{t+k}}{M_t}$$
$$+ \sum_{k=0}^{\infty} \theta_A^k \beta^k \mathbb{E}_t \left(1 - \frac{M_{t+k}}{\bar{p}_t^A}\right) \left[\sum_{k'=0}^{k} (1-\theta_B)\theta_B^{k-k'} \frac{\partial \log \bar{p}_{t+k'}^B / \partial \log \bar{p}_t^A}{2\tau \bar{p}_t^A} \right] \cdot \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \frac{M_{t+k}}{M_t}.$$

Firm A has to take account of how its reset price at t influences the rival firm B's reset price at $t+k'$, which is given by $\partial \log \bar{p}_{t+k'}^B / \partial \log \bar{p}_t^A$. In log-linearization, let us denote $\bar{p}_t^A \equiv p^A M_t e^{p_t^{A*}}$, $p_t^B \equiv p^B M_t e^{\hat{p}_t^B}$ as well as $\partial \log \bar{p}_{t+k}^B / \partial \log \bar{p}_t^A \equiv \Gamma^{BA}$ for any $k \geq 1$. The coefficient Γ^{BA} will be defined in detail later. It is independent of k because we consider a case in which the price of firm A is unchanged at $\bar{p}_t^A$).

Steady State In the steady state, price equals

$$p^A = 1 + \tau \left(\delta - \frac{\log p^A - \log p^B}{\tau} \right) \left(1 - \frac{(1-\theta_B)(1+\theta_B - \beta\theta_A\theta_B)}{1-\beta\theta_A\theta_B} \beta\theta_A \Gamma^{BA} \right)^{-1}. \quad (22)$$

Unless Γ^{BA} is zero, the steady state under nominal rigidity is different from that without nominal rigidity. Firms take account of the effect of their price on the rival firm's price in the following periods. Specifically, if Γ^{BA} is positive, there is a dynamic strategic complementarity. An increase in firm A's price increases firm B's price in the following periods. This effect increases the steady-state price level. The above equation also shows that the steady-state price level becomes identical with that in the scenario without nominal rigidity in the limit of $\theta_A \to 0$. Given Γ^{BA}, the steady-state price level increases as θ_A increases.

Log-linearization around the Steady State The optimal reset prices are expressed in the following forms:

$$p_t^{A*} = \Gamma^{AA}\hat{p}_{t-1}^{A} + \Gamma^{AB}\hat{p}_{t-1}^{B} + \Gamma^{A\varepsilon}\varepsilon_t \tag{23}$$

$$p_t^{B*} = \Gamma^{BB}\hat{p}_{t-1}^{B} + \Gamma^{BA}\hat{p}_{t-1}^{A} + \Gamma^{B\varepsilon}\varepsilon_t, \tag{24}$$

$$\partial \log \bar{p}_{t+k}^{B} / \partial \log \bar{p}_t^{A} = \partial p_{t+k}^{B*} / \partial p_t^{A*} = \Gamma^{BA}. \tag{25}$$

Firms A and B set their prices simultaneously, so that neither firm knows whether the rival resets its price in the current period. Therefore, the optimal reset price is written as a function of prices in not the current period but the previous period. Furthermore, firm A's value is influenced by firm B's reset price in the current period, if resetting occurs, and firm B's reset price is influenced by firm A's price in the previous period. Therefore, firm A's optimal reset price depends on its own price in the previous period. Further, the optimal reset price depends on a stochastic aggregate shock in the current period.

The coefficients Γ^{AA} and Γ^{BB} (hereafter, summarized as Γ) show the elasticity of the optimal price in the current period with respect to a change in its own in the previous period. The coefficients Γ^{AB} and Γ^{BA} (hereafter, summarized as Γ^*) show the elasticity of the optimal price in the current period with respect to a change in the rival's price in the previous period. Particularly, Γ^* shows the degree of dynamic strategic complementarity if it is positive. The coefficients $\Gamma^{A\varepsilon}$ and $\Gamma^{B\varepsilon}$ (hereafter, summarized as Γ^{ε}) show the elasticity of the optimal price with respect to the money supply shock. A smaller Γ^{ε} means that the price reacts less strongly to the money supply shock, amplifying the real effect of monetary policy. In general, the policy function for the optimal reset price, particularly Γ^*, depends on the aggregate state. However, owing to log-linearization, it is written as a constant, which simplifies our analysis.

Note that, if nominal price is unchanged, the log-linearized price denoted by $\hat{p}$ changes by the amount of the change in the aggregate money supply times -1: $\hat{p}_t = \hat{p}_{t-1} - \varepsilon_t$.

Finally, aggregate output is given by $Y_t = M_t/P_t$, which is log-linearized as

$$\hat{Y}_t = -\hat{P}_t. \tag{26}$$

3.4 Simulation

A time unit is a quarter. In the benchmark, we normalize $W = 1$. We set transport cost $\tau = 0.125$, so that the steady-state markup (without price stickiness) and the demand elasticity are the same as those assumed in a standard New Keynesian model based on CES preferences and monopolistic competition. That is, the elasticity of substitution σ equals 9, as assumed in Gali 2015. See Appendix for the comparison with a standard New Keynesian model. The benchmark price stickiness is set at $\theta = 0.75$, which implies price revisions occur once per year. We also use $\rho = 0.85$ and $\beta = 0.99$.

Coefficients Γ, Γ^*, and Γ^ε in the policy function are determined to satisfy the first-order condition for the optimal $\bar{p}_t^A$ and $\bar{p}_t^B$. We solve Γ, Γ^*, and Γ^ε numerically.

When Firms are Symmetric Let us begin with the results under symmetry, which replicates Ueda (2021). The upper left-hand panel and the other three panels of Figure 4 show the steady-state price and the coefficients on the policy function (Γ, Γ^*, and Γ^ε), respectively. For each panel, two solid lines are depicted for firms A and B, in addition to the dashed line for a representative monopolistic firm in a standard New Keynesian model based on CES preferences and monopolistic competition. The horizontal axis indicates the degree of asymmetry in competitiveness, δ, so that $\delta = 1$ represents the case of symmetry.

The figure shows that both Γ and Γ^* are positive. This suggests that a firm revises its price upward when its previous price was high (i.e., $\Gamma > 0$) or its rival's previous price was high (i.e., $\Gamma^* > 0$). Particularly, positive Γ^* implies the dynamic strategic complementarity, thereby causing a higher markup in the steady state under sticky prices than that under flexible prices, as illustrated in equation (22). In the standard New Keynesian 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, aggregate prices in our model are more staggered than those in the standard New Keynesian model, yielding a larger real effect of monetary policy, as we will show below.

We calculate the impulse response functions (IRFs) to a positive money supply shock ($\mu_t = 1$ at $t = 1$) for aggregate inflation rate π_t and output $\hat{Y}_t$. The solid line in Figure 5 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 larger by approximately 50% than that in the standard New Keynesian model, shown as the dashed line.

When Firms are Asymmetric in Terms of Competitiveness Next, consider asymmetry $\delta > 1$. As δ increases, firm A becomes more competitive than firm B. Figure 4 shows that this asymmetry increases and decreases the markup of firms A and B, respectively. Whereas Γ is hardly different between firms A and B, the dynamic strategic complementarity Γ^* comes to depart as δ increases. Specifically, Γ^{AB} for firm A decreases, while Γ^{BA} for firm B increases. As firm A becomes more competitive, it cares firm B less and firm B cares firm A more. Consequently, firm A responds to the aggregate shock more strongly, while firm B does less.

Although this result seems intuitive and straightforward, early studies actually obtain opposing results. Atkeson and Burstein (2008) and Wang and Werning (2020) argue that a firm with a larger market share responds more strongly to a rival firm's price, while the rival firm becomes less responsive. WHY???

The next question is how much these asymmetric responses of the two firms change aggregate implications. The solid line with filled circles in Figure 5 shows that the IRFs under asymmetry, specifically, when $\delta = 3$. It shows that asymmetry in competitiveness does not influence aggregate consequences. On the one hand, less competitive firm (firm B) makes stickier price setting, which increases the real effect of monetary policy. On the other hand, more competitive firm (firm A) makes less sticky price setting, which decreases the real effect of monetary policy. These two cancel out each other, leading to the hardly changed real effect of monetary policy by heterogeneity in competitiveness.

When Firms are Asymmetric in Terms of Price Stickiness We investigate the effects of asymmetry in terms of price stickiness θ. In Figure 6, the horizontal axis indicates θ_A for firm A. Price stickiness θ_B for firm B changes following $\theta_B = 2\theta - \theta_A$ so that the aggregate price stickiness θ is kept at 0.75. Thus, $\theta_A = 0.75$ corresponds to the case of symmetry. For a representative monopolistic firm in the standard New Keynesian model, we assume that θ for all firms changes homogeneously.

The lower left-hand panel shows that, on the one hand, the pricing of firm A with low price stickiness (θ_A) entails a greater degree of dynamic strategic complementarity Γ^{AB}. Firm A understands that the rival's price is sticky and thus likely to be kept unchanged today. Thus, the rival's price in the previous period becomes an increasingly important state variable for firm A as θ_B increases (i.e., θ_A decreases). On the other hand, the pricing of firm B with high price stickiness entails a smaller degree of dynamic strategic complementarity Γ^{BA}.

The next question is again how much these asymmetric responses of the two firms change aggregate implications. Note that firm B's price setting is less frequent. Thus, even if firm B decreases a degree of dynamic strategic complementarity, firm B's price is already sticky. By contrast, firm A's price setting is frequent. Thus, the effect of the increase in dynamic strategic complementarity Γ^{AB} on firm A's price stickiness is large. Therefore, aggregate price stickiness increases due to the heterogeneity in price stickiness.

Figure 7 shows that this is indeed the case. 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 show the IRFs to a positive money supply shock ($\mu_t = 1$ at $t = 1$). 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 δ ($\delta = 3$), and duopolistic firms with asymmetric δ and θ ($\delta = 3$, $\theta_A = 0.6$, and $\theta_B = 0.9$). Note that the case of asymmetric δ is almost identical with the case of symmetry, as was shown in Figure 5, which indicates that the real effect of monetary policy is larger by approximately 50% than that in the standard New Keynesian model. Moreover, it should be noted that the asymmetry in terms of price stickiness θ is irrelevant to the IRFs in the log-linearized standard New Keynesian model, which we show in Appendix.

The amplified real effect of monetary policy can be explained also by the change in the price response to the aggregate shock Γ^{ε}. The lower right-hand panel of Figure 6 shows coefficient Γ^{ε}. Particularly, firm A's Γ^{ε} decreases when 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 a need for preemptive price increase today for this continuation of positive aggregate state. In fact, 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 the dynamic strategic complementarity. As we discussed in the above, lower price stickiness for firm A (θ_A) combined with higher price stickiness for the rival (θ_B) increases the degree of dynamic strategic complementarity Γ^{AB} for firm A. Owing to this enhanced strategic complementarity, firm A responds less strongly to the aggregate shock, decreasing Γ^{ε}. By contrast, firm B does not pay much attention to firm A (thus, small Γ^{BA}). Thus, the gap of 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 size of the strategic pricing effect on Γ^{ε} depends on the value of θ and decreases as θ increases. Therefore, in aggregation, 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 aggregate price in response to the aggregate shock and increasing the real effect of monetary policy.

The upper left-hand panel of Figure 6 shows that price stickiness influences the steady-state price level. As equation (22) shows, the steady-state price level is influenced by price stickiness θ_A and the dynamic strategic complementarity Γ^*; moreover, Γ^* is influenced by θ_A. On the one hand, lower θ_A decreases the steady-state price level. On the other hand, as discussed above, lower θ_A increases Γ^*, which in turn increases the steady-state price level. Therefore, the effect of price stickiness on the steady-state price level is not monotonic. According to the simulation, the steady-state price level exhibits a U shape, where an intermediate value of θ^A around 0.7 yields the lowest steady-state price level for firm A. The figure also shows that the steady-state price for firm B increases more than that for firm A when $\theta_B > \theta_A$.

These results suggest that, although firm A can revise its price more frequently, enhanced strategic complementarity works to increase aggregate price stickiness. In contrast, firm B with higher price stickiness sets its price with smaller strategic complementarity and reacts more strongly to the aggregate shock, decreasing aggregate price stickiness. Now we ask how much these asymmetric responses change the aggregate effect of monetary policy.

The real effect of monetary policy is further stronger when two types of asymmetry coexists. We consider duopolistic firms with asymmetric δ and θ ($\delta = 3$, $\theta_A = 0.6$, and $\theta_B = 0.9$), because we observed in the empirical part of this paper that a firm with a higher market share (i.e., higher δ) tends to change prices more frequently (i.e., smaller θ). The figure shows that the size of real effects is almost three times as large as that in the standard New Keynesian model.

4 Concluding Remarks

The model suggests that a large firm makes the following price setting. The firm is competitive so that it has little need to pay attention to rivals. It makes aggressive price setting in response to aggregate shocks. However, the firm tends to have low nominal price stickiness. Thus, the firm realizes that rivals may not follow quickly when it changes its price, which decreases its profits. Thus, the firm need to pay attention to rivals, preventing it from aggressive price setting. In aggregate, nominal stickiness increases.

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Table 1: Reasons for Low Price Increase Expectations (Q12)

	No of firms	1 Applicable well	2 Applicable	3 Not very applicable	4 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) Others	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 to the current level?" Then, we asked the firms that answered "the increase will be less than 1 percent annually" "What is the reason why you expect that the level of shipping prices will not increase much compared to 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. So there is no need to raise shipping prices." Reasons (2) to (7) started from 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 they 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)." Unit is percent except for the number of firms.

Table 2: Reasons for Insufficient Price Increase under Yen Depreciation (Q21)

	No of firms	1 Applicable well	2 Applicable	3 Not very applicable	4 Not at all
(1) Because you expected a significant decrease in sales volume if you raised prices.	109	34.9	48.6	12.8	3.7
(2) Because distributors (wholesalers and retailers) were strongly opposed to the price increase.	110	28.2	41.8	20.9	9.1
(3) Because other firms in the same industry were expected to keep their prices unchanged.	110	23.6	39.1	27.3	10.0
(4) Because the depreciation of yen is unlikely to continue forever and we have decided to endure it until it ends.	109	3.7	16.5	45.0	34.9
(5) Because you thought that raising the price might cause anger or antipathy among consumers.	109	11.0	33.0	41.3	14.7
(6) Others	14	85.7	14.3	0.0	0.0

Notes: In the preceding question (Q20), we asked firms, "Was your firm's price increase for this product in response to the depreciation of yen between December 2012 and June 2015 sufficient?" Then, we asked the firms that chose "to some extent, but not sufficiently" or "not at all" in this question, "Please explain why you were not able to fully pass on the weaker yen to shipping prices." Unit is percent except for the number of firms.

Table 3: Reasons for Price Rigidity in Relation to Competition

	(1) Q12 (competitors)	(2) Q21 (competitors)	(3) Q12 (consumers)	(4) Q21 (consumers)	(5) Q12 (retailers)	(6) Q21 (retailers)
Log(no. of competitors)	-0.119***	-0.058	-0.104	-0.108	-0.140**	-0.084
	(0.043)	(0.081)	(0.074)	(0.067)	(0.062)	(0.075)
Market share	0.000	0.011**	-0.000	-0.002	-0.003	0.002
	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.006)
Constant	2.116***	2.222***	2.202***	2.199***	2.284***	2.214***
	(0.165)	(0.265)	(0.228)	(0.257)	(0.219)	(0.275)
N	87	76	87	75	86	76
R2	0.051	0.094	0.033	0.038	0.047	0.023

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: In Q12, we asked firms, "What is the reason why you expect that the level of shipping prices will not increase much compared to the current level, or will decrease?" In Q21, we asked firms, "Please explain why you were not able to fully pass on the weaker yen to shipping prices." For each question, we asked whether the reason is that competitors are unlikely to raise their prices (competitors), consumers are price sensitive (consumers), or retailers are opposed to price increases (retailers). Firms choose an answer from 1 to 4 for each reason, where 1 is "applicable well," 2 is "applicable", 3 is "not very applicable," and 4 is "not at all."

Table 4: Price Change in Response to Depreciation from December 2012

	(1) Frequency	(2) Size	(3) Frequency	(4) Size
Log(no. of competitors)	0.001	-0.114	-0.207	-1.739
	(0.064)	(0.630)	(0.131)	(1.804)
Market share	0.009*	0.104	0.017**	0.287**
	(0.005)	(0.063)	(0.007)	(0.094)
Constant	0.376	2.835	0.808	4.485
	(0.281)	(2.533)	(0.448)	(5.834)
N	49	49	21	21
Category fixed effect	no	no	yes	yes
No. of categories	–	–	9	9
R2	0.064	0.095	0.627	0.755
Within R2	0.064	0.095	0.322	0.519

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: In Q19, we asked firms, "In response to the depreciation of yen between December 2012 and June 2015, did your firm actually raise the shipping price of this product?" Firms answered the frequency, size, and timing of price changes.

Table 5: Relationship between the Frequency of Regular-Price Changes and the Competitive Environment

	Frequency of regular price changes:					
	Product level			Firm level		
	fr^+	fr^-	$fr^+ - fr^-$	fr^+	fr^-	$fr^+ - fr^-$
Market share	0.0004***	0.0004***	-0.00005***	0.0002***	0.0002***	0.000007**
	(73.55)	(83.41)	(-10.26)	(70.58)	(57.95)	(2.05)
HHI	0.0005	0.0008**	-0.0003	-0.0005***	-0.0005***	-0.000059
	(1.46)	(2.32)	(-0.94)	(-3.71)	(2.32)	(-0.39)
Observations	262,156	262,156	262,156	323,119	323,119	323,118

Notes: *p<0.1; **p<0.05; ***p<0.01. The values in the parenthesis are the t-values.
Dummies: period, firm, category
Use only data from the top 100 products/firms by (market share × sample period)

Table 6: Relationship between Sales and Price-Change Correlation with Other Firms

	Dependent variable:
	$n^+ - n^-$
Market share	0.011***
	(34.41)
Observations	18,249
Dummy	category

Notes: *p<0.1; **p<0.05; ***p<0.01. The value in the parenthesis is the t-value. For the dependent variable, n^+ and n^- represent the fraction of firms with the significant positive and negative, respectively, Spearman's rank correlations for price changes between a pair of firms.

Table 7: Relationship between Price Increase and the Competitive Environment

	Dependent variable:			
	π	fr	π	fr
	(1)	(2)	(3)	(4)
Market share	0.071^{**}	0.005^{***}	0.124^{***}	0.005^{***}
	(0.029)	(0.001)	(0.030)	(0.001)
HHI	0.084^{***}	-0.002^{***}	0.447	-0.027^{*}
	(0.015)	(0.001)	(0.462)	(0.016)
Constant	0.019^{***}	0.003^{***}		
	(0.004)	(0.0001)		
Observations	1741	1741	1741	1741
Dummy	No	No	period/category	period/category
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 8: Relationship between Price Decrease and the Competitive Environment

	Dependent variable:			
	π	fr	π	fr
	(1)	(2)	(3)	(4)
Market share	-0.094	0.003^{**}	-0.157^{***}	0.004^{***}
	(0.057)	(0.001)	(0.058)	(0.001)
HHI	0.086^{**}	-0.002	3.361	0.008
	(0.043)	(0.001)	(2.151)	(0.051)
Constant	-0.055^{***}	0.002^{***}		
	(0.011)	(0.0003)		
Observations	401	401	401	401
Dummy	No	No	period/category	period/category
Note:				*p<0.1; **p<0.05; ***p<0.01

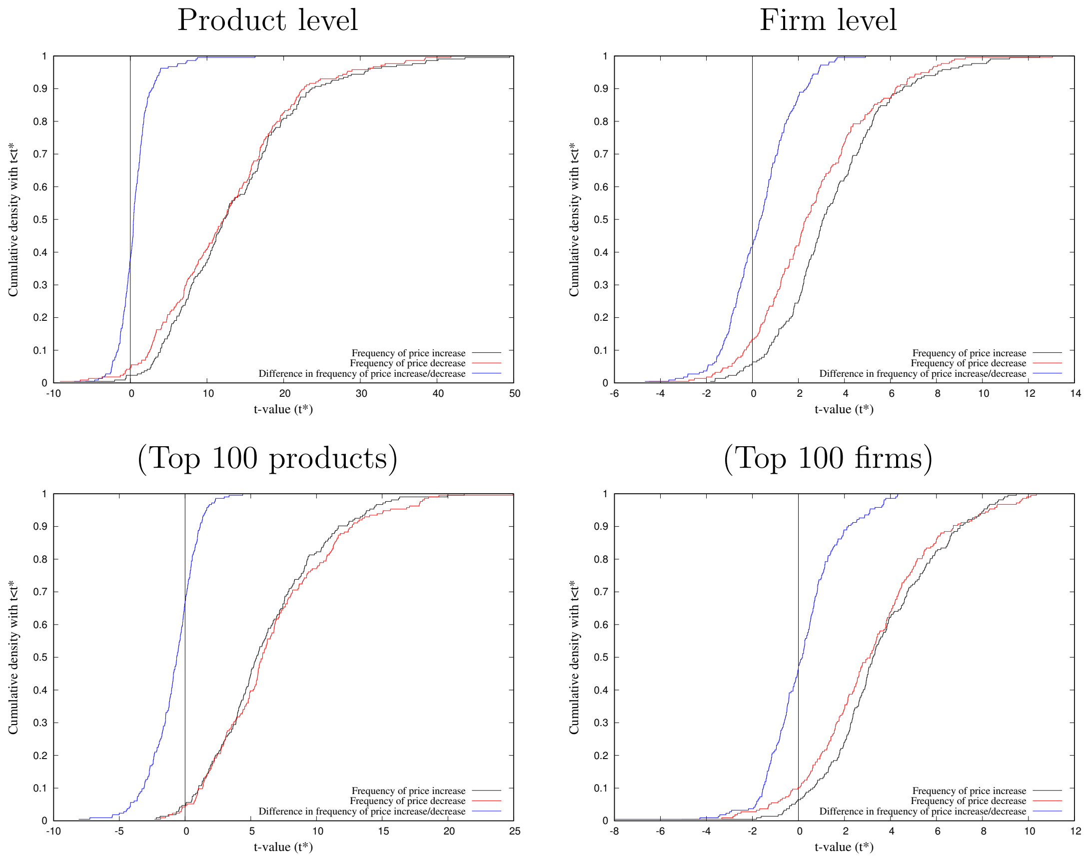
Table 9: Dates of Price Increases and Their Annoucements

Category	Date of Price Revision		Firm	Market share
	Announcement	Revison		
Coffee	09-Dec-2004	01-Mar-2005	UCC	
	10-Feb-2005	01-Mar-2005	Key Coffee	
Mayonnaise	08-May-2007	01-Jun-2007	Kewpie	
	29-May-2007	03-Jul-2007	Ajinomoto	
Pasta	02-Aug-2007	01-Sep-2007	Nisshin Foods	
	14-Aug-2007	03-Sep-2007	NIPPN	
Pasta	01-Oct-2007	15-Nov-2007	Nisshin Foods	
	04-Oct-2007	20-Nov-2007	NIPPN	
	06-Oct-2007	20-Nov-2007	Showa Sangyo	
	22-Oct-2007	01-Dec-2007	Hagoromo Foods	
Instant noodle	06-Sep-2007	01-Jan-2008	Nisshin Foods	
	25-Sep-2007	01-Jan-2008	Myojo Foods	
	03-Oct-2007	01-Jan-2008	Toyo Suisan	
	11-Oct-2007	01-Jan-2008	Acecook	
	19-Oct-2007	01-Jan-2008	Maruka Foods	
Pasta	17-Jan-2008	01-Mar-2008	Nisshin Foods	
	24-Jan-2008	01-Mar-2008	NIPPN	
	24-Jan-2008	01-Mar-2008	Showa Sangyo	
	28-Jan-2008	01-Mar-2008	Hagoromo Foods	
Mayonnaise	23-May-2008	01-Aug-2008	Kewpie	
	20-May-2008	23-Jul-2008	Ajinomoto	
	26-Aug-2008	01-Oct-2008	Otafuku Foods	
Potato chips	08-Sep-2008	03-Nov-2008	Calbee	
	25-Sep-2008	17-Nov-2008	Koikeya	
Coffee	27-Dec-2010	01-Mar-2011	Key Coffee	
	25-Jan-2011	10-Mar-2011	UCC	
	08-Feb-2011	01-Apr-2011	Ajinomoto AGF	
Pasta	23-May-2011	01-Jul-2011	Nisshin Foods	
	26-May-2011	01-Jul-2011	Showa Sangyo	
	27-May-2011	01-Jul-2011	NIPPN	
Mayonnaise	08-May-2013	01-Jul-2013	Kewpie	
	20-May-2013	01-Aug-2013	Ajinomoto	
	22-May-2013	01-Jul-2013	Kenko Mayonnaise	
	30-May-2013	01-Aug-2013	SSK Foods	
Instant noodle	29-Sep-2014	01-Jan-2015	Nisshin Foods	
	02-Oct-2014	01-Jan-2015	Toyo Suisan	
	03-Oct-2014	01-Jan-2015	Myojo Foods	
	08-Oct-2014	01-Jan-2015	Sanyo Foods	
	10-Oct-2014	01-Jan-2015	Acecook	
	16-Oct-2014	16-Jan-2015	House Foods	
	17-Oct-2014	01-Jan-2015	Maruka Foods	

Category	Date of Price Revision		Firm	Market share
	Announcement	Revison		
Pasta	22-Oct-2014	05-Jan-2015	Nisshin Foods	
	30-Oct-2014	05-Jan-2015	NIPPN	
	12-Nov-2014	05-Jan-2015	Showa Sangyo	
	09-Jan-2015	02-Mar-2015	Hagoromo Foods	
Pasta	23-Apr-2015	01-Jul-2015	Nisshin Foods	
	30-Apr-2015	01-Jul-2015	Showa Sangyo	
	01-May-2015	01-Jul-2015	NIPPN	
Chocolate	14-May-2015	07-Jul-2015	Meiji	
	26-May-2015	14-Jul-2015	Morinaga	
	03-Jun-2015	14-Jul-2015	Lotte	
Potato chips	01-Mar-2019	21-May-2019	Calbee	
	06-Mar-2019	01-Jun-2019	Koikeya	
Instant noodle	05-Feb-2019	01-Jun-2019	Nisshin Foods	
	13-Feb-2019	01-Jun-2019	Myojo Foods	
	19-Feb-2019	01-Jun-2019	Toyo Suisan	
	27-Feb-2019	01-Jun-2019	Sanyo Foods	
	27-Feb-2019	01-Jun-2019	House Foods	
	28-Feb-2019	01-Jun-2019	Acecook	
	05-Mar-2019	01-Jun-2019	Maruka Foods	
Pasta	19-May-2021	01-Jul-2021	Nisshin Foods	
	26-May-2021	01-Jul-2021	Showa Sangyo	
	17-Jun-2021	01-Sep-2021	NIPPN	
	14-Jul-2021	01-Sep-2021	Hagoromo Foods	
Mayonnaise	26-Apr-2021	01-Jul-2021	Kewpie	
	28-Apr-2021	01-Jul-2021	Ajinomoto	
	19-May-2021	01-Aug-2021	SSK Foods	
Coffee	08-Jul-2021	01-Sep-2021	UCC	
	03-Aug-2021	01-Oct-2021	Ajinomoto AGF	
	06-Aug-2021	01-Oct-2021	Key Coffee	
	01-Nov-2021	01-Jan-2022	Nestle	
Pasta	25-Oct-2021	04-Jan-2022	Nisshin Foods	
	28-Oct-2021	04-Jan-2022	Showa Sangyo	
	10-Nov-2021	04-Jan-2022	NIPPN	

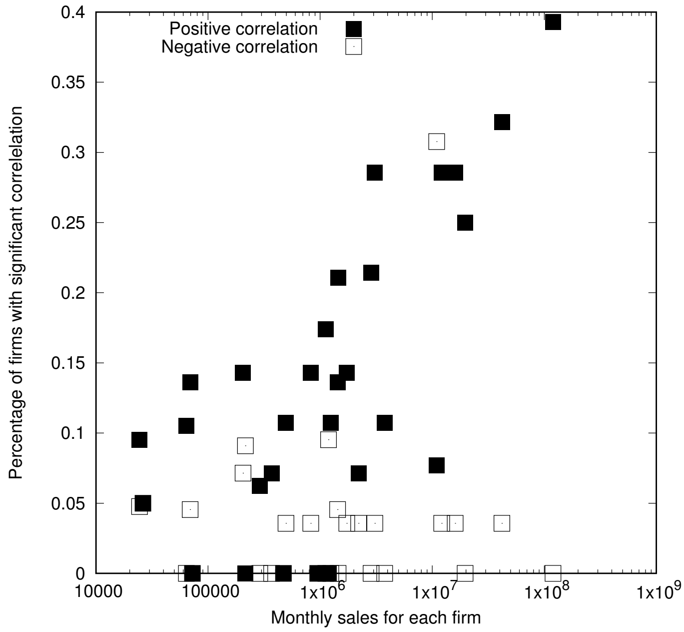
Sources: Nihon Keizai Shinbun and firms' IR materials.

Figure 1: Cumulative Distribution of t-value for the Coefficient on Market Share



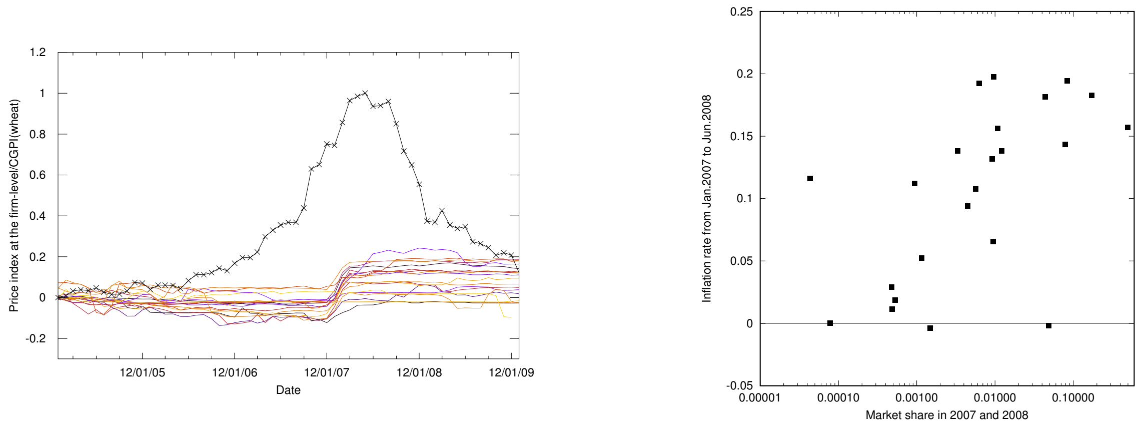
Notes: We run the regression for the frequency of regular-price increase/decrease on the market share for each product cateogry. The vertical axis represents the fraction of product categories in which the t-value for the coefficient on the market share takes a value less than or equal to t^* (horizontal axis). The left- and right-hand panels show the results for product- and firm-level regression, respectively. The upper and lower panels show the results when using all products/firms and top 100 products/firms in terms of market share $\times$ observation periods, respectively.

Figure 2: Relationship between Sales and Price-Change Correlation with Other Firms (Instant Cup-Noodle Category)



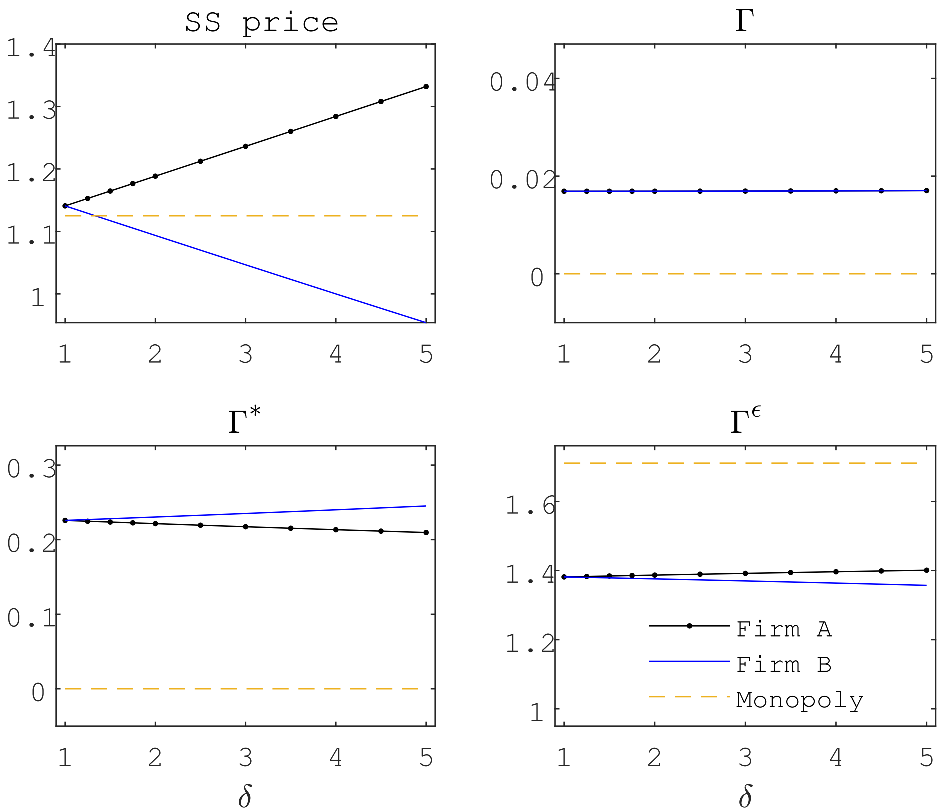
Notes: The vertical axis represents the fraction of firms with the significant correlations for price changes between a pair of firms.

Figure 3: Changes in the Price Index for Each Cup-Noodle Manufacturer



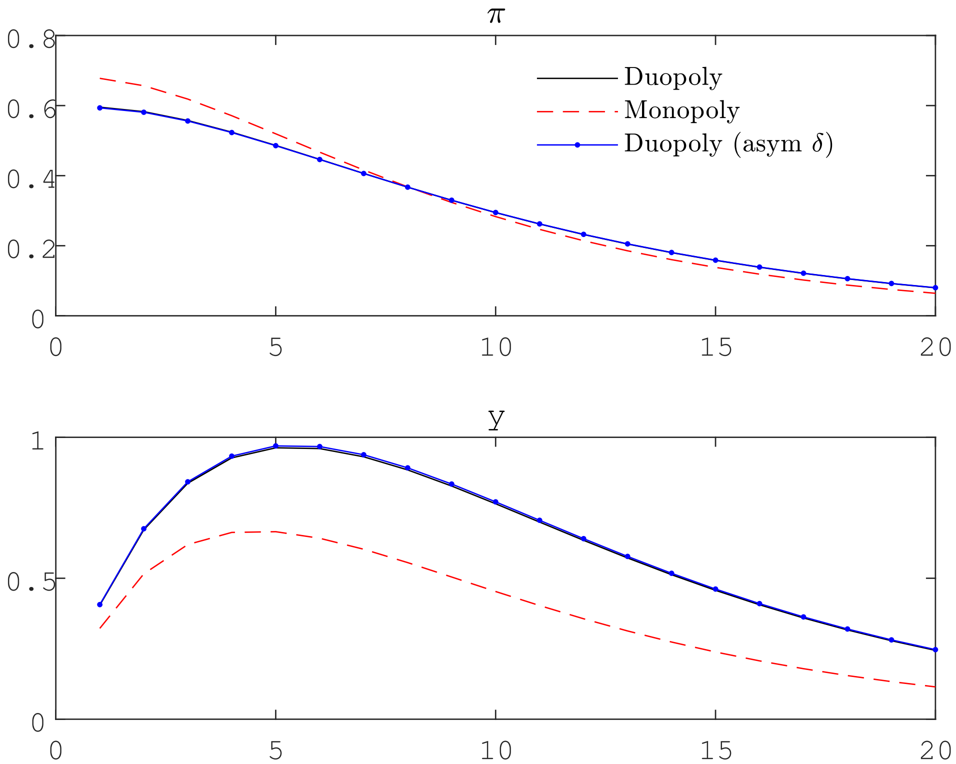
Notes: In the left-hand panel, each line represent the changes in the price index for each instant cup noodle manufactuer, whereas the line with the cross represents the changes in the wheat price based on the CGPI. Prices changes from December 2004 are shown. The right-hand panel shows the scatter plot, where each dot represents an instant cup noodle manufactuer.

Figure 4: Policy Functions under Asymmetry in Competitiveness δ



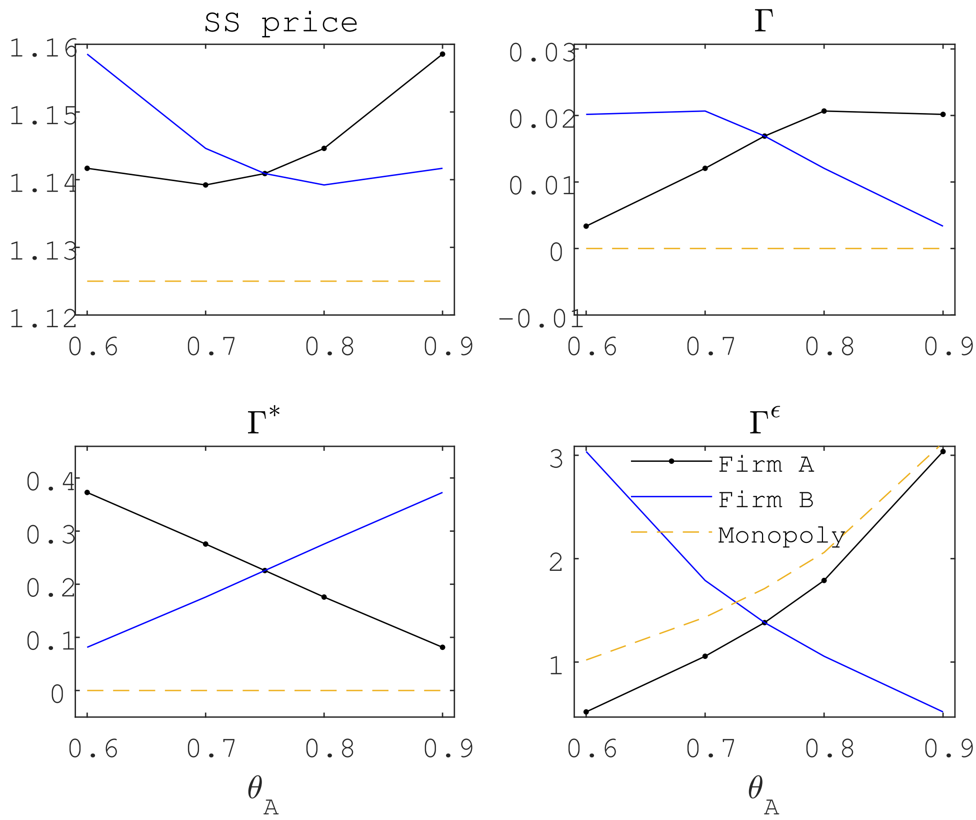
Notes: The figure shows the steady-state (SS) prices and coefficients of policy functions for the optimal reset price. Own and cross elasticity is denoted by Γ and Γ^*, respectively. Specifically, Γ equals Γ^{AA} for firm A and Γ^{BB} for firm B whereas Γ^* equals Γ^{AB} for firm B and Γ^{BA} for firm B. The horizontal axis represents competitiveness δ, where higher δ indicates greater competitiveness of firm A than firm B and two firms are equally competitive when $\delta = 1$.

Figure 5: IRF under Asymmetry in Competitiveness δ



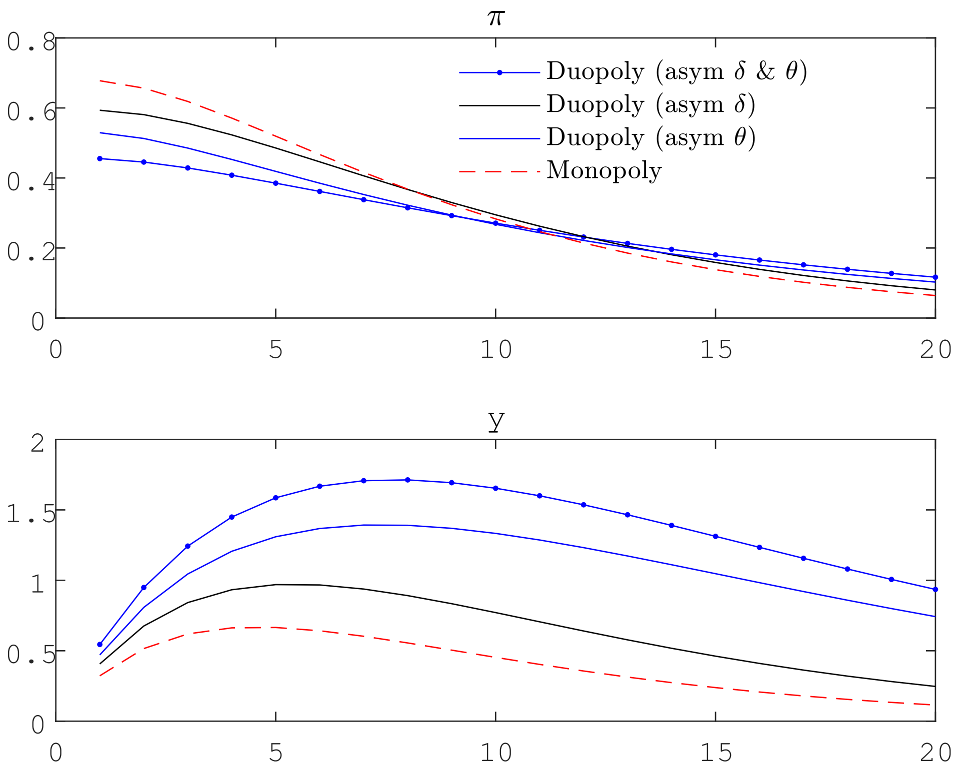
Notes: δ equals 3 in the model "Duopoly (asym δ)."

Figure 6: Policy Functions under Asymmetry in Price Stickiness θ



Notes: The figure shows the steady-state prices and coefficients of policy functions for the optimal reset price. Own and cross elasticity is denoted by Γ and Γ^*, respectively. Specifically, Γ equals Γ^{AA} for firm A and Γ^{BB} for firm B whereas Γ^* equals Γ^{AB} for firm B and Γ^{BA} for firm B. The horizontal axis represents Calvo-type price stickiness for firm A, θ^A. Price stickiness for firm B is $\theta_B = 2\theta - \theta_A$ so that the average price stickiness θ is kept at 0.75.

Figure 7: IRF under Asymmetry in Both Competitiveness δ and Price Stickiness θ



Notes: θ_A and θ_B equal 0.6, and 0.9, respectively, in the model "Duopoly (asym θ);" δ equals 3 in the model "Duopoly (asym δ);" and δ, θ_A, and θ_B equal 3, 0.6, and 0.9, respectively, in the model "Duopoly (asym δ&θ)."