Market Position and Aggregate Price Dynamics

The Role of Industry Leaders in the Pass-Through of Cost Shocks

Gregory Auclair*

October 2023

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Abstract

Do differences in market position affect aggregate price dynamics? The emergence of 'stagflation' in the 1970's challenged the view firms would lower prices given slack demand. Since then, expectations have played a central role in monetary economics. While this paper still emphasizes expectations as a key driver of inflation, it also argues market power and cost-push factors have a prominent role. To do so, it uses a general equilibrium framework incorporating an industry structure with strategic interaction between firms. It links complementarity in pricing to the pass-through of cost shocks. The approach builds upon a set of stylized facts. There are strong indications the leading firm in an industry charges significantly higher markups compared to other firms. At the same time, their pricing behavior differs. Large firms limit the pass-through of cost shocks and respond in-kind to price changes by competitors. Small firms behave monopolistically. The framework replicates this behavior and yields several useful results. First, the pass-through for large firms is relatively low when faced with idiosyncratic shocks. Following an aggregate shock, the pass-through increases around 35 percent. This aligns with evidence from Gödl-Hanisch and Menkhoff (2023) and suggests cost-push inflation is prominent when shocks are general across firms, for example an increase in energy prices. The results also match observed business cycle fluctuations and help explain a number of other outcomes. The framework provides a basis to evaluate dynamic welfare losses from market distortions. The efficient reallocation of demand across firms following a shock crucially depends on how firms exercise market power. When a negative shock affects small firms more, the model shows large firms raise prices, leading to 'excess' profits. The markup distortion amplifies the underlying shock by 10 percent in a baseline scenario.

1 Introduction

Macroeconomic models describing aggregate price dynamics typically assume monopolistic competition across identical firms. Starting with the observation a few firms account for the majority of sales within most industries, a growing body of research indicates market position affects pricing behavior.[1] Leading firms absorb cost shocks and act strategically, matching price changes by rival firms. Meanwhile, smaller firms on the competitive fringe act monopolistically and adjust prices in line with their costs. A simple market structure with identical firms cannot fully account for these dynamics. To evaluate the aggregate effects, this paper embeds a nested-CES demand system featuring asymmetric firms into a New Keynesian framework, matching observed price dynamics across firms. In particular, the results show strategic complementarity

*PhD Candidate in Macroeconomics, International Economics Department, IHEID. My thanks to my advisor Cédric Tille, Annaïg Morin for comments, and many others. Author's email: allan.auclair@graduateinstitute.ch

[1] As will be discussed in section 2.1.2, more than 60 percent of market share is controlled by the top two firms on average when looking within narrowly defined markets for consumer goods. This result appears consistent across various studies.

can affect the pass-through of cost shocks, resulting in large shifts between low-inflation and high-inflation regimes.[2] Differences in the pass-through also explain business cycle fluctuations across firms and evolution of price and markup dispersion following shocks.

The analysis is motivated by concern market concentration in the United States and Europe has increased the pricing power of firms. Market concentration has two distinct dimensions (i) the number of market participants and (ii) control of markets by leading firms. Both aspects appear important. Market participation has declined while the markup and market share of leading firms increased (Grullon et al., 2019). These concerns have rekindled a long-standing debate on whether the pass-through of cost shocks relates to inflation expectations or pricing power. Before the 1970's, many economists believed slack demand would lead prices to fall. The simultaneous rise of unemployment and prices (or 'stagflation') challenged this assumption and expectations were later viewed as the main driver of inflation (Cagan, 1979).[3] This paper shows that changes in the pass-through reflect both expectations and pricing power.[4] In a low-inflation regime, leading firms limit the pass-through of cost shocks, even when shocks are highly persistent. They substantially raise the pass-through during periods of high inflation.

The modeling approach combines a nested-CES demand system and firm heterogeneity to acheive this outcome.[5] Quasi-kinked demand, e.g. Kimball (1995), is commonly used to explain why firms limit the pass-through. In this case, the second derivative of the price elasticity of demand is negative with respect to the firm's *own* price. The resulting curvature makes large price increases costly compared to small ones. The nested-CES specification adds strategic interaction between firms, an element Kimball demand omits. With strategic complementarity, firms match the price movements of their competitors and the cross-price second derivative is positive. Given a realistic market structure with finite firms, both own- and cross-price effects are present. When firms are heterogeneous, these forces offset to varying degrees. The implied pass-through therefore depends on three main factors: the 'aggregate' nature shocks, their expected persistence, and the strength of strategic complementarity across firms.[6] Along with the demand schedule, two additional margins may explain differences in pricing behavior across firms: (i) differing nominal price rigidities and (ii) unequal changes in marginal costs following a shock. Their interaction is not straightforward and this paper considers them separately.

There are several additional outcomes of interest. The model links price dispersion to firm heterogeneity. Compared with price staggering, a more common approach, it better matches the observed changes in price dispersion following shocks, for example Sheremirov (2020). On this point, it has some similarity to Guimaraes and Sheedy (2011), which uses strategic interaction to explain sales. In addition, this paper evaluates the efficiency costs of market power. Changes in market share and the allocation of demand depend on how firms adjust their prices following shocks. Under certain conditions, firms may exploit their market power, leading to an inefficient allocation. This analysis draws on Baqaee et al. (2021), which argues shocks have first-order effects on efficiency and welfare when they act on existing market distortions. Finally, it relates to a large number of studies comparing small and large firms over the business and financial cycles.

The paper is organized as follows. Section 2 presents a set of stylized facts motivating the analysis, first regarding market structure and then for firm pricing behavior. The framework is presented in section 3 along

[2]The analysis looks at cost-push factors, but leaves aside the question whether ongoing inflation is cost-push or demand-pull.

[3]Taylor (2000) finds inflation is positively correlated with its persistence and argues low inflation also lowered the pass-through. See section 4.2 for a discussion.

[4]This paper adds strategic complementarity as a key mechanism. It also builds on Wang and Werning (2022), which looks at the pass-through of marginal costs and monetary policy transmission under oligopoly.

[5]Other papers have used this approach. Heise et al. (2022) looks at how import competition affected market structure and the pass-through of cost shocks. Meanwhile, the analysis here incorporates expectations.

[6]As highlighted in Gabaix (2011), the assumption that shocks are truly 'aggregate' may not hold in practice.

with an overview of the solution method. The calibration and results are discussed in section 4. It covers changes in the pass-through, the dynamic response of the economy to monetary policy and productivity shocks, and an evaluations of allocative efficiency. Section 5 discusses the policy implications and future directions for research. Section 6 concludes.

2 Market Structure and Firm Behavior: Supporting Evidence

2.1 The Consolidation of Market Share by Leading Firms

This section provides a set of stylized facts on market structure. There is substantial evidence the expansion of top firms explains rising concentration in the United States. Along with the distribution of market share, differences in markups are of particular interest. Markups generate distortions from two different perspectives. On the supply side, they act as a 'tax' on the factors of production. This depresses aggregate output. On the demand side, markup dispersion reduces the allocative efficiency of the economy. In an efficient economy, prices reflect the preferences of households along with the supply of different goods. If markups are uniform across goods, then the consumption basket is close to the optimal one. Markup dispersion is costly because it affects the allocation of consumption. It leads households to favor goods with low markups and not those with low production costs.

2.1.1 National Concentration and 'Superstars'

The literature has long established sales within narrowly-defined industries are dominated by a few firms (Simon & Bonini, 1958). In addition, the sales distribution is highly-skewed (Buzzell, 1981).[7] More recent studies find large differences in productivity (Cunningham et al., 2023). When looking at the trend over the past few decades, there is substantial evidence markets in the United States have become more concentrated and that productivity dispersion also grew. The increase in the national Herfindahl–Hirschman index (HHI), the principal measure of product market and industry concentration, is well documented and multiple studies link it to the expansion of 'superstar' firms (Autor et al., 2020; Grullon et al., 2019).[8] There is some evidence for increased concentration in Europe as well, although the trend is less pronounced (Bajgar et al., 2023). Kwon et al. (2023) finds in the late 1970s, the top 0.1 percent of corporations accounted for less than 70 percent of total business assets in the United States. This share increased to almost 90 percent by the end of the 2010s. Similarly, the share of sales accruing to the top 0.1 percent increased 10-15 percentage points and now accounts for almost two-thirds of the total. To add an important nuance, concentration appears the main driver of this trend, not diversification. Autor et al. (2020) finds top firms have expanded their primary business lines while participation across industries decreased. Compared to the 1980s, top firms are active in fewer industries (going from 14 to 10 at the NAICS four-digit level) and are less likely to have significant market share outside their primary business.

[7] Buzzell (1981) uses a market research database to infer firm size distribution, which closely adheres to a semi-logarithmic distribution. Each firm is around 1.7x the size of its next largest rival. The average market share of the top firm was around 33 percent, followed by 19 percent, 12 percent, and 7 percent for the second, third, and fourth largest competitors. More recent papers on this topic look at ancillary questions, including the relationship between the industry life-cycle and firm size (Dinlersoz & MacDonald, 2009), the role of product diversification in growth (Hutchinson et al., 2010), and the distribution of market share within retailers (Wilbur & Farris, 2014).

[8] Superstar firms are those firms that dominate their markets in terms of sales and profits. The HHI is a common measure of concentration, calculated as the sum of the squared market shares of all firms in a given industry. If firms are identical and atomistic, this gives an HHI of 0. If one firm controls 100 percent of the market, this gives an HHI of 10,000.

2.1.2 Measuring Local Product Market Concentration

Most spending is local and retail data may better reflect the choices available to consumers.[9] There is an ongoing debate on whether concentration in local product markets increased or decreased. Two recent papers using product-level data from the Census Bureau find local sales concentration rose in tandem with national measures, namely Autor et al. (2023) and Smith and Ocampo (2022). The underlying data in these studies remain fairly aggregated. Analyses of alternative, more granular commercial data sources in Rossi-Hansberg et al. (2018) and Benkard et al. (2021) suggest local product market concentration *decreased*. Both attribute this decline to the expansion of top firms across markets. As top firms entered new geographic markets and/or product segments, they were increasingly exposed to rivals.[10]

Despite mixed evidence on the trends, local product market concentration in the United States is higher than commonly appreciated. Benkard et al. (2021) uses a market research survey covering around 25,000 consumers per year between 1994 and 2019 and extracts all questions relating to brands purchased, dividing them into goods that are closely substitutable. On this basis, 44 percent of industries have an HHI above 2500 over the sample period.[11] This is much higher than most estimates circulating in the literature and meets the U.S. Horizontal Merger Guidelines criterion for "highly concentrated." Furthermore, the average market share of the top two firms was around 55-60 percent. Along with the findings of Benkard et al., other studies indicate markets are highly concentrated. Looking at IRI retail scanner data, Mongey (2017) finds the median number of effective firms in a product category is around 3.7 and the revenue share of the top two firms is 66 percent. An analysis of Nielsen retail scanner data in Hottman et al. (2016) finds the top three or four firms account for the majority of market share within narrowly-defined product groups. The leading firm has a much large market share than others and typically charges a much higher markup, an indication they have substantial pricing power.[12] Affeldt et al. (2021) looks at concentration in Europe through the lens of antitrust markets, which are defined by the European Commission as part of its merger review process. Looking at cases between 1995 and 2014, the study finds the average post-merger HHI for an antitrust market was around 2200 points with 4 firms competing on average. Using Affeldt et al. (2018), the following section looks at the difference between market leaders and trailing firms in EU antitrust data. Additional summary statistics are provided in the appendix (section A.2).

2.1.2.1 The Distribution of Market Share in the EU

The *EU Merger Control Database* (Affeldt et al., 2018) allows for an analysis of firm characteristics across well-defined market segments. The antitrust context is useful since it concerns markets facing both consumers and producers. The database covers the period between 1990 and 2014 and includes information on more than 5000 cases reviewed by the European Commission as part of its antitrust enforcement.[13] The market share of the largest firm exceeds 30 percent in more than one-half of antitrust markets and exceeds 50 percent in almost one-quarter. The median share is 40 percent. The market leader is substantially larger than other

[9] There are limitations to these measures as well. Many services, intermediate goods, and major durable purchases are absent from retail data. This extends to healthcare, car purchases, private education, and other significant outlays.

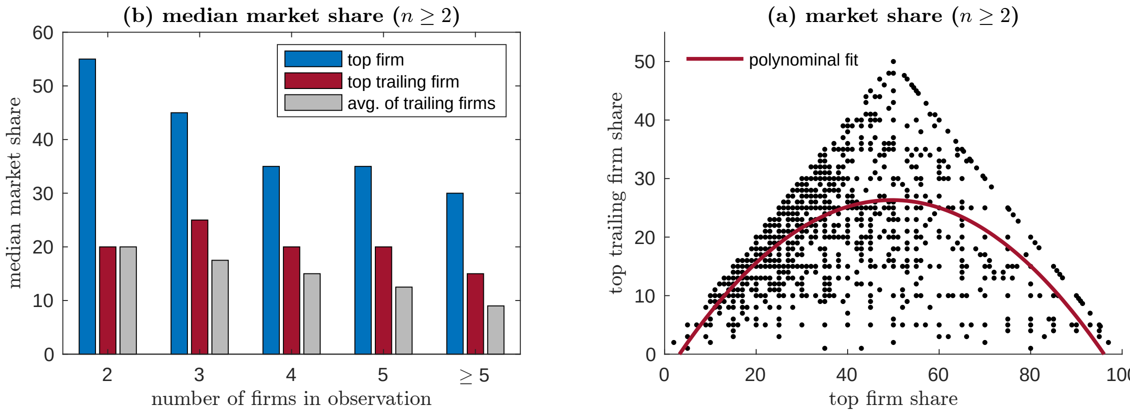
[10] On this topic, Shimomura and Thisse (2012) analyses the welfare effect of the expansion of large firms.

[11] It is also worth noting the 75th and 90th percentiles were at 3600 and 4600 respectively in 2019, where the threshold for monopoly is commonly defined around 6000.

[12] Hottman et al. (2016) finds the markup is 24 to 100 percent higher than the sector average, depending on the approach.

[13] Each case contains the name of the target firm and its potential acquirer, their market shares across different geographies, and whether the merger was approved. Competing firms are identified for a large number of these markets along with the Commission's assessment of their market share. Nearly 31,000 markets are identified, over 23,000 of these observations contain information on the merging entities' market shares, and around 10,000 observations contain information on competing firms and their market shares.

Figure 1: European Commission Antitrust Markets



The left-hand panel separates observations in Affeldt et al. (2018) by the number of firms reported. The median across observations is calculated for the top observed market share, the second largest share, and the average share across all trailing firms. The first set of bars where $n = 2$ makes clear there is usually some residual market share. Around 15 percent is unexplained in the median case and a more complete set of tabulations is in section A.2 of the appendix. The right-hand panel shows the joint distribution of market shares for the top and top trailing firms when both are reported. The top reported market share by observation is on the x-axis and the next largest market share is on the y-axis. A second-order polynominal gives the conditional expectation. The prediction ($y = -0.012x^2 + 1.213x - 3.788$) is very close to what smoothing methods return.

firms in most cases.

Figure 1 presents some key results. The left-hand panel shows how market share is distributed conditional on the number of firms within an observation. The top firm controls around 35 percent of the market in the typical industry (where $n = 4$) and its lead remains fairly consistent as the number of firms increases ($n > 4$). The right-hand panel shows the joint distribution of market share for the market leader and top trailing firm when both are available. The top trailing firm tends to be significantly smaller than market leader. Within an observation, the ratio of the market shares for the leading firm and top trailing firm gives a median value of 1.6x and the mean is around 1.9x.[14] In addition, the top two firms control around 63 percent of the market on average and the median is similar at 61 percent. This cannot be fully generalized to the United States; still, the findings are consistent with Mongey (2017) and Benkard et al. (2021) as well as Buzzell (1981).

2.1.3 Has Market Power Increased?

Since superstar firms tend to be highly efficient, the increase in market share is desirable as long as competition remains strong and there is no corresponding increase in market power. However, this may not be the case. Covarrubias et al. (2019) find concentration in the United States was efficient in the 1990s, but was associated with rising market power in the 2000s. Over this period, markups appear to grow disproportionately for firms already at the top of the markup distribution and the market share of these firms expanded (Baqaee & Farhi, 2019; Barkai, 2020; De Loecker et al., 2020).[15] Most of the aforementioned studies use a 'production function' approach to measure markups. As highlighted in Basu (2019), the resulting estimates are often implausibly large. Some of the assumptions underlying the production function approach

[14] The market share of the post-merger entity is used if the merger was approved. These calculations are limited to cases where both the leader and follower report market shares above 10 percent. The unconditional median is 1.7x.

[15] The appendix provides an overview of the evolution of corporate profitability since the 1980s (see section A.1). There is some ambiguity about the overall trend, in large part because wages and profits are not cleanly separated. Using a comparable measure, profits increased by around 4 percentage points of GDP when comparing the 2010s with the 1980s.

are problematic and several papers have pointed out weaknesses.[16] Despite ambiguity on the main facts, the literature has offered a variety of explanations for rising markups.

To start, network effects could be more prominent than in the past, particularly on digital platforms (OECD, 2022). Top managers may be increasingly adept as exploiting market power (Bao et al., 2022). The increase in markups may equally reflect a decline in labor bargaining power. Unionization rates in the United States are historically low. A large body of research shows concentration among employers is associated with lower wages (Azar et al., 2022; Mertens & Mottironi, 2023). Globalization may be adding pressure as well. Top firms have access to global supply chains and low-cost inputs abroad. They can achieve better economies of scale, diversify into international markets, and gain tax advantages from profit shifting. Markups increase with firm age, which is rising in the United States (Hopenhayn et al., 2018; Peters, 2020). Related to this, a number of studies look at rising barriers to entry, regulatory capture, and rent seeking. For example, Covarrubias et al. (2019) attributes the decline in competition to the entrenchment of market leaders. Similarly, Zingales (2017) and Faccio and McConnell (2020) link regulatory capture and political connections to the lack of business dynamism. Amiti and Heise (2021) attributes rising concentration in the United States to import penetration, which led smaller domestic firms to exit.

The measurement issues should be taken seriously and the rise in markups could stem from relatively benign causes or even prove illusory. The correlation between markups and firm size could simply reflect fixed costs are high for large firms while marginal costs are low. Crouzet and Eberly (2019) attributes weakness in physical investment to intangible capital. Tambe et al. (2020) finds superstar firms accumulated substantial digital capital, which explains much of their apparent productivity advantage.[17] At the same time, markups may result from changes in household preferences. Rising purchasing power may shift the consumption basket towards high-markup goods (Döpper et al., 2022). More broadly, the shift in consumption from manufacturing to services is important as well. Markups are generally higher in service sectors, due in part to the prevalence of owner-employees and pass-through income (Cooper et al., 2015). Variable costs and other indirect costs of production (e.g. marketing, payments to management) are often excluded from markup estimates. Traina (2018) finds markups have been relatively flat since the mid-1980s when these are included. For these reasons, the later analysis focuses on markup dispersion rather than changes in dispersion or aggregate markups.

2.2 Firm Size and Pricing Behavior

As mentioned in the introduction, market position may influence pricing behavior in three different ways: the demand schedule, nominal price rigidities, and changes in marginal costs following a shock. Much of the following discussion focuses on differences between small and large firms across these dimensions. This informs the modeling approach. While the literature tends to look at these elements separately, they are interconnected.

[16] Basu (2019) provides a useful overview. Issues include the neutrality of technological progress across factor inputs (Raval, 2023), the omission of some variable costs (Traina, 2018), and the presence of market power over labor and capital inputs (Mertens & Mottironi, 2023).

[17] The study by Hottman et al. (2016) includes a structural decomposition of the drivers of firm-level demand into four components: cost, markups product scope, and taste. The results indicate taste explains 50 to 75 percent of variation in firm size, while cost accounts for less than 20 percent of total variation.

2.2.1 Market Position and the Price Elasticity of Demand

Early interest in the relationship between market position and price dynamics stemmed from antitrust cases. Markham (1951) discusses how rational market behavior could resemble collusion whenever price 'leaders' anticipate the prices of their rivals. While the industrial organization literature has much to offer, most models for aggregate price dynamics use a relatively simple market structure. General equilibrium requires a coherent relationship between individual prices, changes in the demand schedule, and aggregate dynamics, which limits the toolkit available to researchers. The CES specification is popular because it meets these criteria while incorporating some realism in term of pricing power.

Exploring price dynamics with heterogeneous firms requires a more complicated functional form. Following Dornbusch (1987), Atkeson and Burstein (2008) propose the nested-CES specification used here. It combines a discrete CES aggregator, representing an firms within industry, and a continuous CES aggregator for industries. This leads to strategic interaction between firms within an industry, but not across industries. Since consumers substitute between varieties (i.e. the products of firms within the same industry) more easily than across goods, there is a positive association between market share and pricing power. This paper builds on Shimomura and Thisse (2012), which captures the interaction between large and small firms using a nested-CES specification. Hottman et al. (2016) demonstrates another potential application. There, firms produce a number of closely substitutable varieties, which leads to the cannibalization of own sales.

Several papers test if nested-CES demand describes firm behavior accurately. The prediction is simple – large and small firms face different demand curves and set their prices accordingly. The empirical evidence supports the nested-CES view, at least when studies separate strategic and own-price effects. An analysis of French exporters by Berman et al. (2012) finds large firms generally absorb a large part of exchange rate movements in their markups. Auer and Schoenle (2016) use BLS micro-price data to look at whether firms react to own-cost shocks or price changes by competitors. The results indicate the strength of strategic complementarity is hump-shaped in market share, while the pass-through of exchange rate shocks is U-shaped. Amiti et al. (2019) uses Belgian manufacturing data, which gives a more representative sample. They also employ a research design that better controls for potential endogeniety issues, in particular, the possibility firms anticipate price changes by rivals. The results suggest small firms fully pass through cost shocks while large firms have a much lower pass-through. Furthermore, large firms behave strategically while small firms do not.[18] Dedola et al. (2021) and Bruine De Bruin et al. (2023) also report similar results. All studies report findings consistent with the predictions of nested-CES demand, although some caution is due given potential reporting bias.[19]

2.2.2 Price Adjustment Frictions

Price adjustment frictions can arise from a wide variety of sources. These include (i) explicit and implicit contracts, (ii) strategic interaction and price coordination failures, (iii) menu and information costs, (iv) managerial inattention and misalignment of incentives, (v) fear of alienating customers, and (vi) uncertainty around the duration of shocks.[20] Firm size appears relevant in all these cases. For example, price increases

[18] Rival prices in Amiti et al. (2019) are based on a price index of all firms in the same industry.

[19] Auer and Schoenle (2016) find the pass-through and slope of the best response price are respectively U- and hump-shaped. This is based on the transition from negligible market share to near monopoly. The analysis in this paper focuses on oligopoly – the downward part of the 'U' and upward part of the 'hump,' meaning firms limit their pass-through and become more strategic as market share increases. Monopoly levels of concentration are never considered.

[20] The role of sales in price movements is well documented (Klenow & Malin, 2010; Kryvtsov & Vincent, 2021). On the other hand, Kehoe and Midrigan (2015) argues aggregate prices are sticky even if prices change frequently at the consumer level. Since prices usually return to the exact same level, the 'regular' price is fairly consistent over time. Still, the micro-evidence

by large firms might receive wider media attention.[21] Alternatively, managers at small firms often balance multiple tasks, leading to greater managerial inattention. Studies looking at price adjustment frequency and firm size usually find a link. Still, a limited number are in circulation and they use a variety of data sources and methodologies, making it difficult to draw general conclusions. Other factors correlated with firm size, such as industry, could be latent as well.

Most studies find large firms adjust prices more frequently than small firms. An analysis of US producer prices by Goldberg and Hellerstein (2009) indicates large firms change prices two to three times more frequently than small firms.[22] Among good-producing industries, the implied price duration of 4.3 months for large firms and 8.5 months for small firms. While large firms appear to change prices more often, the average price change is smaller. Amirault et al. (2006) obtains similar results for Canada, as does Stokman and Hoeberichts (2006) for the Netherlands. The latter also finds weaker competition is associated with greater price rigidity. Other relevant studies include Álvarez and Hernando (2005), Coleman and Silverstone (2007), and Copaciu et al. (2010) and the findings are generally consistent. Still, is not entirely clear if large firms face lower price adjustment costs. Small firms adjust their prices by more, albeit less frequently. Not all studies control for differences in firm size across industries, a potential confounding factor. On this point, Gopinath and Itskhoki (2010) suggest most variation in price adjustment costs takes place at highly disaggregated levels, i.e. individual industries. Finally, large firms may be constrained by uniform pricing across markets and their prices may not correspond with local demand conditions, a reason they appear to adjust more frequently (DellaVigna & Gentzkow, 2019).

Price leadership and strategic interaction affect price adjustments as well. A comparison of experimental evidence on Stackelberg and Cournot competition in Hildenbrand (2010) suggests Stackelberg better fits observed outcomes under price competition, but not under quantity competition. Weber and Wasner (2023) argues price leaders only engage in price hikes if they expect their competitors to do the same. Coordination of price increases therefore requires a sector-wide cost shock. Of course, not all sectors have a clear price leader and other aspects of market structure play a role. For example, Levy et al. (1998) relates the high frequency of price changes among grocery stores to the intensity of competition, low margins on each good sold, and the price sensitivity of consumers. In sectors with high transaction volumes, the price serves as an active feedback mechanism and firms can accurately gauge consumer demand and rival prices. In sectors with few sellers and buyers, firms have less information on the price sensitivity of demand, leading to coordination failures (Pennerstorfer et al., 2020).[23]

2.2.3 Firm-Specific Marginal Costs and Aggregate Shocks

Since the publication of Gertler and Gilchrist (1994), studies looking at the financial cycle have paid close attention to firm size, which can serve as a proxy for the presence of financial constraints. The general view has been that small firms are more sensitive to monetary policy than large firms. Still, it is notable the

indicates retailers maintain substantial price flexibility and casual observation, along with empirical evidence, suggests large firms are more adept at price discrimination through sales (Katz, 2019).

[21] For example, when McDonald's increases 'dollar' menu prices, national media often report the price change.

[22] Using product-level data across a number of retailers, Nakamura (2008) suggests most price variation arises at the retail level rather than manufacturer level. At the same time, the analysis of producer prices in Goldberg and Hellerstein suggests a high degree of flexibility, equal to that of consumer goods.

[23] While the analysis here focuses on price dynamics within an industry, there is a long-standing literature looking at how difference in price adjustment speeds across industries affects the propagation of shocks. Basu (1995) shows a roundabout production structure amplifies initial price differences because they affect marginal costs. A subsequent paper by Nakamura and Steinsson (2010) constructs a menu cost model with different price adjustment frictions across sectors. This increases monetary non-neutrality three-fold compared to a model where price frictions are uniform. The model can generate persistent real effects from nominal shocks, even when price stickiness is low.

result in Gertler and Gilchrist is state dependent and the effects of monetary tightening only appear when growth is weak. Largely because of data limitations, both the basic facts on the financial accelerator and their interpretation remain subject to debate. For example, Ottonello and Winberry (2020) identifies firms with low default risk as those most responsive to monetary shocks. Meanwhile, Pérez-Orive and Timmer (2023) finds firms in financial distress respond most strongly to monetary tightening in terms of investment and employment. Financial strength does not appear to explain differences in firm performance over the business cycle at all in Crouzet and Mehrotra (2020).

Turning to the business cycle more generally, Crouzet and Mehrotra (2020) find large firms are less affected by economic fluctuations than small firms due to differences in export exposure. This is intuitive since large firms tend to be more diversified, both across different product categories and geographic markets. Similarly, Hong (2018) reports the markup for small firms fluctuates 45 percent more than for large firms over the business cycle. Along with diversification, there may be other systematic differences between large and small firms. Wages appear particularly important and large firms may exercise substantial power over labor markets (Azar et al., 2022). For example, Mertens and Mottironi (2023) links growth in the markups of large firms to wage compression.[24] Bargaining power among workers and employers likely varies over the business cycle, as highlighted in Lombardi et al. (2023). It is possible wages are more flexible within large firms. For example, they may cut working hours in a downturn, as opposed to firing employees (Babecký et al., 2009). While the aforementioned studies cover the main outcomes of interest, the literature comparing small and large firms over the financial and business cycles is large. Miklian and Hoelscher (2022) provide a more comprehensive overview.

3 A Simple New Keynesian Model with Asymmetric Competition

The modeling approach replicates several key facts from the literature. First, the firm size and productivity distributions are highly skewed within industries. The premise that leading firms charge higher markups also receives a wide range of empirical support and this paper emphasizes markup dispersion as a source of inefficiency. The pass-through and best-response price across firms also align with empirical evidence. The literature finds aggregate shocks affect large and small firms differently. For example, large firms have a higher degree of buyer power in factor markets. Differences in marginal cost shocks across firms are highly relevant to allocative efficiency and form part of the baseline results. Goldberg and Hellerstein (2009) suggests large firms have greater price flexibility than small firms; meanwhile, small firms adjust their prices by larger margins, albeit more infrequently. Given some ambiguity on how to interpret this result, differences in price frictions are saved for the appendix (section A.5).

The framework follows the general template used throughout the New Keynesian literature. It solves for aggregate price dynamics. It is forward looking and assumes rational expectations. It incorporates the standard demand- and supply-side relationships: the investment-saving decision of households, the Phillips curve, and the Taylor rule. While the household side is mostly standard, the firm side has two distinct elaborations. The first and most important is a nested-CES demand system with asymmetric firms. The second is the addition of firm-specific pricing frictions and marginal cost shocks. The model uses Rotemberg price adjustment costs and a first-order solution, which saves a great deal of computational expense. For example, the results establish a relation between market concentration and Phillips curve very close to Wang

[24] Large firms usually offer a wage premium, even when controlling for skills (Gibson & Stillman, 2009). This might be one reason workers are more willing to accept cuts over downturns.

and Werning (2022), which uses a more complicated Calvo setup and an exact solution. A higher-order (or exact) solution appears unnecessary. At the same time, it matches observed changes in price and markup dispersion following shocks. A Calvo setup leads to excessive dispersion.

This section proceeds has four parts: The first part describes the basic setup of households and firms. This is followed by a discussed of nested-CES demand and the presence of own- and cross-price effects. The final two parts give the solution for flexible and sticky prices.

3.1 Households and Firms

Household maximize an intertemporal utility over consumption C and labor L

$$\max_{\{C_t,\,L_t,\,B_t,\,K_{t+1}\}} \quad U_0 = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log(C_t) - L_t\right] \tag{1}$$

subject to the budget constraint

$$P_t C_t + B_t + Q_t\big(K_{t+1} - K_t\big) \leq W_t L_t + R^n_{t-1} B_{t-1} + Z_t K_t + P_t \, \Pi_t + T_t \tag{2}$$

where P is the aggregate price index, B bonds, R^n the nominal return on bonds, K capital, Q its price, W wages, Π profits, and T a lump sum transfer that accounts for price adjustment costs net of a capital subsidy paid by household. The optimality condition for labor implies

$$P_t C_t = W_t \tag{3}$$

The trade-off between consumption and investment gives the Euler equation for capital is

$$1 = \mathbb{E}_t \left[\beta \frac{P_t C_t}{P_{t+1} C_{t+1}} \frac{Z_{t+1} + Q_{t+1}}{Q_t}\right] \tag{4}$$

The trade-off between consumption saving gives the normal Euler equation for bonds

$$1 = \mathbb{E}_t \left[\beta \frac{P_t C_t}{P_{t+1} C_{t+1}} R^n_t\right] \tag{5}$$

Aggregate capital is fixed and price adjustment costs are rebated to households. The model looks at nominal shocks and these are unlikely to affect capital accumulation in the short-run. The capital rental rate does vary however. The resource constraint is then

$$Y_t = C_t \tag{6}$$

Monetary policy follows a Taylor rule

$$R^n_t = e^{m_t} R^n \left(\frac{P_t}{P_{t-1}}\right)^{\phi_\pi} \left(\frac{Y_t}{Y}\right)^{\phi_y} \tag{7}$$

where ϕ_π and ϕ_y determine the strength of the monetary policy response to deviations in inflation and the output. The persistence of monetary policy shocks follows

$$m_t = \rho_m m_{t-1} + \varepsilon_t \quad \text{where} \quad \varepsilon_t \sim \mathcal{N}(0, \sigma_m) \tag{8}$$

Firms, indexed by s, produce a variety of an intermediate good j. They have a Cobb-Douglas production function

$$y_{st} = e^{a_t}\bar{a}_s(k_{st-1})^{\alpha}(\ell_{st})^{1-\alpha} \tag{9}$$

where k is the firm's capital, ℓ labor, and $\bar{a}$ is a firm-specific productivity level. The parameter α represents the capital share in production. The persistence of aggregate productivity shocks follows

$$a_t = \rho_a a_{t-1} + \xi_t \quad \text{where} \quad \xi_t \sim \mathcal{N}(0, \sigma_a) \tag{10}$$

The firm's budget constraint includes a subsidy that offsets the distortion to capital resulting from the steady state markup

$$\Pi_{st} = (1+\tau_t)p_{st}y_{st} - w_t\ell_{st} - z_t k_{st} \quad \text{where} \quad z_t = \frac{Z_t}{P_t} \quad \text{and} \quad w_t = \frac{W_t}{P_t} \quad \text{and} \quad 1+\tau_t = P_t^{\alpha} \tag{11}$$

where the relative price of the firm is denoted by p. The marginal cost $\boldsymbol{\mathcal{C}}$ includes all factors exogenous to the firm

$$\boldsymbol{\mathcal{C}}_{st} = \frac{1}{e^{a_t}\bar{a}_s P_t^{\alpha}}\left(\frac{z_t}{\alpha}\right)^{\alpha}\left(\frac{w_t}{1-\alpha}\right)^{1-\alpha} \tag{12}$$

3.2 Nested-CES Demand

The production structure consists of a nested two-level CES aggregator consisting of industry- and firm-level output.[25] The specification follows Atkeson and Burstein (2008) and Shimomura and Thisse (2012), which is specific case. The general case is discussed first.

3.2.1 General Case

The general nested-CES case has the following structure. Final output bundles together a continuum of goods, each produced by an industry (indexed by j). In turn, industries bundle a finite number of varieties, each produced by an individual firm (indexed by s).

$$(i) \quad Y_t = \left[\int_0^1 y_{jt}^{\frac{\sigma-1}{\sigma}}dj\right]^{\frac{\sigma}{\sigma-1}} \quad \text{where for each industry} \quad (ii) \quad y_{jt} = \left[\sum_{s=1}^{n} y_{sjt}^{\frac{\varphi-1}{\varphi}}\right]^{\frac{\varphi}{\varphi-1}} \tag{13}$$

where $n \geq 2$. The elasticity of substitution across goods is given by σ while φ is the elasticity of substitution across varieties. The corresponding price indices are given by

$$(i) \quad P_t = \left[\int_0^1 P_{jt}^{1-\sigma}dj\right]^{\frac{1}{1-\sigma}} \quad \text{where for each industry} \quad (ii) \quad P_{jt} = \left[\sum_{s=1}^{n} P_{sjt}^{1-\varphi}\right]^{\frac{1}{1-\varphi}} \tag{14}$$

[25] There is an implicit assumption in this paper, general in macroeconomics, that an individual firm cannot change the aggregate price index. Hence the measure of industries is zero.

where P_t is the aggregate price index and P_{jt} gives the price index for each industry. The allocation of demand across goods and varieties takes the standard form

$$(i)\quad y_{jt} = \left(\frac{P_{jt}}{P_t}\right)^{-\sigma} Y_t \qquad \text{and} \qquad (ii)\quad y_{sjt} = \left(\frac{P_{sjt}}{P_{jt}}\right)^{-\varphi} y_{jt} = \left(\frac{P_{sjt}}{P_{jt}}\right)^{-\varphi} \left(\frac{P_{jt}}{P_t}\right)^{-\sigma} Y_t \tag{15}$$

The demand schedule for each firm is written as

$$y_{sjt} = p_{sjt}^{-\varphi} \left[\sum_{s=1}^{n} p_{sjt}^{1-\varphi}\right]^{\frac{\varphi-\sigma}{1-\varphi}} Y_t \tag{16}$$

The price elasticity of demand is therefore

$$\Psi_{sjt} \equiv \frac{\partial \log(y_{sjt})}{\partial \log(p_{sjt})} = (\varphi - \sigma) x_{sjt} - \varphi \quad \text{where} \quad x_{sjt} = \left(\frac{p_{sjt}}{p_{jt}}\right)^{1-\varphi} \equiv \frac{p_{sjt} y_{sjt}}{\sum_{s=1}^{n} p_{sjt} y_{sjt}} \tag{17}$$

$$= \frac{\varphi - \sigma}{n} - \varphi \quad \text{(if firms are identical)} \tag{18}$$

The price elasticity of demand is affected by a firm's market share x (as long as $\varphi \neq \sigma$). Normally, the elasticity of substitution within an industry is greater than substitution across industries, i.e. $\varphi > \sigma$. In other words, it is easier to substitute across relatively homogeneous varieties of a good than different goods.[26] To give the extreme cases, when the firm's market share is negligible, it only considers substitution across varieties, i.e.

$$\lim_{x_s \to 0} \Psi_s = -\varphi \tag{19}$$

When the firm controls the entire market and is only sensitive to substitution across goods

$$\lim_{x_s \to 1} \Psi_s = -\sigma \tag{20}$$

as in the standard CES case. Going between the two cases, demand becomes less sensitive to prices as firm's market share increases.

3.2.2 Nested-CES with Asymmetric Firms

Following Shimomura and Thisse (2012), I specify an asymmetric setup where a sector has a mix of large and small firms. To simplify, firms are divided by size $s \in \{L, S\}$ into large (L) and small (S). Within each category, they are identical. The industry-level price index becomes

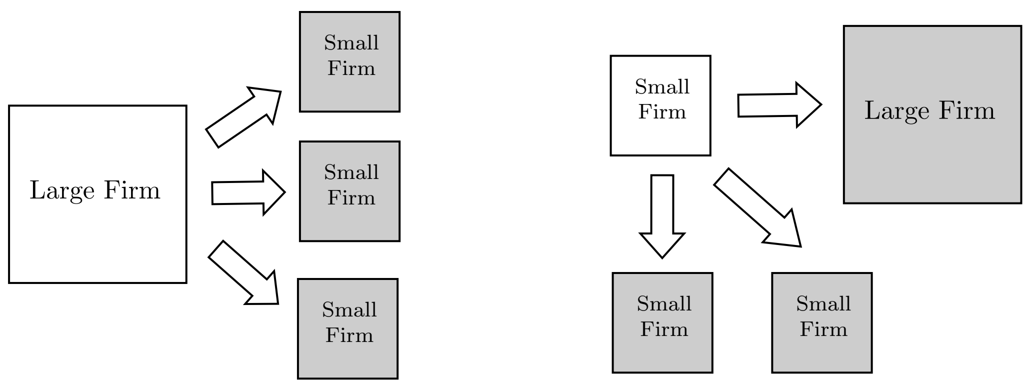
$$p_{jt} = \Big[\underbrace{(p_{sjt}^{i})^{1-\varphi}}_{\text{own price}} + \underbrace{(n_s - 1)(p_{sjt}^{-i})^{1-\varphi} + n_{-s}(p_{-sjt}^{-i})^{1-\varphi}}_{\text{rival prices}}\Big]^{\frac{1}{1-\varphi}} \tag{21}$$

where $i \in \{a, b\}$ denotes the firm making the pricing decision (a) and rival firms (b). This specification adheres to the general nested-CES case. Since all small and large firms are otherwise identical, they are summed together. This entails solving for cross-price effects. Generally, just one large firm (or 'leader')

[26] For example, a household may buy a different type of toothpaste if their preferred variety becomes too expensive. They could also use baking soda, but might resist this change since the goods are not perfect substitutes.

is assumed so that $n_L = 1$. The leader faces multiple smaller rivals where $n_S > 1$.[27] Figure 2 shows the market structure for an industry where one large and three small firms compete. The large firm dominates the market and views the small firms as rivals. Meanwhile, each small firm views the other small firms and the large firm as rivals. In the latter case, cross-price effects include both the large firm and the other small firms. This enters into each firm's optimization problem through the price elasticity of demand, as evident in expression 17.

Figure 2: Competition within an Industry from the Firm's Perspective



This figure helps clarify the competition structure in the model and the intuition behind expression 21. When $n_L = 1$, the large firm only faces smaller rivals and solves for prices accordingly (as on the left). When a small firm sets prices considers both the actions of other small firms and the large firm (as on the right).

3.2.3 Linking the Price Elasticity of Demand to Firm Behavior

The key aspects of firm behavior – markups, the pass-through of marginal costs, and the best response price – relate to the slope and curvature of the price elasticity of demand. Among specifications allowing for a non-linear relationship between relative prices and relative demand, Kimball (1995) is probably the most common. In this case, the 'superelasticity' or second-derivative, is negative and results from the firm's own price. When this is introduced into the firm's problem, it reduces its markup and limits the pass-through of marginal cost shocks in order to maintain sales. The presence of a finite number of firms introduces strategic behavior, which is not an inherent feature of Kimball demand. Firms adjust prices in response to price changes by other firms. The strength and direction of their response is described by the cross-price superelasticity of demand. Prices are strategic complements if the cross-price superelasticity is positive, meaning firms raise prices in response to a price hike by a rival firm. It is also possible they are substitutes. The cross-price are typically omitted when firms are identical, but are important when asymmetries are present.

3.2.3.1 The Curvature of Demand

The price elasticity of demand is defined as Ψ_t^i. It is related to markups in a simple way, as explained in Ueda (2023). Take a one-period profit maximisation problem where the budget constraint for firm is

$$\Pi_t^i = \left(p_t^i - \mathcal{C}_t^i\right) y_t^i \tag{22}$$

[27] The total number of firms in an industry $n = n_L + n_S$.

Defining the markup μ_t^i as price over marginal cost, the solution can be rearranged so that

$$p_t^i = \frac{\Psi_t^i}{\Psi_t^i + 1}\boldsymbol{\mathcal{C}}_t^i \quad \iff \quad \mu_t^i = \frac{\Psi_t^i}{\Psi_t^i + 1} \tag{23}$$

Next, I define the own-price superelasticity

$$\Psi_t^{i,i} \equiv \frac{\Psi_t^i}{\partial \log(p_t^i)} \tag{24}$$

Generally this term is negative, which implies large price adjustments are more costly for firms than small adjustments. In the standard CES case $\Psi_t^{i,i} = 0$. The co-movement of markups and prices describes the pass-through of marginal costs. The elasticity of the markup to the price is

$$\Psi_t^{\mu_i} \equiv \frac{\partial \log(\mu_t^i)}{\partial \log(p_t^i)} = \frac{\Psi_t^{i,i}}{\Psi_t^i(\Psi_t^i + 1)} \tag{25}$$

Following Amiti et al. (2019), the pass-through $\boldsymbol{\mathcal{P}}_t^i$ is defined as

$$\boldsymbol{\mathcal{P}}_t^i \equiv \frac{1}{1 + \Psi_t^{\mu_i}} \tag{26}$$

Next, turning to strategic interaction, the cross-price superelasticity with respect to a competitor is given by

$$\Psi_t^{i,\text{-}i} \equiv \frac{\Psi_t^i}{\partial \log(p_t^{\text{-}i})} \tag{27}$$

and the slope of the best response price $\boldsymbol{\mathcal{B}}_t^i$ is given by

$$\boldsymbol{\mathcal{B}}_t^i \equiv \frac{\partial \log(p_t^i)}{\partial \log(p_t^{\text{-}i})} = \frac{\Psi_t^{i,\text{-}i}}{\Psi_t^i(\Psi_t^i + 1)} \tag{28}$$

Both the pass-through $\boldsymbol{\mathcal{P}}$ and the slope of the best response $\boldsymbol{\mathcal{B}}$ serve as target values in the baseline calibration.

3.2.3.2 Asymmetric Nested-CES Case

Given asymmetric firms, where the industry-level price index follows (21), the price elasticity of demand is

$$\Psi_{st}^i = (\varphi - \sigma)\left(\frac{p_{sjt}^i}{p_{jt}}\right)^{1-\varphi} - \varphi \tag{29}$$

The firm's own-price superelasticity $\Psi^{i,i}$ is then

$$\Psi_{st}^{i,i} = (\varphi - \sigma)(1 - \varphi)\left[\left(\frac{p_{sjt}^i}{p_{jt}}\right)^{1-\varphi} - \left(\frac{(p_{sjt}^i)^2}{p_{jt}^2}\right)^{1-\varphi}\right] \tag{30}$$

$$= (\varphi - \sigma)(1 - \varphi)\frac{(n_s - 1)(p_{1jt}^i p_{1jt}^{\text{-}i})^{1-\varphi} + n_{\text{-}s}(p_{1jt}^i p_{2jt}^{\text{-}i})^{1-\varphi}}{p_{jt}^2} \tag{31}$$

and the cross-price superelasticity $\Psi^{i,\text{-}i}$ is

$$\Psi_{st}^{i,\text{-}i} = -(\varphi - \sigma)(1-\varphi)\frac{(n_s - 1)(p_{1jt}^{i} p_{1jt}^{\text{-}i})^{1-\varphi} + n_{\text{-}s}(p_{1jt}^{i} p_{2jt}^{\text{-}i})^{1-\varphi}}{p_{jt}^2} \tag{32}$$

This expression can be divided into two components.

$$\Psi'^{\,i,\text{-}i}_{st} = -(\varphi - \sigma)(1-\varphi)\frac{(n_s - 1)(p_{sjt}^{i} p_{sjt}^{\text{-}i})^{1-\varphi}}{p_{jt}^2} \tag{33}$$

$$\Psi''^{\,i,\text{-}i}_{st} = -(\varphi - \sigma)(1-\varphi)\frac{n_{\text{-}s}(p_{sjt}^{i} p_{\text{-}sjt}^{\text{-}i})^{1-\varphi}}{p_{jt}^2} \tag{34}$$

The first component ($\Psi'^{\,i,\text{-}i}$) represents the cross-price elasticity to other firms that are the same size. Since these firms will choose the exact same price, separating this term simplifies some of the subsequent analysis. The second term ($\Psi''^{\,i,\text{-}i}$) is the cross-price elasticity to firms that are a different size. It also happens the own- and cross-price elasticities perfectly offset with nested-CES demand

$$\Psi_{st}^{i,i} = -\Psi_{st}^{i,\text{-}i}$$

If firms are identical, these forces are equal and the price elasticity of demand becomes fully linear given an aggregate shock. In other words, asymmetry is needed for a nested-CES specification to meaningfully differ from the standard CES specification.[28]

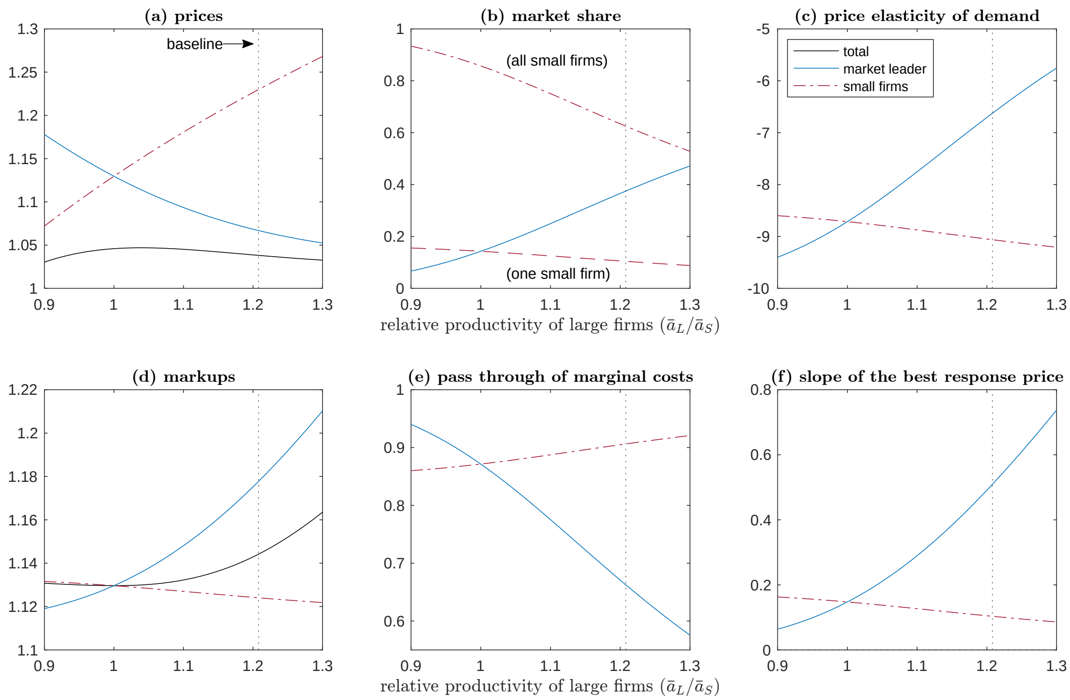
Figure 3 shows the market structure resulting from nested-CES demand when firms are asymmetric. There is one market leader ($n_L = 1$) and multiple trailing firms ($n_S = 6$). In equilibrium, the market share of firms is set by their relative efficiency ($\bar{a}$). This lowers marginal costs and translates into a price advantage. The vertical lines show the baseline calibration. The x-axis displays the relative productivity of the market leader. Moving from left to right in each plot, the market leader becomes more efficient and its production costs go down. It sets a lower price (panel a) and gains market share (panel b), which increases its markup (panel d). Because there are multiple trailing firms within each industry, they remain relatively small. In the baseline calibration, the market share of each small firm is constrained to a maximum of 16.7 percent.[29] Therefore, customers remain price sensitive and small firms cannot raise their markups by much. In addition, small firms do not respond to price adjustments by other firms and fully pass through cost shocks. The opposite is true of large firms (i.e. the 'market leader'). In the baseline calibration, the market leader passes through around 65 percent of marginal cost increases to consumers, as opposed to 90 percent for small firms (panel e). Also, the leader matches around 50 percent of price increases by its rivals (panel f).

The following sections will show price dynamics remain highly tractable given the setup. In fact, own- and cross-price superelasticities serve as direct inputs when using undetermined coefficients and the solution method can readily accommodate other demand functions. Section A.3.1 in the appendix includes some further discussion the price elasticity of demand given strategic interaction.

[28] Quasi-kinked demand (Kimball, 1995) is an example of where the demand curve is adjusted by the firm's own-price superelasticity. Kimball demand can mimic strategic behavior if the curvature is adjusted appropriately, as suggested in Wang and Werning (2022). However, the correct adjustment is not always clear. Also, a nested-CES specification is more flexible. It an be used when there is a mix of idiosyncratic and aggregate shocks and/or shocks affect firms differently.

[29] Since $n_S = 6$. Note small firms are generally treated as less efficient than the market leader. The instance where they have a cost advantage is included for illustration only.

Figure 3: Market Structure under Flexible Prices



The x-axis gives the relative productivity advantage of large firms over small firms, which is increasing from left to right. When large firms have a productivity advantage, they set a lower relative price (panel a). In turn, this increases demand for their variety and their market share increases (panel b). As market share increases, demand becomes less sensitive to price changes, which allows large firms to increase their markups (panel d). Given the curvature of demand, large firms limit the pass through of marginal cost shocks (panel e) and respond to competitors prices when their productivity advantage grows (panel f).

3.3 Flexible Price Equilibrium

This section gives the solution method for the flexible price equilibrium in the presence of cross-price effects (figure 3).[30] While numerical methods are preferred, an approach using log-linearization is included. The dynamic problem is more complicated, but follows the exact same approach. In the absence of price adjustment costs or rigidities, firms optimize their profits as follows

$$\max_{p^i_{st}} \quad \Pi^i_{st} = \left(p^i_{st} - \boldsymbol{\mathcal{C}}^i_{st}\right) y^i_{st} \tag{35}$$

With identical firms, the solution for prices is straightforward. The solution for asymmetric firms incorporates the best reply into the firm's decision rule.

3.3.1 Identical firms

When firms and industries are identical, demand follows (18) and the solution to the maximisation problem becomes

$$\frac{\partial \Pi_t}{\partial p_t} = 0 \quad \implies \quad \left(1 - \frac{\boldsymbol{\mathcal{C}}_t}{p_t}\right)\left(\frac{\varphi - \sigma}{n} - \varphi\right) = -1 \tag{36}$$

Solving for the price is simple in this case

$$p^*_t = \frac{(n-1)\varphi + \sigma}{(n-1)\varphi + \sigma - n}\boldsymbol{\mathcal{C}}^*_t \tag{37}$$

This indicates the price is a direct function of marginal costs. Also setting $n = 1$ leads to the standard CES case (as does $\varphi = \sigma$). It is relatively straightforward to determine how the number of firms in an industry affects the markup

$$\frac{\partial \mu^*}{\partial n} = \frac{\sigma - \varphi}{[(n-1)\varphi + \sigma - n]^2} \quad < 0 \quad \text{given} \quad \varphi > \sigma \tag{38}$$

This indicates greater concentration is associated with rising markups.

3.3.2 Asymmetric firms

The solution to the firm's optimization problem under asymmetric oligopoly ($n \geq 2$) proceeds as follows.[31] Going back to the profit maximization problem faced by the firm

$$\frac{\partial \Pi_{st}}{\partial p^i_{st}} = 0 \quad \implies \quad \left(1 - \frac{\boldsymbol{\mathcal{C}}_{st}}{p^i_{st}}\right) \underbrace{\left[(\varphi - \sigma)\left(\frac{p^i_{st}}{p_{jt}}\right)^{1-\varphi} - \varphi\right]}_{\Psi^i_{st}} = -1 \tag{39}$$

Solving prices requires inverting the demand function

$$p^i_{st} = \frac{\Psi^i_{st}}{\Psi^i_{st} + 1}\boldsymbol{\mathcal{C}}_{st} \tag{40}$$

[30] The flexible price equilibrium is also equivalent to the zero-inflation steady state in the dynamic problem. The log-linearized solution is only locally accurate, but useful for illustrative purposes. The error becomes larger as prices move further from their starting point and numerical methods are more precise.

[31] Industries are identical and the index is reduced to s whenever possible to lighten the notation.

The optimal price can be solved numerically or approximated using the method of undetermined coefficients. While the method of undetermined coefficients is accurate around an initial point (e.g. p^*), the nested-CES specification is non-linear system and a numerical solution is generally preferable (away from p^*).[32] Log-linearizing and taking a first-order Taylor expansion around the equilibrium price gives the following relationship

$$\tilde{p}^{i}_{st} = \underbrace{\frac{\Psi^i_s(\Psi^i_s+1)\boldsymbol{\mathcal{C}}_s}{p^i_s(\Psi^i_s+1)^2-(\Psi^{i,i}+\Psi'^{\,i,\text{-}i}_s)\boldsymbol{\mathcal{C}}_s/p^i_s}}_{1+\Omega'_s}\widetilde{\boldsymbol{\mathcal{C}}}_{st} + \underbrace{\frac{\Psi''^{\,i,\text{-}i}\boldsymbol{\mathcal{C}}_s}{p^{\text{-}i}_s[p^i_s(\Psi^i_s+1)^2-(\Psi^{i,i}+\Psi'^{\,i,\text{-}i}_s)\boldsymbol{\mathcal{C}}_s/p^i_s]}}_{\Omega^*_s}\tilde{p}^{\text{-}i}_{\text{-}st} \tag{41}$$

The term for similar-size rivals ($\tilde{p}^{\text{-}i}_{st}$) is already incorporated on the left-hand side (since $\tilde{p}^{i}_{st}=\tilde{p}^{\text{-}i}_{st}$). Prices are a function of the firm's marginal costs and rival prices. The decision rule can be summarized as

$$\tilde{p}^{i}_{st} = (1+\Omega'_s)\,\widetilde{\boldsymbol{\mathcal{C}}}_{st} + \Omega^*_s\,\tilde{p}^{\text{-}i}_{\text{-}st} \tag{42}$$

Using the decision rule of rival firms allows the problem to be solved as a function of marginal costs alone

$$\tilde{p}^{i}_{st} = \frac{1+\Omega'_s}{1-\Omega^*_s\Omega^*_{\text{-}s}}\widetilde{\boldsymbol{\mathcal{C}}}_{st} + \frac{\Omega^*_s(1+\Omega'_{\text{-}s})}{1-\Omega^*_s\Omega^*_{\text{-}s}}\widetilde{\boldsymbol{\mathcal{C}}}_{\text{-}st} \tag{43}$$

Markups and market share are determined using (40) and (17) respectively.

3.4 Price Dynamics with Nominal Rigidities

Price adjustment frictions are specified using quadratic costs, as in Rotemberg (1982).[33] When looking at aggregate outcomes, this gives the same first-order solution as Calvo pricing if trend inflation is zero and the system is linear.[34] The solution has several steps that are explained as follows: The first part of this section gives the first-order solution for each firm's decision rule. Next, changes in firm-specific marginal costs are related to aggregate shocks. The final part derives the Phillips curve. This section focuses on intuition and the appendix (section A.3) provides a more comprehensive overview of the solution method and steps.

3.4.1 Firm Optimization

Pricing frictions take the form of Rotemberg adjustment costs in the dynamic model, which are rebated to households

$$\frac{\Theta_s}{2}\left(\frac{P^i_{st}}{P^i_{st-1}}-1\right)^2 Y_t \quad \text{where} \quad \Theta_s=\gamma_s x_s \Theta \tag{44}$$

The price adjustment costs Θ are specified so they are proportional across firms. Accordingly, Θ is multiplied by the steady state market share of each firm. This ensures the 'weight' firms put on their markup is equal to the weight they put on the quadratic price adjustment costs. To examine how differences in adjustment

[32]See figure 12 in the appendix and corresponding discussion.

[33]In other words, large price adjustments are more costly than small ones. Rotemberg (1982) argues consumers preferred firms that maintained stable price paths given imperfect information.

[34]When higher-order approximations are needed, there has been some debate about which specification better describes aggregate price dynamics. The evidence supporting Rotemberg pricing is generally favorable. Richter and Throckmorton (2016) finds a baseline New Keynesian model using Rotemberg pricing better fits observed price dynamics compared to an equivalent specification with Calvo pricing. Similarly, Oh (2020) finds Rotemberg pricing better fits the data when looking at uncertainty shocks.

costs affect outcomes, a firm-specific shifter for the price adjustment cost γ_s is included as well. In the baseline, $\gamma_s = 1$. With this in mind, the profit maximization problem becomes

$$\mathcal{L} = \mathbb{E}_t \sum_{k=0}^{\infty} \Lambda_{t+k} \left[\left(p_{st+k} - \boldsymbol{\mathcal{C}}_{st+k}\right) y_{st+k} - \frac{\Theta_s}{2} \left(\pi_{t+k} \frac{p_{st+k}}{p_{st+k-1}} - 1 \right)^2 P_{t+k} Y_{t+k} \right] \tag{45}$$

Aggregate inflation appears as an additional term. This is exogenous to the firm and represents a negative externality. Stochastic discounting follows from the household Euler condition

$$\Lambda_{t+k} = \beta^k \frac{P_t}{P_{t+k}} \frac{C_t}{C_{t+k}} \tag{46}$$

The FOC with respect to p^i_{st} yields[35]

$$0 = p^i_{st} y^i_{st} + \left(p^i_{st} - \boldsymbol{\mathcal{C}}^i_{st}\right) y^i_{st} \Psi^i_{st} - \Theta_s Y_t \left\{ \left(\pi_t \frac{p^i_{st}}{p^i_{st-1}} - 1 \right) \pi_t \frac{p^i_{st}}{p^i_{st-1}} + \beta \mathbb{E}_t \left[\left(\pi_{t+1} \frac{p^i_{st+1}}{p^i_{st}} - 1 \right) \pi_{t+1} \frac{p^i_{st+1}}{p^i_{st}} \right] \right\} \tag{47}$$

Since demand can be written as a function of prices, the log-linearized decision rule for each firm is assumed to follow[36]

$$\tilde{p}^i_{st} = \Gamma_s \, \tilde{p}^i_{st-1} + \left(1 + \Gamma'_s\right) \widetilde{\boldsymbol{\mathcal{C}}}^i_{st} + \Gamma^*_s \, \tilde{p}^{-i}_{-st} + \widehat{\Gamma}_s \, \tilde{\pi}_t \tag{48}$$

This expression is solved using undetermined coefficients. Rotemberg pricing is forward looking, but embeds past prices as state variable and they appear in the decision rule. Future prices are solved in expectation. The term for similar-size rivals is already incorporated on the left-hand side (since $\tilde{p}^i_{st} = \tilde{p}^{-i}_{st}$). Following Ueda (2023), the rival's decision rule gives the best reply. Together they give

$$\tilde{p}^i_{st} = \underbrace{\frac{\Gamma_s}{1 - \Gamma^*_s \Gamma^*_{-s}}}_{\Upsilon_s} \tilde{p}^i_{st-1} + \underbrace{\frac{\Gamma^*_s \Gamma_{-s}}{1 - \Gamma^*_s \Gamma^*_{-s}}}_{\Upsilon^*_s} \tilde{p}^{-i}_{-st-1} + \underbrace{\frac{1 + \Gamma'_s}{1 - \Gamma^*_s \Gamma^*_{-s}}}_{\Upsilon'_s} \widetilde{\boldsymbol{\mathcal{C}}}^i_{st} + \underbrace{\frac{\Gamma^*_s (1 + \Gamma'_{-s})}{1 - \Gamma^*_s \Gamma^*_{-s}}}_{\Upsilon''_s} \widetilde{\boldsymbol{\mathcal{C}}}^{-i}_{-st} + \underbrace{\frac{\widehat{\Gamma}_s + \Gamma^*_s \widehat{\Gamma}_{-s}}{1 - \Gamma^*_s \Gamma^*_{-s}}}_{\Upsilon^{\pi}_s} \tilde{\pi}_t \tag{49}$$

The final decision rule reflects price inertia and marginal costs, both for the deciding firm and its rivals, and aggregate inflation. The corresponding terms are collected into the Υ's for convenience. Marginal costs are also related to aggregate output using the method of undetermined coefficients. For the monetary policy shock

$$(i) \quad \tilde{\pi}_t = \Gamma^{\pi} m_t \qquad\qquad (ii) \quad \widetilde{Y}_t = \Gamma^{y} m_t \tag{50}$$

where Γ^{π} and Γ^{y} capture the overall response of inflation and output to the shock. The persistence of the shock implies

$$(i) \quad \mathbb{E}_t[\tilde{\pi}_{t+1}] = \rho_m \Gamma^{\pi} m_t \qquad\qquad (ii) \quad \mathbb{E}_t[\widetilde{Y}_{t+1}] = \rho_m \Gamma^{y} m_t \tag{51}$$

[35] The problem is fully described in section A.3.2 in the appendix.

[36] This is defined as $\tilde{x} = \log\left(\frac{x_t}{\bar{x}}\right)$ where $\bar{x}$ is the steady state value. The notation for the steady state drops the time subscript.

The exact same relation holds for the productivity shock.[37] After log-linearizing (47) and collecting terms, the coefficients are

$$\Upsilon_s = \frac{(\psi_s + \beta\Theta_s\Upsilon^*_s)\Upsilon^*_{\text{-}s} + \Theta_s}{\kappa_s - \beta\Theta_s\Upsilon_s} \qquad \text{(own past price)} \tag{52}$$

$$\Upsilon^*_s = \frac{(\psi_s + \beta\Theta_s\Upsilon^*_s)\Upsilon_{\text{-}s}}{\kappa_s - \beta\Theta_s\Upsilon_s} \qquad \text{(rival past price)} \tag{53}$$

$$\Upsilon'_s = \frac{(\psi_s + \beta\Theta_s\Upsilon^*_s)\Upsilon''_{\text{-}s} - (p^i_s)^{-\varphi}p_j^{\varphi-\sigma}\Psi^i_s\boldsymbol{\mathcal{C}}^i_s}{\kappa_s - \beta\Theta_s(\Upsilon_s + \rho)} \qquad \text{(own marginal cost)} \tag{54}$$

$$\Upsilon''_s = \frac{(\psi_s + \beta\Theta_s\Upsilon^*_s)\Upsilon'_{\text{-}s}}{\kappa_s - \beta\Theta_s(\Upsilon_s + \rho)} \qquad \text{(rival marginal cost)} \tag{55}$$

$$\Upsilon^\pi_s = \frac{(\psi_s + \beta\Theta_s\Upsilon^*_s)\Upsilon^\pi_{\text{-}s} - \Theta_s(1-\rho\beta)}{\kappa_s - \beta\Theta_s(\Upsilon_s + \rho)} \qquad \text{(inflation)} \tag{56}$$

where the convenience terms κ and ψ are defined as

$$\kappa_s = \Theta_s + \beta\Theta_s - (p^i_s)^{1-\varphi}p_j^{\varphi-\sigma}\left[\left(1 - \frac{\boldsymbol{\mathcal{C}}_s}{p^i_s}\right)\frac{\Psi^{i,i}_s + \Psi'^{\,i,\text{-}i}_s}{p^i_s} + \Psi^i_s\frac{\boldsymbol{\mathcal{C}}_s}{p^i_s}\right] \tag{57}$$

$$\psi_s = (p^i_s)^{1-\varphi}p_j^{\varphi-\sigma}\left(1 - \frac{\boldsymbol{\mathcal{C}}_s}{p^i_s}\right)\frac{\Psi''^{\,i,\text{-}i}_s}{p^{\text{-}i}_{\text{-}s}} \tag{58}$$

In the solution for the Υ's above, the term ρ refers to either the persistence of the monetary or productivity shock, depending on the case. It embeds expectations for future prices along with the best reply by rival firms. The steps behind the derivation are provided in the appendix (section A.3.2). The system consists of ten unknowns and ten equations, which are solved numerically.

3.4.2 Aggregate Output and Firm-Specific Marginal Costs

The link between marginal costs and aggregate output still needs to be clarified. This is not straightforward. While wages and output share a simple relationship, capital rental costs depend on the marginal product of capital. The appendix (section A.3.3) explains the asset market clearing and the link between capital rental costs and the aggregate shocks. The resulting capital rental price corresponds to nominal output

$$\tilde{z}_t = \widetilde{P}_t + \widetilde{Y}_t \tag{59}$$

Real wages are given by the household labor-leisure trade-off

$$w_t = C_t \quad \Longrightarrow \quad \widetilde{w}_t = \widetilde{Y}_t \tag{60}$$

The log-linear marginal cost for each firm becomes

$$\widetilde{\boldsymbol{\mathcal{C}}}_{st} = \alpha\tilde{z}_t + (1-\alpha)\widetilde{w}_t - a_{st} - \alpha\widetilde{P}_t \tag{61}$$

Substituting in capital rental costs and wages gives

$$\widetilde{\boldsymbol{\mathcal{C}}}_{st} = \widetilde{Y}_t - a_t \tag{62}$$

[37] Variables without a time subscript are at their steady state value.

Marginal costs are a function of aggregate output and productivity. Firm-specific changes in marginal costs are discussed in the appendix (section A.6). Also note the capital subsidy eliminates the price distortion to capital.

3.4.3 Aggregate Shocks and the Phillips Curve

This section connects the monetary policy and productivity shocks to changes in output and inflation. It covers the solution for identical firms. The solution for asymmetric firms requires a recursive approach that is covered in appendix (section A.4). In the case of the monetary policy shock, the Phillips curve is described by the ratio of Γ^π and Γ^y while the sacrifice ratio is the inverse.

3.4.3.1 Monetary Policy Shocks with Identical Firms

Firms take both costs and aggregate demand as given. The monetary policy shock acts on demand through the household Euler equation. In log-linear form, expressions (5) and (6) give

$$\widetilde{Y}_t = \mathbb{E}_t\left[\widetilde{Y}_{t+1} + \widetilde{P}_{t+1}\right] - \widetilde{P}_t - \widetilde{R}^n_t \tag{63}$$

In log-linear Taylor rule is

$$\widetilde{R}^n_t = m_t + \phi_\pi \tilde{\pi}_t + \phi_y \widetilde{Y}_t \tag{64}$$

Using this, the household Euler equation for bonds is

$$\widetilde{Y}_t = \mathbb{E}_t\left[\widetilde{Y}_{t+1} + \tilde{\pi}_{t+1}\right] - m_t - \phi_\pi \tilde{\pi}_t - \phi_y \widetilde{Y}_t \tag{65}$$

Replacing $\widetilde{Y}$ and $\tilde{\pi}$, gives aggregate demand

$$\Gamma^y m_t = \rho_m(\Gamma^y + \Gamma^\pi)m_t - m_t - \phi_\pi \Gamma^\pi m_t - \phi_y \Gamma^y m_t \tag{66}$$

$$\implies \Gamma^\pi = \frac{(1 + \phi_y - \rho_m)\Gamma^y + 1}{\rho_m - \phi_\pi} \tag{67}$$

When firms are identical, there is no variation in relative prices and the decision rule boils down to aggregate supply

$$-\Upsilon^\pi \tilde{\pi}_t = \Upsilon' \widetilde{\boldsymbol{\mathcal{C}}}^*_t \tag{68}$$

where

$$(i) \quad \Upsilon^\pi = \frac{\Theta}{n}(\rho_m \beta - 1) \quad \text{and} \quad (ii) \quad \Upsilon' = n^{\frac{\varphi-\sigma}{1-\varphi}}(p^*)^{1-\sigma}\left(\varphi - \frac{\varphi - \sigma}{n}\right)\frac{\boldsymbol{\mathcal{C}}^*}{p^*} \tag{69}$$

Replacing the terms $\tilde{\pi}$ and $\widetilde{Y}$ again, the monetary policy shock enters as

$$-\Upsilon^\pi \Gamma^\pi m_t = \Upsilon' \Gamma^y m_t \tag{70}$$

$$\implies \quad \Gamma^y = \frac{-\Upsilon^\pi}{\Upsilon'}\Gamma^\pi \tag{71}$$

Along with (67) there are now two equations (describing aggregate supply and demand) where the Γ^π and Γ^y are the unknowns. Solving gives the reaction of output and inflation to a monetary policy shock.

When firms are asymmetric, aggregate demand (67) is the same. Aggregate supply (71) is replaced by

$$\rho_m \Gamma^\pi m_t = \mathbb{E}_t \left[\frac{n^i (P_s)^{-\varphi} (\widetilde{P}_{st+1} - \widetilde{P}_{st}) + n^{\text{-}i} (P_{\text{-}s})^{-\varphi} (\widetilde{P}_{\text{-}st+1} - \widetilde{P}_{\text{-}st})}{P^{-\varphi}} \right] \tag{72}$$

where

$$\mathbb{E}_t \left[\widetilde{P}_{st+1} \right] - \widetilde{P}_{st} = \left[\rho_m \Gamma^\pi + (\Upsilon_s - 1)\Gamma^m_s + \rho_m \Gamma^m_s + \Upsilon^*_s \Gamma^m_{\text{-}s} \right] m_t \quad \text{and} \quad \Gamma^m_s = \Upsilon^\pi_s \Gamma^\pi + (\Upsilon'_s + \Upsilon''_s)\Gamma^y \tag{73}$$

Combining expressions, the only unknowns are Γ^π and Γ^y after some cancellation.

3.4.3.2 The Phillips Curve with Identical Firms

When firms are identical, the slope of the Phillip curve is

$$\frac{\Gamma^\pi}{\Gamma^y} = \frac{n^{\frac{1-\sigma}{1-\varphi}} (p^*)^{-\sigma} \left(\varphi - (\varphi - \sigma)/n \right) \boldsymbol{\mathcal{C}}^*}{\Theta(1 - \rho_m \beta)} \tag{74}$$

It is easy to take the limit case. Setting $n = 1$ gives

$$\frac{\Gamma^\pi}{\Gamma^y} = \frac{\sigma (p^*)^{-\sigma} \boldsymbol{\mathcal{C}}^*}{\Theta(1 - \rho_m \beta)} \quad \text{where} \quad p^* = \frac{\sigma}{\sigma - 1} \boldsymbol{\mathcal{C}}^* \tag{75}$$

When the elasticity of substitution across goods $\sigma = 1$, the markup becomes infinite and Phillips curve goes to zero. Other factors influence the slope as well. Lower Rotemberg adjustment costs steepen the slope of the Phillips curve. When prices are fully flexible, i.e. $\Theta = 0$, the Phillips curve is vertical and monetary policy is completely neutral. The same applies for the expected persistence of monetary policy shocks. As ρ_m increases, the slope of the Phillips curve steepens.

3.4.3.3 Aggregate Productivity Shocks with Identical Firms

For productivity, the relation between the shock and aggregate output and inflation is given by

$$(i) \quad \widetilde{Y}_t = \Omega^y a_t \qquad\qquad (ii) \quad \tilde{\pi}_t = \Omega^\pi a_t \tag{76}$$

The resulting aggregate supply curve is

$$\Omega^y = \frac{-\Upsilon^\pi}{\Upsilon'} \Omega^\pi + 1 \tag{77}$$

The result is similar to (71). As before, the household Euler equation and the Taylor rule can be combined so that

$$\Omega^\pi = \frac{(1 + \phi_y - \rho_a)}{\rho_a - \phi_\pi} \Omega^y \tag{78}$$

There are two equations and two unknowns, which gives the solution for the elasticity output and inflation to a productivity shock. Again, the asymmetric case is described in the appendix (section A.4).

4 The Response of Firms to Aggregate Shocks

The first part of this section presents the calibration and associated target values. Next, it looks at how concentration affects the slope of the Phillips curve. The third part covers the pass-through. The fourth part of this section describes the dynamic response to a monetary policy and productivity shocks across firms. The final part covers dynamic reallocation and how shocks can amplify steady state distortions.

4.1 Model Calibration

As the model uses Rotemberg pricing and firms reset their prices every period, dispersion arises solely from the cross-section of firms. This contrasts with most models incorporating Calvo price frictions, where dispersion arises from price staggering. The model is solved at a quarterly frequency. The baseline calibration is given in table 1, which is matched to industry characteristics.

Table 1: Baseline Parameter Values

Parameter	Value	Description
β	0.99	Household time discount
α	0.30	Capital share
σ	1	Elasticity of substitution across goods
φ	10	Elasticity of substitution across varieties
Θ	125	Rotemberg price adjustment costs
γ_s	1	Relative price adjustment costs
n_L	1	Number of large firms in an industry
n_S	6	Number of small firms in an industry
$\bar{a}_L$	0.91	Productivity of large firms
$\bar{a}_S$	1.09	Productivity of small firms
ϕ_π	1.50	Monetary policy inflation reaction
ϕ_y	0.125	Monetary policy output gap reaction
ρ_m	0.85	Persistence of monetary policy shocks
ρ_a	0.90	Persistence of productivity shocks

The time discount factor and the capital share of income use standard values.[38] The Taylor rule coefficients match the values originally proposed in Taylor (1993). The parameters describing the elasticity of substitution across varieties and goods follow Atkeson and Burstein (2008). The number of firms and their relative productivity are based on several target moments, described in tables 2 and 3. Targets include the distribution of market share across large and small firms, the pass-through, and the best response price. Additional outcomes of interest include the industry HHI, the aggregate markup, and price dispersion. Generally, steady state values align closely with the desired results, excepting a small mismatch in the pass-through and best response price of small firms. The parameter for the price adjustment cost Θ is equivalent to a 35 percent reset probability under Calvo pricing.[39] This appears consistent with the data. Large and small firms are assumed to have the same price adjustment costs in the baseline ($\gamma_s = 1$).

[38] The persistence of monetary policy shocks matches table 1 column 5 in Coibion and Gorodnichenko (2012). The persistence of productivity shocks follows table 1 column 3 in Pancrazi and Vukotić (2013).

[39] The corresponding parameter under Calvo pricing θ is the probability a firm keeps the same price. The average price elasticity of demand in an industry is around 8.1 and setting $\Theta = 125$ matches a benchmark model using Calvo pricing where $\theta \approx 0.65$, which implies the average duration is 8.6 months. Klenow and Kryvtsov (2008) report the same average duration for the regular price.

Table 2: Industry-Level Targets

Description	Large firms Target	Large firms Value	Small firms Target	Small firms Value	Source
Targeted					
Market share	0.35	0.37	0.12	0.10	Affeldt et al. (2018)
Pass-through	0.65	0.66	0.97	0.91	Amiti et al. (2019)
Slope of best response price	0.48	0.51	0.00	0.10	Ibid.
Markup ($\mu - 1$)	0.24	0.18	0.16	0.12	Hottman et al. (2016)
Implied					
Log price	–	0.06	–	0.21	–

The market shares in table 2 are based on an analysis of the EU Merger Control database (Affeldt et al., 2018). The large firm target takes the average of the top reported market share across observations. The small firm target is based on the average market share of all trailing firms in an observation.[40] The slope of the best response price and the pass-through are from Amiti et al. (2019).[41] The model does fully not match the level of markups reported in Hottman et al. (2016), but the relative gap is the same.[42] Moving to table 3, the HHI estimated by Benkard et al. (2021) provides an alternative target for the distribution of market share. The study finds the median HHI in local product markets decreased from 2360 to 2045 between the years 1994 and 2019. The value generated by the model is at the lower end of this range. The aggregate markup is based on the long-term average of corporate accounting profits. The underlying tabulations are discussed in the appendix (see section A.1). A meta-study by Tetlow (2022) finds the sacrifice ratio usually falls between 2 and 3 and this informs the target for the Phillips curve.

Table 3: Aggregate Targets

Description	Target (range)	Value	Source
Targeted			
Median Industry HHI	2045 - 2360	2060	Benkard et al. (2021)
Aggregate Markup ($\mu - 1$)	0.13 - 0.16	0.14	See appendix[43]
Slope of the Phillips curve	0.33 - 0.50	0.36	Tetlow (2022)
Implied			
Price dispersion (std. dev.)	–	0.07	–
Markup dispersion (std. dev.)	–	0.02	–

Due to the presence of asymmetries, the model generates dispersion in prices and markups across the cross-section of firms. This is measured using the standard deviation of log prices and markups, weighted by market share. Using Compustat data, Meier and Reinelt (2022) documents an increase in the variance of markups over time. Towards the end of the sample period, the variance of log markups within a 4-digit industry is around 0.08 – an order of magnitude higher than what the model implies. This does not mean the model performs poorly. The data in Meier and Reinelt are not fully disaggregated. Furthermore, markups

[40] Only observations with four or more firms are included (meaning there are at least three trailing firms). Both the mean and median market share align for small firms (12 percent) and around 85 percent of market share is explained on average.

[41] The pass-through is taken from table 1 column 4 while table 2 column 1 gives the pass-through costs for small firms.

[42] The values correspond to the top decile and median firm in table 8 in Hottman et al. (2016). The markup estimates assume monopolistic competition and use product-level elasticities.

[43] Section A.1. Note that the relation between markups and aggregate profits is $\frac{Y_t}{Y_t - \Pi_t} = \mu_t$

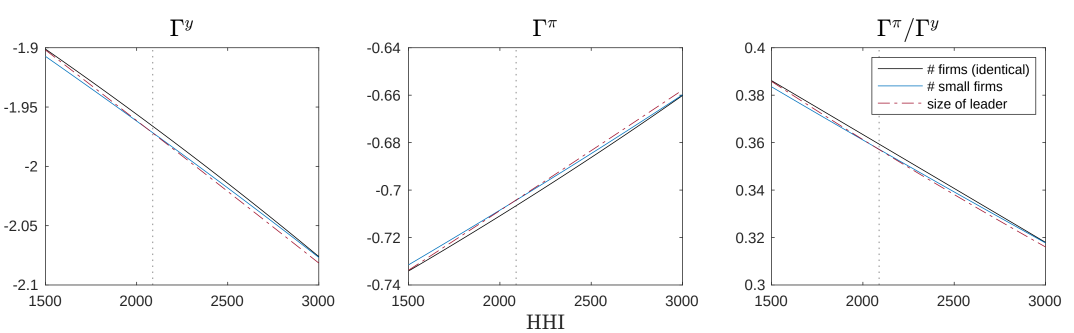
are not directly observed and measurement issues could affect the variance estimate.[44] For these reasons, markup dispersion is not targeted.

There are many estimates of price dispersion in the literature, but few apply directly to the model. Abbott (1989) is the only example looking at producer prices. The study finds variation in prices is around 16 percent for the median industry when dividing the interquartile range for prices by the median. The model returns 15 percent by the same calculation. There are a fairly large set of studies looking at price dispersion across retailers. Even for identical goods, the variation across retailers can be fairly large. Sheremirov (2020) finds the standard deviation is around 6.6 log points for homogeneous products in IRI retail scanner data. Kaplan and Menzio (2015) finds the standard deviation of normalized prices for identical goods is 0.19 while this rises to 0.25 for closely substitutable goods.[45] Yet even when studies include near substitutes, it is unclear whether price dispersion arises from differences in producer prices or those set by retailers. As with markups, price dispersion is not targeted. The slope of the Phillips curve, another key outcome, is discussed in the following section.

4.1.1 Concentration and the Slope of the Phillips Curve

The Phillips curve describes the relationship between inflation and output. Wang and Werning (2022) looks at how higher concentration affects the slope. Figure 4 presents a similar set of results. The panel on the left of the figure gives the responsiveness of output to a monetary policy shock (Γ^y). The center panel gives the responsiveness of inflation (Γ^π). Their ratio gives the slope of the Phillips curve, which is presented on the right. Moving from left to right along the x-axis corresponds to an increase in concentration. This is evaluated in three ways: (i) identical firms where the number n decreases, (ii) the baseline calibration where the number of small firms n_S decreases, and (iii) the baseline calibration where the productivity of the leader $\bar{a}_L$ rises, resulting in a higher market share. The vertical dotted line shows the HHI implied by the baseline calibration. The results here are close to those presented in Wang and Werning. In the their study, a naïve oliogopoly model closely matches a more sophisticated model with strategic complementarity. The same could be said here. When looking at a range of plausible values for the HHI, a specification with asymmetry yields results very close to a specification with identical firms.

Figure 4: Concentration and the Aggregate Response to a Monetary Policy Shock (Baseline)



The x-axis displays the HHI and a move from left to right corresponds to an increase in concentration. The vertical dotted line gives the HHI corresponding to the baseline calibration. The left-hand panel shows the response of aggregate output to a monetary policy shock, while the center panel gives the response of inflation. The right-hand panel gives their ratio, i.e. the slope of the Phillips curve, which is decreasing as concentration rises. The three lines give (i) identical firms where n decreases, (ii) the baseline calibration where n_S decreases, and (iii) the baseline calibration where the productivity of the leader improves and it gains market share.

[44] Ridder et al. (2021) demonstrates assumptions on the production function can have a large impact on results for example.
[45] Similarly, Böheim et al. (2021) finds a coefficient of variation around 0.12 comparing online prices across retailers in Austria

While it is tempting to link higher concentration to the flattening of the Philips Curve, even modest change requires a large increase in concentration.[46] In part, this is a consequence of the parameterization. Differences in price adjustment costs between firms change outcomes as well. This is explored in-depth in the appendix (section A.5).

4.2 The Pass-Through of Cost Shocks

There is a long-standing debate on whether the pass-through of cost shocks reflects inflation expectations or pricing power.[47] The view pricing power contributed to inflation helped rationalize the introduction of wage and price controls in the United States in the early 1970s. In retrospect, inflation expectations were likely the main driver. Taylor (2000) finds strong evidence inflation was positively correlated with its persistence over this period. The expected persistence of inflation plays a prominent role in the New Keynesian model as well. Still, there are arguments low inflation over recent decades reflects changes in market structure. Both Auer and Fischer (2010) and Heise et al. (2022) link import competition to changes in the pass-through for example.[48]

The analysis here parses various elements of this debate. The results suggest inflation expectations play a key role in the pass-through, in addition, large firms will significantly raise their pass-through during inflationary episodes. In practice, this resembles an expansion of pricing power. While solution for an aggregate shock remains the same as before, the response to an idiosyncratic shock requires some further explanation. Most elements are similar to the solution for an aggregate shock in section 3.4.1, but two adjustments are necessary. First, the cross-price elasticities become

$$(i) \quad {\Psi'}^{i,\text{-}i}_{st} = 0 \qquad \text{and} \qquad (ii) \quad {\Psi''}^{i,\text{-}i}_{st} = -(\varphi - \sigma)(1-\varphi)\frac{(n_s - 1)(p^i_{1jt}p^{\text{-}i}_{1jt})^{1-\varphi} + n_{\text{-}s}(p^i_{1jt}p^{\text{-}i}_{2jt})^{1-\varphi}}{p^2_{jt}} \tag{79}$$

The Υ's are re-estimated accordingly. With an idiosyncratic shock, the change in prices is given by

$$(i) \quad \tilde{p}^i_{st} = \Upsilon_s\, \tilde{p}^i_{st-1} + \Upsilon^*_s\, \tilde{p}^{\text{-}i}_{\text{-}st-1} + \Upsilon'_s\, \widetilde{\mathcal{C}}^i_{st} \qquad \text{and} \qquad (ii) \quad \tilde{p}^{\text{-}i}_{\text{-}st} = \Upsilon_{\text{-}s}\, \tilde{p}^{\text{-}i}_{\text{-}st-1} + \Upsilon^*_{\text{-}s}\, \tilde{p}^i_{st-1} + \Upsilon''_{\text{-}s}\, \widetilde{\mathcal{C}}^i_{\text{-}st} \tag{80}$$

Nominal costs lead to a degree of smoothing, meaning the change in prices tends to be smaller – but also more durable – than the cost shock itself. For this reason, the pass-through is measured over the duration of the shock using

$$\boldsymbol{\mathcal{P}} = \frac{\sum_t \tilde{p}^i_{st}}{\sum_t \widetilde{\mathcal{C}}^i_{st}}$$

where t is large enough to ensure both variables return to the steady state (or at least very close). The model is re-estimated over a range of settings for the persistence and results are presented in figure 5.

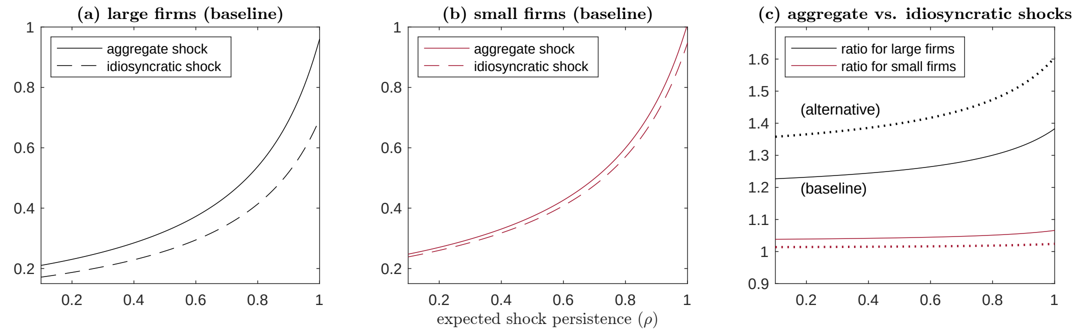
Expectation play a role because firms weigh the future benefit of adjusting prices against the costs of doing so. When shocks are temporary, firms prefer relatively small adjustments (see panels a and b in figure

[46] A decrease in the slope of the Philips curve by 0.01 implies an increase in the HHI of more than 200 points.

[47] Many of the intuitions in this paper appear in Cagan (1979). Before the 1970's there was a general assumption that slack demand would lead prices to fall. The simultaneous rise of unemployment and prices challenged this assumption and expectations were later viewed as the main driver.

[48] The study by Heise et al. (2022) also uses nested-CES demand and many of the underlying intuitions are also similar to this paper. The presence of import competition helps explain several key outcomes. Smaller firms exited the market, which increased concentration. As large firms accumulated market share, they limited the pass-through of cost shocks and cut prices in response to imports. While empirical estimates indicate both concentration and import competition lowered the pass-through, their relative contribution is not separable.

Figure 5: The Pass-Through of Cost Shocks (Baseline)



The x-axis displays the expected persistence of the shock and the y-axis gives the pass-through, measured over the entire duration of the shock. The solid lines in the left-hand and center panels give the response to an aggregate shock while the dashed lines describe the response when shocks are idiosyncratic. The right-hand panel takes the ratio of aggregate and idiosyncratic shocks. The alternative scenario (dotted lines) modifies the baseline so that $\bar{a}_L = 0.87$. This increases the market share of the leading firm to 49 percent and significantly lowers the pass-through of idiosyncratic shocks.

5). If changes in costs are permanent, there is complete pass-through. Along with changes in the expected persistence of the shock, it also matters if shocks are perceived as idiosyncratic or aggregate. The right-hand panel gives their ratio. For large firms, the difference is significant: on the order of 35 percent when $\rho = 0.9$. This appears consistent with Gödl-Hanisch and Menkhoff (2023), which finds the pass-through for idiosyncratic shocks is around 40 percent smaller compared to an aggregate shock.[49] The differences in pass-through are also supported by Dedola et al. (2021). In addition, a working paper by Lafrogne-Joussier et al. (2023) finds a strong role for strategic complementarity among large firms. Along with the baseline, an alternative scenario is included with greater asymmetry between firms. The market share of the leading firm is around 12 percentage points larger. Accordingly, the gap between the idiosyncratic and aggregate regime becomes grows, mostly due to a reduction in pass-through from idiosyncratic shocks. The model predicts a positive association between firm size, inflation, and the pass-through, which highlights the difficulty of empirical work. Firm behavior under a low-inflation regime will not apply under a high-inflation regime – explaining why past estimates of the pass-through and slope of the Phillips curve appear low at present.

4.3 The Dynamic Response to Shocks

This section looks at price dynamics following a shock. Impulse responses are measured as the percent deviation from the steady state. The productivity shock is discussed first, followed by the productivity shock. Given the simplicity of the model, monetary tightening is also analogous to a negative demand shock.

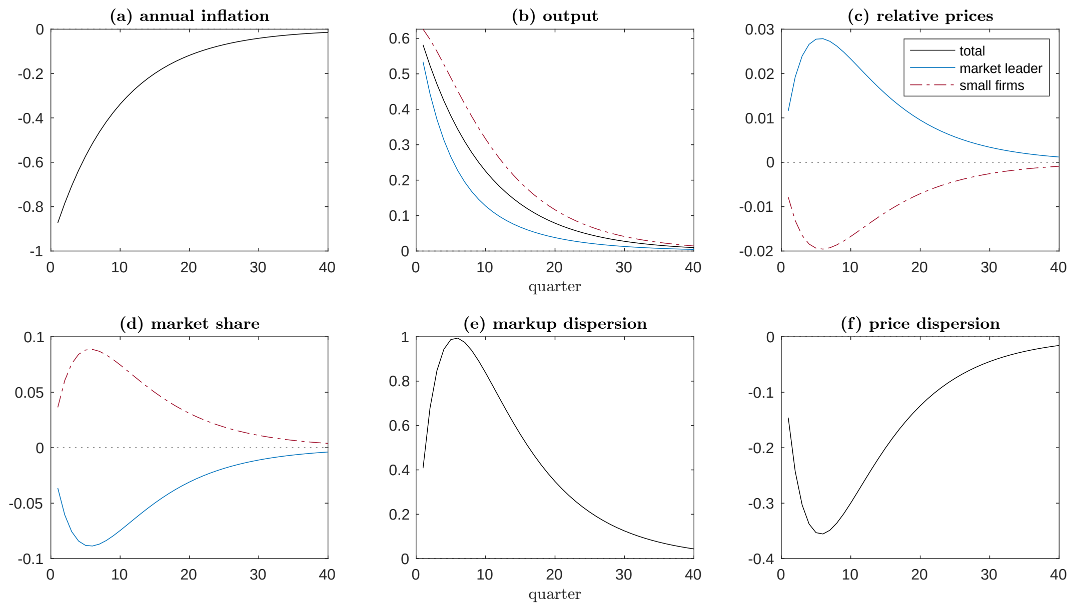
4.3.1 Aggregate Productivity Shock

Figure 6 gives the dynamic response to a one percent productivity shock. As expected, it increases aggregate output. While this raises the cost of labor and capital inputs for firms, the shock also improves their efficiency and prices drop. Because prices demonstrate significant inertia compared to costs, markups increase, particularly for large firms. This amplifies the steady state distortion and markup dispersion rises. As with the monetary shock, the gap in relative prices relates to differences in the pass-through. Large firms only pass through part of the cost saving to households and they cut their prices by less compared to small firms. Since the price level of large firms is below the level set by small firms in the steady state, the shock leads to

[49]The level of pass-through depends on the persistence of the shock. Bruine De Bruin et al. (2023) finds the average pass-through following the Covid-19 shock was 60 percent, consistent with a persistence of 0.8 or a half-life around 1 year.

price compression. Differences in the the evolution of relative prices also explain the reallocation of market share towards small firms.

Figure 6: Baseline Impulse Response to a Productivity Shock ($\xi_0 = 1$)



The initial shock increases aggregate productivity by one percent. Inflation drops and output expands. These outcomes are standard for a New Keynesian model. While wages and capital rental costs increase, efficiency is also higher. The latter effect dominates and firms reduce their marginal costs. Small firms pass their savings to consumers and cut their relative prices more than large firms. This reduces price dispersion. Large firms increase their markup by more than small firms. This increases markup dispersion.

The results align with two empirical studies. Sheremirov (2020) observes a positive co-movement between dispersion in regular prices and inflation.[50] For a 1 percentage point increase in inflation, dispersion in the log of regular prices increases 0.026 percent. The model implies a value of 0.027 percent and aligns closely with this point estimate. The results also indicate small firms are more sensitive to the business cycle, which is consistent with Crouzet and Mehrotra (2020). They find a differential in the response of sales to a change in GDP. The estimated elasticity of sales to GDP is 2.5 for the top 1 percent of firms (by size) and 3.1 for the bottom 99 percent.[51] Looking at output, the model implies small firms are around 35 percent more sensitive to the business cycle than large firms, whereas the corresponding figure from Crouzet and Mehrotra is 24 percent ($= 3.1/2.5 - 1$).

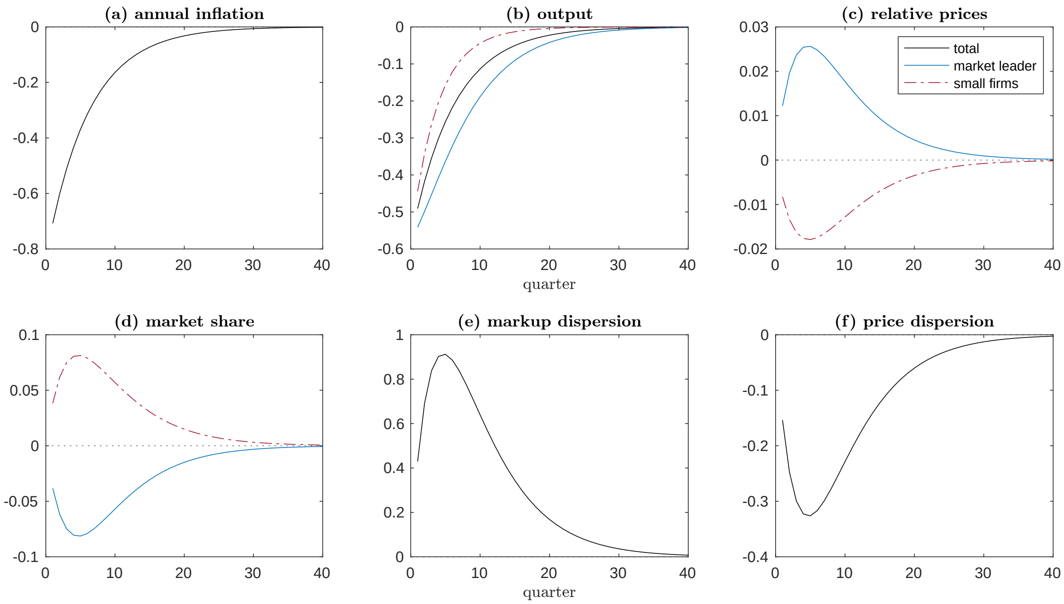
4.3.2 Monetary Policy Shock

Figure 7 presents the dynamic response to a one percentage point increase in the annualized interest rate across large and small firms. Both aggregate inflation and output decline in response to the shock (a standard outcome). Due to differences in the price elasticity of demand, the effect of the shock on prices and output is not symmetric across firms. Large firms have a larger response. This relates to the pass-through. When monetary policy tightens, marginal costs fall in line with output. Large firms do not fully pass these cost savings through to consumers and they cut prices by less than small firms. Demand for the variety produced by the large firm drops since its relative price is higher, which leads to a decline in market share.

[50] Sheremirov (2020) also observes the Calvo model overstates the comovement of price dispersion with inflation by a factor of 15 and a similar analysis is included in the appendix in section A.7.

[51] While there are no industry controls in the baseline, estimates are similar when using NAICS 3-digit controls.

Figure 7: Baseline Impulse Response to Monetary Tightening ($\varepsilon_0 = 0.25$)



The monetary policy shock is equivalent to a one percentage point increase in the nominal interest rate. The x-axis gives the quarter following the shock. The y-axis is scaled to give the deviation from the steady state. Inflation drops by around 0.7 percent in the first period. The response of aggregate inflation and output are standard. The change in the relative price of small and large firms results from differences in pricing behavior. Marginal costs fall. Large firms do not fully pass through savings and set a higher relative price following the shock. As a consequence, they lose market share. Because large firms increase their markup by more than small firms, this amplifies markup dispersion.

Since small firms set a higher price in the steady state, changes in relative prices following monetary tightening lead to price compression.[52] Meanwhile, markup dispersion rises. Both small and large firms increase their markups, but the increase for large firms is more pronounced. Large firms already charge a higher markup in equilibrium, so this amplifies the steady state distortion. This outcome is consistent with the findings in Meier and Reinelt (2022) where a contractionary monetary shock increases markup dispersion while easing lowers it. The implied change in the level of the variance from a 1 percentage point increase in the interest rate is 0.001, which matches what Meier and Reinelt report.

Given monetary easing, the results are fully symmetric. When looking at detailed firm-level microdata from the US Census Bureau's Quarterly Financial Report survey, Crouzet and Mehrotra (2020) do not find a statistically significant difference in the response across large and small firms to monetary policy.[53] It is possible differences in the price elasticity of demand across firms are confounded by other factors, such as financial frictions or price adjustment costs.[54]

[52] Price dispersion is measured using the weighted standard deviation of log prices in each time period, where the market share of each firm gives the weight. Log markups are similarly used to measure markup dispersion.

[53] The authors suggest economies of scope may play an important role in explaining why small firms are more sensitive to aggregate shocks. Large firms often operate in multiple industries and are more likely to experience an 'aggregate' shock whereas small firms are more exposed to industry-specific conditions.

[54] When price adjustment cost for large firms is set lower than the cost for small firms (i.e. $\gamma_L < \gamma_S$), this significantly dampens the response for example (see section A.5 in the appendix).

4.4 Allocative Efficiency and Strategic Complementarity

The allocation of demand influences the overall efficiency of the economy. In the context of the model, the change in aggregate productivity A has two main components:

$$(i) \quad \frac{A_t^w}{A} = e^{a_t} \qquad (ii) \quad \frac{A_t^b}{A} = \frac{y_{St} n_S \bar{a}_S + y_{Lt} n_L \bar{a}_L}{y_S n_S \bar{a}_S + y_L n_L \bar{a}_L} \qquad \text{where} \quad A = y_S n_S \bar{a}_S + y_L n_L \bar{a}_L \tag{81}$$

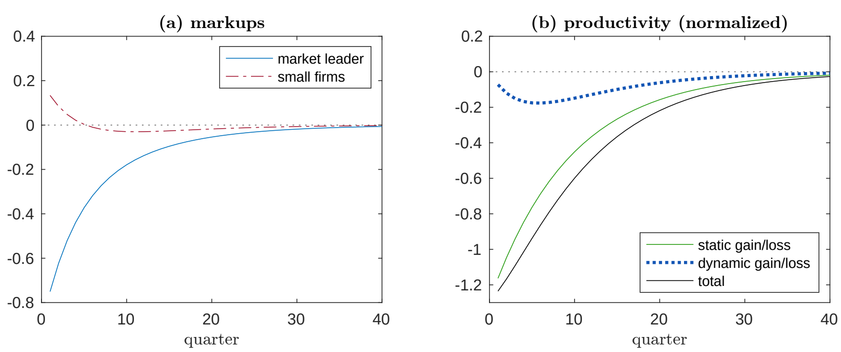
First, there is the change in productivity A^w holding market share constant, often called the 'within' component. The change from dynamic reallocation A^b, or the 'between' component, is more interesting since it reflects differences in the pass-through. Large and small firms have different productivity levels in the steady state and the reallocation of demand across firms following shocks affects the aggregate productivity level. This can be compared to a monopolistic benchmark to infer the efficiency cost of price dispersion.

The baseline monetary policy and productivity shocks both lead to efficiency losses. It is evident large firms lose market share in figures 7 and 6, which lowers the overall efficiency of the economy. Still, the effect is somewhat trivial. For monetary policy tightening, the cumulative loss amounts to 3.4 percent of potential output, mostly from the shock itself. Around 0.1 percentage points is explained by reallocation across firms. The productivity shock would lead to a cumulative output gain of 4 percentage points of potential output by itself. Reallocation to small firms lowers this by 0.2 percentage points and the total cumulative gain is 3.8 percent. While these losses are a second-order concern, shocks may affect firms unequally.[55] In this case, the role of dynamic reallocation becomes more prominent, as will be discussed.

4.4.1 Firm-Specific Cost Shocks

Figures 8 and 9 give the response of markups, prices, and productivity to firm-specific shocks.[56]

Figure 8: Impulse Response Given a Negative Shock to Large Firms ($\xi_0 = -1$)



A one percent productivity shock is applied to large firms. Large firms aggressively cut their markup, but small firms have a relative price advantage following the shock. The change in efficiency is divided between two components. The first is the effect of the productivity shock holding the allocation of demand constant. The second is productivity gain resulting from the reallocation of demand to high productivity firms.

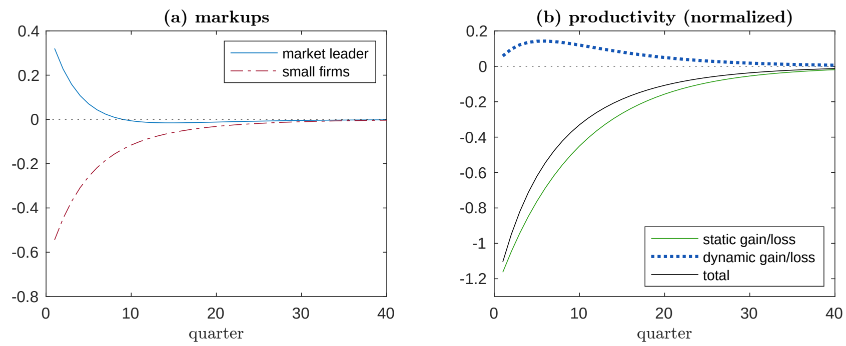
In figure 8, a negative productivity shock is only applied to large firms. The resulting drop in aggregate output lowers marginal costs, benefiting small firms. The shock is also inflationary. Large firms both raise prices and cut their markups in response to the shock. Small firms raise prices gradually and their markup

[55]For example Gabaix (2011) suggests idiosyncratic shocks to the top 100 firms in the United States explains around one-third of GDP fluctuations.

[56]The outcomes for productivity in figures 8 and 9 are normalized to reflect an equally-sized shock given the respective weight of large and small firms in the economy. The results are fully isomorphic given a positive shock.

remains relatively constant. With a higher relative prices, large firms lose market share. Since they are the most efficient producers, this reallocation further diminishes the overall efficiency of the economy. This amplifies 'static' losses from the shock, i.e. losses before changes in market share are taken into account. The cumulative static losses are around 4 percentage points of potential output. Meanwhile, the additional loss from dynamic reallocation is around 1 percentage points of potential output, accounting for 21 percent of the total.

Figure 9: Impulse Response Given a Negative Shock to Small Firms ($\xi_0 = -1$)



A one percent productivity shock is applied to small firms. The interpretation is the same as figure 8 but the outcomes are different. First, small firms cut their markup by less than large firms when facing a comparable shock; meanwhile, large firms raise their markups by more. Despite the shift in markups, the relative price of small firms increases by more and demand shifts towards large firms. This reallocation partially offsets the static losses resulting from the shock.

If small firms receive a negative productivity shock, there is a dynamic gain from reallocation to large firms (figure 9). Following the shock, small firms are forced to raise their prices and large firms gain a price advantage. Large firms also raise their price and markup in response, reflecting strategic complementarity. The cumulative static loss is 5.8 percentage points of potential output. The cumulative dynamic gain is 1.2 percentage points of potential output, meaning the total impact is around 4.6 percentage points. The dynamic gain would be 35 percent larger – 1.7 percentage points – if strategic complementarity was absent.[57] The 0.4 percentage point difference reflects the 'cost' of market power in the model. This is also consistent with the observation some firms earn excess profits following shocks.[58]

5 Policy Implications and Further Extensions

The results presented in figure 5 suggest the pass-through will appear low when inflation is low. With higher inflation, there are indications the pass-through has recently increased (Amiti et al., 2023).[59] This is consistent with the model's predictions and highlights the role of strategic complementarity in price setting. There are several takeaways. First, the nature of shocks matters. For example, shocks to energy prices appears to have a high pass-through (Lafrogne-Joussier et al., 2023). One possibility is they affect all firms and price complementarities are strong. Second, the increase in pass-through following an aggregate shock makes inflation worse. While the model here is completely forward looking, this should have a first-order

[57] To find the counterfactual, the number of firms is increased while targeting the same equilibrium allocation of market share between large and small firms. In practice, the alternative setting is $n_L = 200$ and $n_S = 1900$. This eliminates both own-price effects and strategic complementarity since each firm's market share is negligible, but there is still a gap in productivity.

[58] For example, the Spanish government has imposed a windfall tax on banks and energy companies.

[59] While rising concentration could explain the observed flattening of the Phillips curve over the 2000s, it was more likely a consequence of the inflation regime. The observed steepening of the Phillips curve may also relate to rising inflation and a pass-through Hobijn et al. (2023).

effect when there is inertia in expectations. In other words, a large aggregate shock can lead to cost-push inflation, which raises households' inflation expectations, which leads them to bring forward consumption, further raising inflation and so on. This channel could be further explored.

Differences in the pass-through across firms explain other outcomes as well. For example, small firms appear more sensitive to the business cycle due to lower pricing power. The results also suggest that large firms disproportionately benefit from monetary easing. This contributes to a large literature showing low interest rates over the 2010s likely exacerbated the concentration trend. One obvious channel is M&A activity, which favors established firms (Blonigen & Pierce, 2016; Chatterjee & Eyigungor, 2023; Kroen et al., 2021). Low interest rates likely affected R&D as well, allowing market leaders to pull ahead. While the model here focuses on short- and medium-run dynamics, an extension with endogenous growth could be useful. Liu et al. (2019) argues low rates have widened the gap between firms at the innovation frontier and those behind, discouraging competition and market entry.[60] That is, once market leaders pull sufficiently far ahead of their rivals, innovation may decline.

Finally, strategic complementarity plays a strong role when shocks are firm-specific. This relates to so-called 'greedflation' – the idea large corporates exploited inflation to exercise market power (Weber & Wasner, 2023). As highlighted in the section on dynamic reallocation, strategic complementarity is a source of inefficiency when small firms are more exposed to cost/productivity shocks, which might have been the case following the Covid pandemic. This is much less the case with aggregate shocks. Given a negative productivity shock, large firms will absorb cost increases to some extent. Of course, the model cannot capture all salient features of the recent crisis. It is not clear if producers could increase supply given global disruptions. Also, the problem of 'greedflation' raises a normative question: should companies raise prices if they are already highly profitable? In a time of crisis, the answer is not completely clear. The analysis here establishes the economic costs are potentially large when shocks are firm-specific.

Several further extensions appear useful. Aggregate efficiency may not correlate with household welfare. With CES preferences, households gain utility from the presence of multiple varieties and may prefer to allocate their income across varieties despite the efficiency costs. The model can also help weigh various static and dynamic trade-offs. For example, the vertical integration of firms and their suppliers appears to benefit consumers since there is no 'double markup' (Bellucci & Rungi, 2022). At the same, vertical integration may increase the rigidity of supply chains, lowering dynamic efficiency. Realism on household preferences as well a more complex interlinkages between sectors are needed to fully evaluate these outcomes.

Firms exit is another important aspect to explore (Hopenhayn, 1992). A VAR analysis in Hamano and Zanetti (2022) indicates monetary policy tightening both reduces firm entry and increases firm exit. Due to low rates of market entry, the short-term impact on productivity is negative – incumbent firms are insulated from competition and increase their markups. These dynamics seems simple to replicate and could explain market hysteresis following shocks. This is left for a future extension, but one that appears straightforward to implement. In addition, Heise et al. (2022) shows import competition played an important role in the concentration trend. Adding foreign firms subject to different cost shocks could also enrich the dynamic model. Others point to the slowdown in productivity growth along with demographic changes and declining entrepreneurship as potential culprits behind declining business dynamism (Hopenhayn et al., 2018; Karahan et al., 2019; Olmstead-Rumsey, 2019).

[60] The authors further argue this regime is not fully passive, rather leading firms use innovation to realize a strategic advantage. Similarly, Cunningham et al. (2021) documents the presence of 'killer' acquisitions where incumbents acquire rival firms solely to disrupt innovation within their industry.

6 Conclusion

This paper embeds an industry structure featuring strategic interaction between firms within a standard New Keynesian framework. It aligns with three key empirical findings: first, industry leaders usually control a significant share of the market; second, they charge higher markups; and third, firm size affects pricing behavior. As the economy goes from a low-inflation regime were idiosyncratic shocks dominate to a high-inflation regime, there is a significant increase in the pass-through. As concentration increases, the gap between low- and high-inflation regimes widens. The reason is relative simple: as their market share grows, industry leaders increasingly focus on competition between industries. They have higher markups and they choose to absorb idiosyncratic shocks more. In addition to the pass-through, the framework links differences in market power and pricing behavior across firms to a number of other outcomes. It explains why small firms appear more sensitive to the business cycle. It generates appropriate changes price and markup dispersion following shocks, Finally, the framework is used to evaluate whether strategic complementarity is economically relevant from an aggregate perspective. Under specific circumstances, for example a shock affecting small firms more than large firms, such behavior may generate sizable efficiency losses.

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A Appendix

A.1 The Evolution of Accounting Profits by Form of Incorporation

The headline profits of US corporations have risen over the past 40 years, but there are several caveats. The separation of wages and profits typical for C-corporations is less well defined for other forms of incorporation. Most growth in registered businesses has been from partnerships and S-corporations.[61] With both, profits are 'passed through' directly to owners, who report the income on their individual tax returns. This blurs the normal separation of wages and profits. For pass-through business owners, there is no large tax advantage to reporting either form of income, at least for upper tax brackets.[62] In addition, many partnerships and S-corporations are set up as investment vehicles. Returns on other investments are reported as 'profits' and applicable taxes are paid accordingly. Therefore, headline profits should be adjusted for both officer compensation and portfolio income to ensure they are measured consistently over time.

Officer compensation (i.e. payments to owner employees) is large relative to net income in the corporate sector. For S-corporations, officer compensation averaged 70 percent of net income 1992-2016 while it was around 40 percent of net income for C-corporations. Notably, this ratio declined over time for both S- and C-corporations due to stricter enforcement of 'reasonable pay' clauses. A decline in the effective tax rate on corporate profits probably motivated this shift as well. While payments to owner-employees for their labor cannot be easily distinguished from profits, it is possible to add officer compensation and profits together as an alternative measure. This leads to a 50 percent upward revision for overall business profitability in the 1980s. Business activity was dominated by C-corporations during this period and officer compensation was relatively high. The same adjustment increases profitability by only 20 percent in the 2010s. As mentioned, a second source of bias comes from the inclusion of portfolio income in the net income of S-corporations and partnerships. Many are set up purely as investment vehicles and the share of portfolio income in net income has grown over time. This leads to a potential double-counting problem for profits. To mitigate this, a second adjustment takes only business (or 'ordinary') income earned by S-corporations and partnerships into account.

For internal consistency, the results for Table 4 are given in terms of net receipts rather than GDP. The growth in total net income (before adjustment) between 1981-89 and 2010-16 is equal to 7 percentage points of GDP − a significant increase. Including officer compensation lowers this slightly to 6 percentage points of GDP. Further excluding portfolio income reduces the change to 4 percentage points of GDP. By this meaasure, profits went from around 11 percent of GDP in the 1980s to 15 percent in the 2010s.[63] A shift-share decomposition indicates the majority of the change in overall profitability is explained by S-corporations and partnerships. The decomposition takes the following form

$$\Delta X_{it} = \underbrace{\sum_i (\Delta X_{ijt})\omega_{it-1}}_{within} + \underbrace{\sum_i (\Delta\omega_{it}) X_{it-1}}_{between} + \underbrace{\sum_i (\Delta X_{it})(\Delta\omega_{it})}_{dynamic\, reallocation}$$

[61] These tend to be smaller businesses, or at least closely held. The growth of pass-through entities is also consistent with growing service consumption since firms in the service sector tend to be smaller than in manufacturing.

[62] Cooper et al. (2015) finds that the effective tax rate on partnerships and S-corporations is lower than C-corporations, which may explain their rapid growth.

[63] As a rule of thumb, net receipts are around 2.2x GDP. CBO data for households indicate a corresponding increase around 4.8 percentage points for business income (including dividends) over the same period. Gross net income for the pass-through sector is larger in the IRS data than what CBO reports as household business income (e.g. \$1.64 trillion compared to \$1.01 trillion in 2016). There are several explanations for the discrepancy. First, there is a well-known mismatch between personal tax records and business income. Second, some share of net income reported to the IRS may go towards net lending by firms. Finally, some share of profits may go to foreign nationals.

where X is total income over a time period, subdivided by type of entity i weighted by their share of total receipts ω_i. The decomposition accounts for changes 'within' a category, holding weights constant. Notably, the within component is positive across all types of incorporation. The 'between' component describes the change in weights, which is negative for C-corporations and sole proprietorships. While large public companies are more profitable than in the past, they explain a smaller share of total activity. This is relevant to the debate on superstar firms and markups. Most of the overall increase in profitability is explained by S-corporation and partnerships. Because ownership is concentrated (with 2-3 owners for the median S-corporation) and potentially less diversified, investors may demand higher returns to offset higher idiosyncratic risk.

Table 4: Corporate Profitability by Business Type, Period Averages

(a) Share of Total Receipts

	1981-89	1990-99	2000-9	2010-16
C-corporation	0.833	0.742	0.665	0.625
S-corporation	0.068	0.149	0.175	0.192
Partnership	0.041	0.058	0.119	0.146
Sole proprietorship	0.058	0.051	0.041	0.038

(b) Net Income to Receipts

	1981-89	1990-99	2000-9	2010-16
Total	0.035	0.051	0.056	0.069
C-corporation	0.027	0.036	0.035	0.046
S-corporation	0.021	0.042	0.056	0.064
Partnership[a]	0.059	0.114	0.119	0.134
Sole proprietorship	0.152	0.209	0.213	0.228

(c) Shift-Share Decomposition

Δ Within	Between	Dynamic	Total
0.026	0.000	0.008	0.034
0.016	-0.006	-0.004	0.006
0.003	0.003	0.005	0.011
0.003	0.006	0.008	0.017
0.004	-0.003	-0.002	0.000

(d) Net Income and Officer Compensation to Receipts

	1981-89	1990-99	2000-9	2010-16
Total	0.053	0.068	0.072	0.082
C-corporation	0.046	0.053	0.048	0.056
S-corporation	0.039	0.078	0.094	0.101
Partnership[a]	0.059	0.114	0.119	0.134
Sole proprietorship	0.152	0.209	0.213	0.228

(e) Shift-Share Decomposition

Δ Within	Between	Dynamic	Total
0.020	-0.002	0.012	0.029
0.008	-0.010	-0.002	-0.004
0.004	0.005	0.008	0.017
0.003	0.006	0.008	0.017
0.004	-0.003	-0.002	0.000

(f) Net Ordinary Income and Officer Compensation to Receipts

	1981-89	1990-99	2000-9	2010-16
Total	0.051	0.064	0.062	0.071
C-corporation	0.046	0.053	0.048	0.056
S-corporation	0.035	0.069	0.083	0.095
Partnership[a]	0.031	0.069	0.058	0.067
Sole proprietorship	0.152	0.209	0.213	0.228

(g) Shift-Share Decomposition

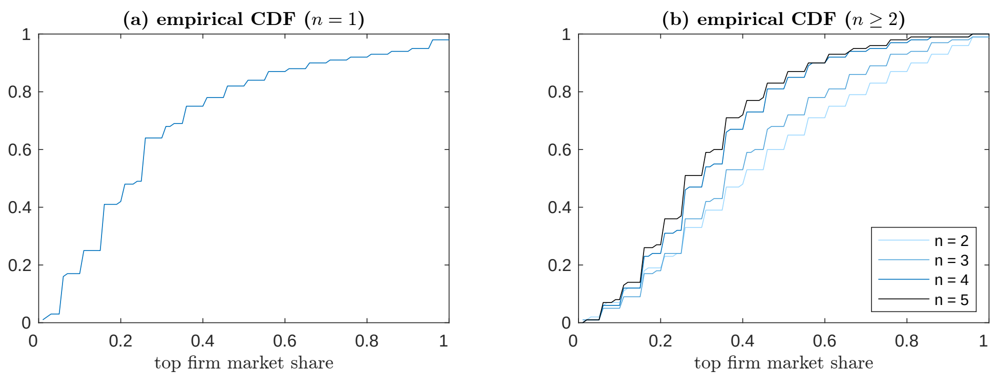
Δ Within	Between	Dynamic	Total
0.018	-0.005	0.008	0.020
0.008	-0.010	-0.002	-0.004
0.004	0.004	0.007	0.016
0.001	0.003	0.004	0.009
0.004	-0.003	-0.002	0.000

Notes: The shift-share decomposition compares the periods 1981-9 and 2010-16. The needed series are not available for 1980. All tabulations are in terms of net receipts. Net receipts are roughly 2.2x GDP on average, although is varies over time.
[a]Partnerships exclude capital gains and real estate and rental income from net income for all years.
Source: IRS Statistics of Income.

A.2 Evidence from Antitrust Markets

Figure 10 shows the CDF of market share reported in Affeldt et al. (2018). The left-hand panel shows the CDF for observations where only the market share of the post-merger entity is reported. The right-hand panel shows the CDF of the top market share when observations include competing firms. Each line is based on the number of competitors. The results suggest there is a strong correlation between the number of firms reported and the market share of the leading firm. This might be a feature of the data or a sign of upward bias when reporting is incomplete.

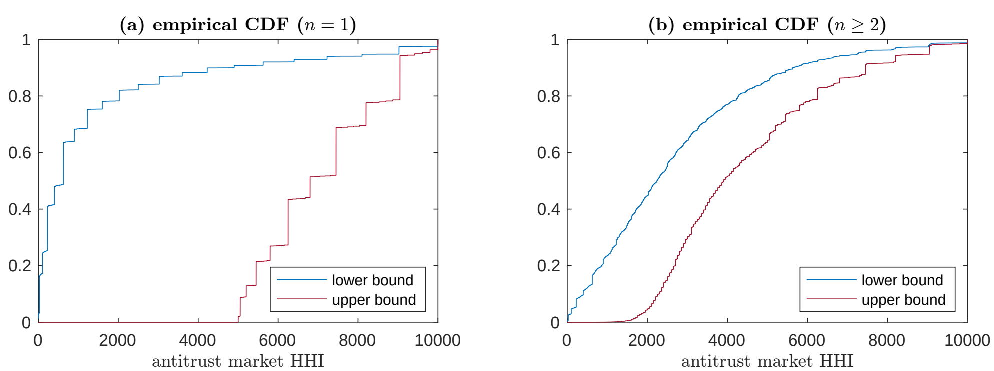
Figure 10: Cumulative Distribution of Top Market Shares across Antitrust Markets



Source: Affeldt et al. (2018)

Affeldt et al. calculate HHIs for each market.[64] The lower bound HHI is calculated in the normal way, except all unattributed market share is treated as a zero – equivalent to perfect competition between firms. The upper bound for the post-merger HHI adds the square of the residual market share. In other words, the residual market share is treated as one missing competitor. The corresponding CDFs are given in figure 11.

Figure 11: Distribution of HHIs across Antitrust Markets



Source: Affeldt et al. (2018)

Looking at the difference between the lower and upper bound in the left-hand panel of figure 11, most market share is treated as a residual and the resulting gap is large. The lower bound estimate in the right-hand panel is more interesting. It suggest the HHI is above 2000 in the median antitrust market, at least when market share was evaluated as part of the merger review.[65] This threshold is significant since the

[64] The calculation uses the post-merger market share if applicable and the market shares of competing firms.

[65] While it is likely more detailed information was collected on markets that are concentrated, the majority of cases (51 percent) include information on competitors. For cases where information on competitors is omitted, the post-merger entity is only marginally smaller than cases including such information: 30 versus 34 percent.

EU guidelines on horizontal mergers flag potential competition concerns for higher levels of concentration. Furthermore, almost one-quarter of market are assessed to have an HHI of 3000 or higher. As with Benkard et al. (2021), this suggests the prevailing level of concentration in most markets is higher than commonly appreciated.

Table 5: Descriptive Statistics for Antitrust Markets by Number of Firms ($n \geq 2$)

		Top Firm Market Share		
# Firms	Count	Mean	Median	Std. Dev.
2	1940	52.8	55.0	22.3
3	2523	46.0	45.0	18.8
4	2766	38.2	35.0	16.4
5	1411	36.1	35.0	15.7
> 5	1288	33.5	30.0	14.9
Total	**9928**	**42.1**	**40.0**	**19.3**

		Avg. Share of Trailing Firms		
# Firms	Count	Mean	Median	Std. Dev.
2	1940	22.1	20.0	12.4
3	2523	17.5	17.5	7.0
4	2766	13.8	15.0	4.7
5	1411	11.8	12.5	3.7
> 5	1288	9.0	9.0	3.0
Total	**9928**	**15.5**	**15.0**	**8.3**

		Share of Leader vs. Follower		
# Firms	Count	Mean	Median	Std. Dev.
2	1441	2.17	1.75	1.24
3	2172	1.97	1.57	1.11
4	2400	1.78	1.50	0.88
5	1228	1.80	1.50	0.89
> 5	1075	1.73	1.50	0.81
Total	**8316**	**1.90**	**1.59**	**1.02**

		Residual Market Share		
# Firms	Count	Mean	Median	Std. Dev.
2	1940	25.4	20.0	24.9
3	2523	19.8	15.0	20.2
4	2766	21.1	19.0	19.6
5	1411	17.7	15.0	18.2
> 5	1288	16.2	10.0	17.2
Total	**9928**	**20.5**	**15.0**	**20.6**

Source: Affeldt et al. (2018).

Table 5 provides a set of descriptive statistics from Affeldt et al. (2018), tabulated by the number of firms within an observation (including the post-merger entity). Outcomes of interest include the top firm's market share, the average market share of trailing firms, the ratio of market shares for the leader and top trailing firm, and the market share not attributed to any firm. The ratio of the leader and top follower is restricted to observations where both have a market share greater than 10 percent.

A.3 Nested-CES Demand

A.3.1 Solving the Flexible Price Equilibrium

The method of undetermined coefficients is solved around the point where all firms are identical. As figure 12 makes clear, it is only locally accurate around p^*. Since small firms set prices monopolistically, the curvature is minimal and the method of undetermined coefficients works well. This is less the case for large firms, since the pricing behavior is non-linear. A higher-order Taylor approximation is not straightforward to implement when incorporating the best reply of rival firms. One option is that firms may solve for their own price using a second-order approximation while using a first-order approximation for rival prices.

Figure 12: Comparison of Solution Methods in the Flexible Price Equilibrium

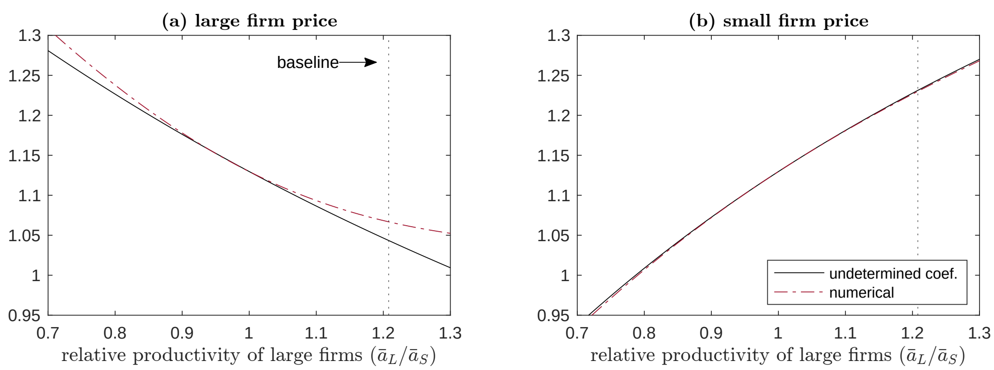


Table 6 gives the pricing rules when firms are identical. The Ω's are the same as in (43). The Υ's collect the coefficients for the firm's own marginal cost (Υ') and the marginal cost of its rival (Υ'').

Table 6: Estimated Decision Rules at p^*

	Ω'	Ω^*	Υ'	Υ''
Large firms	-0.116	0.116	0.897	0.103
Small firms	-0.0213	0.0213	0.979	0.021

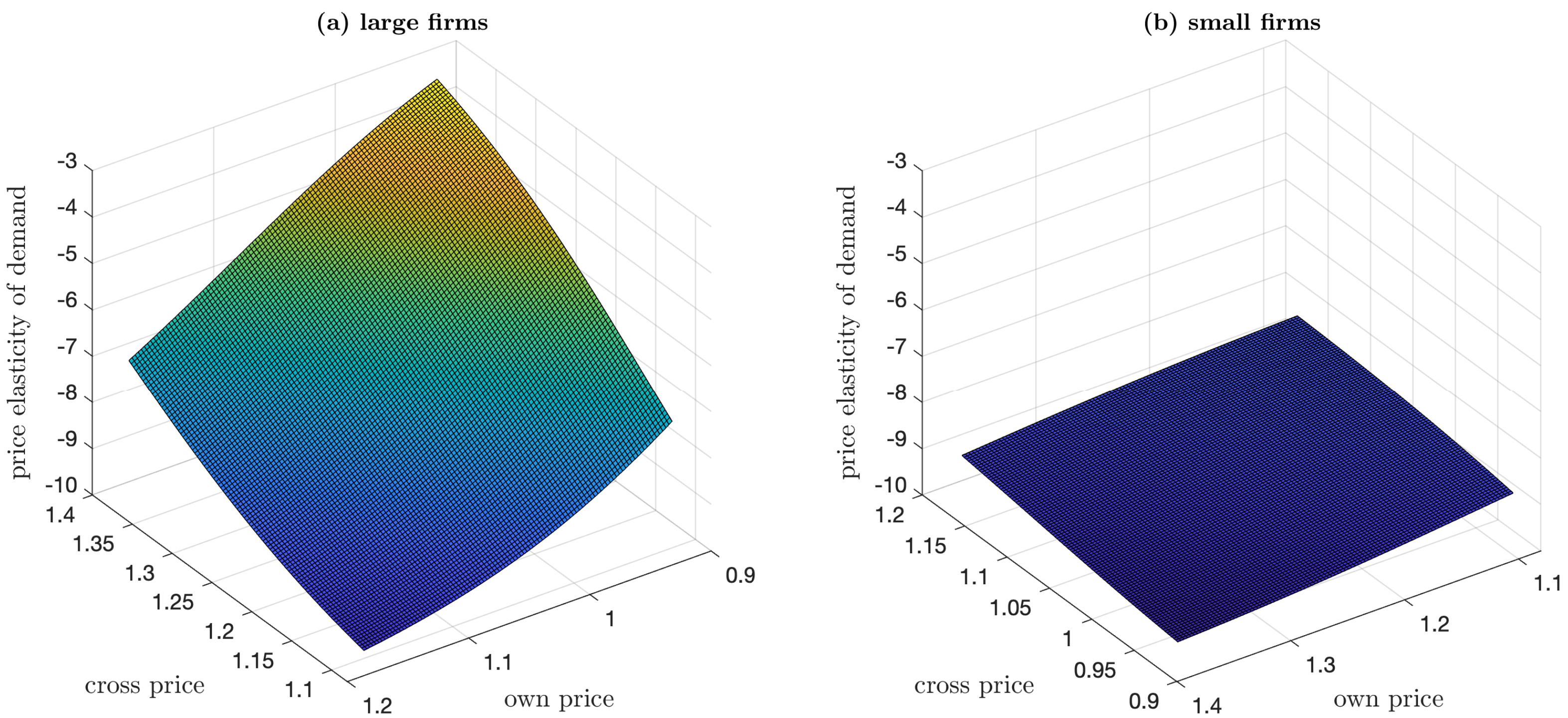
The difference between large and small firms in terms of pricing behavior is already apparent. Large firms put most weight on their own marginal costs, but also consider the marginal costs of their rivals to some degree. Meanwhile, small firms do not consider the costs of rival firms. With asymmetry between firms, the decision rule becomes

Table 7: Estimated Decision Rules for Baseline Productivity Gap

	Ω'	Ω^*	Υ'	Υ''
Large firms	-0.323	0.280	0.735	0.206
Small firms	-0.034	0.039	0.968	0.038

Here, the strength of strategic complementarity becomes more evident. The weight of rival marginal costs in the decision rule of large firms grows (see the values for Υ' and Υ'' in table 8). Figure 13 shows how the price elasticity of demand changes over different relative prices

Figure 13: The Price Elasticity of Demand Across Relative Prices



Each surface displays the price elasticity of demand for large and small firms across price combinations. Demand depends both on the firm's price and that of differently-sized rivals. The center of each surface is the steady state price elasticity of demand. In the case of large firms, this value is highly sensitive to changes in own- or cross-prices. An increase in the firm's own price lowers demand, as does a decrease in rival prices. The surface is flat for small firms, meaning they are not sensitive own- or cross-price effects.

A.3.2 Solving the Dynamic Problem

With Rotemberg adjustment costs, the profit maximization problem becomes

$$\mathbb{E}_t \sum_{k=0}^{\infty} \Lambda_{t+k} \left[\left(p_{sjt+k} - \boldsymbol{\mathcal{C}}_{sjt+k}\right) y_{sjt+k} - \frac{\Theta_s}{2} \left(\pi_{t+k} \frac{p_{sjt+k}}{p_{sjt+k-1}} - 1 \right)^2 P_{t+k} Y_{t+k} \right] \tag{82}$$

The FOC with respect to p_{sjt} gives

$$\begin{aligned} 0 = {} & p_{sjt} y_{sjt} \left[1 + \Psi^i_{st} \left(1 - \frac{\boldsymbol{\mathcal{C}}_{sjt}}{p_{sjt}} \right) \right] - \Theta_s \left(\pi_t \frac{p_{sjt}}{p_{sjt-1}} - 1 \right) \pi_t \frac{p_{sjt}}{p_{sjt-1}} Y_t \dots \\ & + \beta \Theta_s \mathbb{E}_t \left[\frac{C_t}{C_{t+1}} \left(\pi_{t+1} \frac{p_{sjt+1}}{p_{sjt}} - 1 \right) \pi_{t+1} \frac{p_{sjt+1}}{p_{sjt}} Y_{t+1} \right] \end{aligned} \tag{83}$$

The solutions for identical and asymmetric firms follow. In both cases, any unnecessary index is dropped from the notation.

A.3.2.1 Identical Firms

Using (15) and noting that

$$p_{jt} = n^{\frac{1}{1-\varphi}} p_{sjt} \tag{84}$$

where the solution for p_{sjt} is given by (37). The FOC of the pricing equation (45) becomes

$$0 = p_{st}^{1-\varphi} p_{jt}^{\varphi-\sigma} Y_t \left[1 + \left(\frac{\varphi - \sigma}{n} - \varphi \right) \left(1 - \frac{\boldsymbol{\mathcal{C}}_{st}}{p_{st}} \right) \right] - \frac{\Theta}{n} \left(\pi_t \frac{p_{st}}{p_{st-1}} - 1 \right) \pi_t \frac{p_{st}}{p_{st-1}} Y_t \dots \tag{85}$$

$$+ \beta \Theta_s \mathbb{E}_t \left[\frac{C_t}{C_{t+1}} \left(\pi_{t+1} \frac{p_{st+1}}{p_{st}} - 1 \right) \pi_{t+1} \frac{p_{st+1}}{p_{st}} Y_{t+1} \right]$$

$$= n^{\frac{\varphi-\sigma}{1-\varphi}} p_s^{1-\sigma} \left[1 + \left(\frac{\varphi - \sigma}{n} - \varphi \right) \left(1 - \frac{\boldsymbol{\mathcal{C}}_{st}}{p_{st}} \right) \right] - \frac{\Theta}{n} \left(\pi_t - 1 \right) \pi_t + \frac{\beta \Theta}{n} \mathbb{E}_t \left[\Lambda_{t+1} \left(\pi_{t+1} - 1 \right) \pi_{t+1} \right] \tag{86}$$

given $C_t = Y_t$. Log-linearizing the pricing equation

$$0 = n^{\frac{\varphi-\sigma}{1-\varphi}} p_s^{1-\sigma} \left(\varphi - \frac{\varphi - \sigma}{n} \right) \frac{\boldsymbol{\mathcal{C}}_s}{p_s} \widetilde{\boldsymbol{\mathcal{C}}}_{st} - \frac{\Theta}{n} \tilde{\pi}_t + \frac{\beta \Theta}{n} \tilde{\pi}_{t+1} \quad \text{where} \quad p_s = \frac{(n-1)\varphi + \sigma}{(n-1)\varphi + \sigma - n} \boldsymbol{\mathcal{C}}_s \tag{87}$$

Monopolistic competition is a special case of nested-CES demand where $n = 1$. The elasticity of inflation to the monetary shock is

$$\Gamma^y = \frac{\Theta(1 - \rho_m \beta)/n}{n^{\frac{\varphi-\sigma}{1-\varphi}} p_s^{1-\sigma} \left(\varphi - (\varphi - \sigma)/n \right) \boldsymbol{\mathcal{C}}_s / p_s} \Gamma^\pi \tag{88}$$

where (67) gives the second equation. The elasticity of inflation to the productivity shock is similarly

$$\Omega^y = \frac{\Theta(1 - \rho_m \beta)/n}{n^{\frac{\varphi-\sigma}{1-\varphi}} p_s^{1-\sigma} \left(\varphi - (\varphi - \sigma)/n \right) \boldsymbol{\mathcal{C}}_s / p_s} \Omega^\pi + 1 \tag{89}$$

where (78) gives the second equation.

A.3.2.2 Asymmetric Firms

The FOC with respect to p^i_{st} gives

$$
\begin{aligned}
0 &= p^i_{st} y^i_{st} \left[1 + \left((\varphi - \sigma) \left(\frac{p^i_{st}}{p_{jt}} \right)^{1-\varphi} - \varphi \right) \left(1 - \frac{\boldsymbol{\mathcal{C}}^i_{st}}{p^i_{st}} \right) \right] \ldots \\
&- \Theta_s \left(\pi_t \frac{p^i_{st}}{p^i_{st-1}} - 1 \right) \pi_t \frac{p^i_{st}}{p^i_{st-1}} Y_t + \beta \Theta_s \mathbb{E}_t \left[\frac{C_t}{C_{t+1}} \left(\pi_{t+1} \frac{p^i_{st+1}}{p^i_{st}} - 1 \right) \pi_{t+1} \frac{p^i_{st+1}}{p^i_{st}} Y_{t+1} \right]
\end{aligned} \tag{90}
$$

Using (15) and dividing through by Y_t this becomes

$$
\begin{aligned}
0 &= (p^i_{st})^{1-\varphi} p_{jt}^{\varphi-\sigma} \left[1 + \Psi^i_{st} \left(1 - \frac{\boldsymbol{\mathcal{C}}^i_{st}}{p^i_{st}} \right) \right] - \Theta_s \left(\pi_t \frac{p^i_{st}}{p^i_{st-1}} - 1 \right) \pi_t \frac{p^i_{st}}{p^i_{st-1}} \ldots \\
&+ \beta \Theta_s \mathbb{E}_t \left[\left(\pi_{t+1} \frac{p^i_{st+1}}{p^i_{st}} - 1 \right) \pi_{t+1} \frac{p^i_{st+1}}{p^i_{st}} \right]
\end{aligned} \tag{91}
$$

Log-linearizing and taking a first-order Taylor expansion, noting that $\tilde{p}^i_{st} = \tilde{p}^{\text{-}i}_{st}$

$$
\begin{aligned}
0 &= (1-\varphi)(p^i_s)^{-\varphi} p_j^{\varphi-\sigma} \left[1 + \Psi^i_s \left(1 - \frac{\boldsymbol{\mathcal{C}}^i_s}{p^i_s} \right) \right] \tilde{p}^i_s \ldots \\
&+ (\varphi - \sigma)(p^i_s)^{1-\varphi} p_j^{2\varphi-\sigma-1} \left[1 + \Psi^i_s \left(1 - \frac{\boldsymbol{\mathcal{C}}^i_s}{p^i_s} \right) \right] \left[n_s (p^i_s)^{-\varphi} \tilde{p}^i_{st} + n_{\text{-}s} (p^{\text{-}i}_{\text{-}s})^{-\varphi} \tilde{p}^{\text{-}i}_{\text{-}st} \right] \ldots \\
&+ (p^i_s)^{1-\varphi} p_j^{\varphi-\sigma} \left[\left(1 - \frac{\boldsymbol{\mathcal{C}}^i_j}{p^i_s} \right) \left[\frac{\Psi^{i,i}_s + \Psi'^{i,\text{-}i}_s}{p^i_s} \tilde{p}^i_{st} + \frac{\Psi''^{i,\text{-}i}_s}{p^{\text{-}i}_{\text{-}s}} \tilde{p}^{\text{-}i}_{\text{-}st} \right] - \Psi^i_s \frac{\boldsymbol{\mathcal{C}}^i_j}{p^i_s} (\widetilde{\boldsymbol{\mathcal{C}}}^i_{st} - \tilde{p}^i_{st}) \right] \ldots \\
&- \Theta_s (\tilde{\pi}^i_t + \tilde{p}^i_{st} - \tilde{p}^i_{st-1}) + \beta \Theta_s \mathbb{E}_t \left[\tilde{\pi}^i_{t+1} + \tilde{p}^i_{st+1} - \tilde{p}^i_{st} \right]
\end{aligned} \tag{92}
$$

In the steady state

$$
\Psi^i_s = - \left(1 - \frac{\boldsymbol{\mathcal{C}}^i_s}{p^i_s} \right)^{-1} \quad \Longrightarrow \quad 1 + \Psi^i_s \left(1 - \frac{\boldsymbol{\mathcal{C}}^i_s}{p^i_s} \right) = 0 \tag{93}
$$

so the first part of (92) can be ignored

$$
\begin{aligned}
0 &= (p^i_s)^{1-\varphi} p_j^{\varphi-\sigma} \left[\left(1 - \frac{\boldsymbol{\mathcal{C}}^i_j}{p^i_s} \right) \left[\frac{\Psi^{i,i}_s + \Psi'^{i,\text{-}i}_s}{p^i_s} \tilde{p}^i_{st} + \frac{\Psi''^{i,\text{-}i}_s}{p^{\text{-}i}_{\text{-}s}} \tilde{p}^{\text{-}i}_{\text{-}st} \right] - \Psi^i_s \frac{\boldsymbol{\mathcal{C}}^i_j}{p^i_s} (\widetilde{\boldsymbol{\mathcal{C}}}^i_{st} - \tilde{p}^i_{st}) \right] \ldots \\
&- \Theta_s (\tilde{\pi}^i_t + \tilde{p}^i_{st} - \tilde{p}^i_{st-1}) + \beta \Theta_s \mathbb{E}_t \left[\tilde{\pi}^i_{t+1} + \tilde{p}^i_{st+1} - \tilde{p}^i_{st} \right]
\end{aligned} \tag{94}
$$

Expression 94 shows the role of the superelastiticies in a clear way. Given a log-linear approximation around the steady state, they adjust the slope of the price elasticity of demand. They also perfectly offset if firms are identical. The decision rule is characterized as

$$
\tilde{p}^i_{st} = \Upsilon_s \, \tilde{p}^i_{st-1} + \Upsilon^*_s \, \tilde{p}^{\text{-}i}_{\text{-}st-1} + \Upsilon'_s \, \widetilde{\boldsymbol{\mathcal{C}}}^i_{st} + \Upsilon''_s \, \widetilde{\boldsymbol{\mathcal{C}}}^{\text{-}i}_{\text{-}st} + \Upsilon^\pi_s \tilde{\pi}_t \tag{95}
$$

Rival firms follow

$$
\tilde{p}^{\text{-}i}_{\text{-}st} = \Upsilon_{\text{-}s} \, \tilde{p}^{\text{-}i}_{\text{-}st-1} + \Upsilon^*_{\text{-}s} \, \tilde{p}^i_{st-1} + \Upsilon'_{\text{-}s} \, \widetilde{\boldsymbol{\mathcal{C}}}^{\text{-}i}_{\text{-}st} + \Upsilon''_{\text{-}s} \, \widetilde{\boldsymbol{\mathcal{C}}}^i_{\text{-}st} + \Upsilon^\pi_{\text{-}s} \tilde{\pi}_t \tag{96}
$$

Given some aggregate shock, expected prices in the next period are

$$\mathbb{E}_t\left[\tilde{p}^i_{st+1}\right] = \Upsilon_s\,\tilde{p}^i_{st} + \Upsilon^*_s(\Upsilon_{\text{-}s}\,\tilde{p}^{\text{-}i}_{\text{-}st-1} + \Upsilon^*_{\text{-}s}\,\tilde{p}^i_{st-1} + \Upsilon'_{\text{-}s}\,\widetilde{\boldsymbol{\mathcal{C}}}^{\text{-}i}_{\text{-}st} + \Upsilon''_s\,\widetilde{\boldsymbol{\mathcal{C}}}^{i}_{st} + \Upsilon^\pi_s\tilde{\pi}_t)\;... \\ + \rho\left[\Upsilon'_s\,\widetilde{\boldsymbol{\mathcal{C}}}^{i}_{st} + \Upsilon''_s\,\widetilde{\boldsymbol{\mathcal{C}}}^{\text{-}i}_{\text{-}st} + \Upsilon^\pi_s\tilde{\pi}_t\right] \tag{97}$$

where ρ is the persistence of the shock. This suggests

$$\Upsilon_s = \frac{(\psi_s + \beta\Theta_s\Upsilon^*_s)\Upsilon^*_{\text{-}s} + \Theta_s}{\kappa_s - \beta\Theta_s\Upsilon_s} \tag{98}$$

$$\Upsilon^*_s = \frac{(\psi_s + \beta\Theta_s\Upsilon^*_s)\Upsilon_{\text{-}s}}{\kappa_s - \beta\Theta_s\Upsilon_s} \tag{99}$$

$$\Upsilon'_s = \frac{(\psi_s + \beta\Theta_s\Upsilon^*_s)\Upsilon''_{\text{-}s} - (p^i_s)^{-\varphi}p_j^{\varphi-\sigma}\Psi^i_s\boldsymbol{\mathcal{C}}^i_s}{\kappa_s - \beta\Theta_s(\Upsilon_s + \rho)} \tag{100}$$

$$\Upsilon''_s = \frac{(\psi_s + \beta\Theta_s\Upsilon^*_s)\Upsilon'_{\text{-}s}}{\kappa_s - \beta\Theta_s(\Upsilon_s + \rho)} \tag{101}$$

$$\Upsilon^\pi_s = \frac{(\psi_s + \beta\Theta_s\Upsilon^*_s)\Upsilon^\pi_{\text{-}s} - \Theta_s(1-\rho\beta)}{\kappa_s - \beta\Theta_s(\Upsilon_s + \rho)} \tag{102}$$

where

$$\kappa_s = \Theta_s + \beta\Theta_s - (p^i_s)^{1-\varphi}p_j^{\varphi-\sigma}\left[\left(1 - \frac{\boldsymbol{\mathcal{C}}_s}{p^i_s}\right)\frac{\Psi^{i,i} + \Psi'^{\,i,\text{-}i}_s}{p^i_s} + \Psi^i\frac{\boldsymbol{\mathcal{C}}_s}{p^i_s}\right] \tag{103}$$

$$\psi_s = (p^i_s)^{1-\varphi}p_j^{\varphi-\sigma}\left(1 - \frac{\boldsymbol{\mathcal{C}}_s}{p^i_s}\right)\frac{\Psi''^{\,i,\text{-}i}_s}{p^{\text{-}i}_{\text{-}s}} \tag{104}$$

Once relative prices are known, the change in the market share of each firm is given by

$$\tilde{x}^i_{st} = \frac{\Psi^{i,i}_s + \Psi'^{\,i,\text{-}i}_s}{(\varphi-\sigma)p^i_s}\tilde{p}^i_{st} + \frac{\Psi''^{\,i,\text{-}i}_s}{(\varphi-\sigma)p^{\text{-}i}_{\text{-}s}}\tilde{p}^{\text{-}i}_{\text{-}st} \tag{105}$$

As suggested before, output for each firm is equal to

$$\tilde{y}^i_{st} = \tilde{x}^i_{st} + \widetilde{Y}_t + \widetilde{P}_t - \tilde{p}^i_{st} \tag{106}$$

Table 8: Estimated Decision Rules (Baseline Calibration)

	Υ	Υ^*	Υ'	Υ''	Υ^π
Large firms	0.777	0.028	0.101	0.015	-0.392
Small firms	0.776	0.004	0.145	0.002	-0.360

A.3.3 Capital Rental Costs and Aggregate Output

The capital rental price is equal to the marginal product of capital. To simplify dynamics, aggregate capital is held fixed and the capital share of total income is

$$z_tK = (1+\tau_t)\frac{\alpha}{\mu_t}Y_t \tag{107}$$

where μ_t is the aggregate markup and τ is an offsetting subsidy paid to firms. Although aggregate capital is fixed, firms may trade capital so that its marginal product is equalized

$$\frac{p_{st}y_{st}}{k_{st}} = \frac{p_{\text{-}st}y_{\text{-}st}}{k_{\text{-}st}} \quad \implies \quad \frac{k_{st}}{k_j - n_s k_{st}} = \frac{x_{st}}{1 - n_s x_{st}} \quad \text{given} \quad \frac{p_{st}y_{st}}{n_{\text{-}s}p_{\text{-}st}y_{\text{-}st}} \equiv \frac{x_{st}}{1 - n_s x_{st}} \tag{108}$$

where capital in each industry $k_j = n_s k_{st} + n_{\text{-}s}k_{\text{-}st}$. Payments on capital within an industry must equal the sum of payments by firms

$$z_t = \frac{n_s z_t k_{st} + n_{\text{-}s} z_t k_{\text{-}st}}{k_j} \tag{109}$$

where k_j is proportional to K given identical industries. In log-linear form, this expression becomes

$$\tilde{z}_t = \frac{n_s k_s}{k_j}(\tilde{k}_{st} + \tilde{z}_t) + \frac{n_{\text{-}s}k_{\text{-}s}}{k_j}(\tilde{k}_{\text{-}st} + \tilde{z}_t) \tag{110}$$

noting that k_j is fixed since K is fixed. As before, the rental rate on capital equals its marginal product. This can be related to market share, using expressions 15 and 17

$$\tilde{k}_{st} = \tilde{p}_{st} + \tilde{y}_{st} - \tilde{z}_t \quad \implies \quad \tilde{k}_{st} = \tilde{x}_{st} + \widetilde{P}_t + \widetilde{Y}_t - \tilde{z}_t \quad \text{given} \quad \tilde{p}_{st} + \tilde{y}_{st} = \tilde{x}_{st} + \widetilde{P}_t + \widetilde{Y}_t \tag{111}$$

noting p_{jt} and y_{jt} are proportional to P_t and Y_t given identical industries. This implies

$$\tilde{z}_t = \frac{n_s k_s}{k_j}(\tilde{x}_{st} + \widetilde{P}_t) + \widetilde{Y}_t + \frac{n_{\text{-}s}k_{\text{-}s}}{k_j}(\tilde{x}_{\text{-}st} + \widetilde{P}_t + \widetilde{Y}_t) \tag{112}$$

By (108)

$$\frac{k_s}{k_j} \equiv x_s \tag{113}$$

Movements in market share perfectly offset

$$n_s x_s \tilde{x}_{st} + n_{\text{-}s} x_{\text{-}s} \tilde{x}_{\text{-}st} = 0 \tag{114}$$

The resulting capital rental price is

$$\tilde{z}_t = \widetilde{P}_t + \widetilde{Y}_t \tag{115}$$

A.4 Aggregate Shocks with Asymmetric Firms

A.4.1 Monetary Policy

As before, the elasticity of output and inflation to the monetary policy shock is

$$\widetilde{Y}_t = \Gamma^y m_t \tag{116}$$

$$\tilde{\pi}_t = \Gamma^\pi m_t \tag{117}$$

The decision rule for each firm can be written

$$\widetilde{P}_{st} - \widetilde{P}_t = \Upsilon_s^\pi \Gamma^\pi m_t + \Upsilon_s \left(\widetilde{P}_{st-1} - \widetilde{P}_{t-1}\right) + \Upsilon_s^* \left(\widetilde{P}_{\text{-}st-1} - \widetilde{P}_{t-1}\right) + \left(\Upsilon_s' + \Upsilon_s''\right) \Gamma^y m_t \tag{118}$$

The log-linearized price index is

$$\widetilde{P}_t = \frac{n_s (P_s)^{-\varphi} \widetilde{P}_{st} + n_{\text{-}s} (P_{\text{-}s})^{-\varphi} \widetilde{P}_{\text{-}st}}{P^{-\varphi}} \tag{119}$$

while (67) gives the relation between Γ^y and Γ^π. The price index is a restriction. If all small firms set their relative price above it, then the relative price of all large firms must set their price below. Recalling Γ^π solves

$$\Gamma^\pi = \frac{\widetilde{P}_t - \widetilde{P}_{t-1}}{m_t} \tag{120}$$

the decision rule can be restated as

$$\widetilde{P}_{st} - \widetilde{P}_t - \Upsilon_s (\widetilde{P}_{st-1} - \widetilde{P}_{t-1}) - \Upsilon_s^* (\widetilde{P}_{\text{-}st-1} - \widetilde{P}_{t-1}) = \left[\Upsilon_s^\pi \Gamma^\pi + (\Upsilon_s' + \Upsilon_s'') \Gamma^y\right] m_t \tag{121}$$

In the first period of the monetary policy shock, this reduces to

$$\frac{\widetilde{P}_{st} - \widetilde{P}_t}{m_t} = \Gamma_s^m \quad \text{where} \quad \Gamma_s^m = \Upsilon_s^\pi \Gamma^\pi + (\Upsilon_s' + \Upsilon_s'') \Gamma^y \tag{122}$$

Recognizing the recursive nature of the problem

$$\mathbb{E}_t \left[\frac{\widetilde{P}_{st+1} - \widetilde{P}_{t+1}}{m_t} \right] = \Upsilon_s \Gamma_s^m + \rho_m \Gamma_s^m + \Upsilon_s^* \Gamma_{\text{-}s}^m \tag{123}$$

This implies

$$\mathbb{E}_t \left[\frac{\widetilde{P}_{st+1} - \widetilde{P}_{st}}{m_t} \right] = \mathbb{E}_t \left[\frac{\widetilde{P}_{t+1} - \widetilde{P}_t}{m_t} \right] + (\Upsilon_s - 1) \Gamma_s^m + \rho_m \Gamma_s^m + \Upsilon_i^* \Gamma_{\text{-}s}^m \tag{124}$$

Using (120)

$$\mathbb{E}_t \left[\widetilde{P}_{st+1} \right] - \widetilde{P}_{st} = \left[\rho_m \Gamma^\pi + (\Upsilon_s - 1) \Gamma_s^m + \rho_m \Gamma_s^m + \Upsilon_s^* \Gamma_{\text{-}s}^m\right] m_t \tag{125}$$

Accordingly, Γ^π solves the following identity (using expressions 67, 120, and 125 and the definitions of Γ_i^m above)

$$\mathbb{E}_t \left[\widetilde{P}_{t+1} \right] - \widetilde{P}_t = \mathbb{E}_t \left[\frac{n^i (P_s)^{-\varphi} (\widetilde{P}_{st+1} - \widetilde{P}_{st}) + n^{\text{-}i} (P_{\text{-}s})^{-\varphi} (\widetilde{P}_{\text{-}st+1} - \widetilde{P}_{\text{-}st})}{P^{-\varphi}} \right] \tag{126}$$

A.4.2 Aggregate Productivity

The decision rule for each firm can be written in terms of relative prices

$$\widetilde{P}_t^i - \widetilde{P}_t = \Upsilon_s^\pi \, \Omega^\pi a_t + \Upsilon_s \, (\widetilde{P}_{t-1}^i - \widetilde{P}_{t-1}) + \Upsilon_s^* \, (\widetilde{P}_{t-1}^{-i} - \widetilde{P}_{t-1}) + (\Upsilon_s' + \Upsilon_s'') \, (\Omega^y a_t - a_t) \tag{127}$$

where

$$\Omega^\pi = \frac{\widetilde{P}_t - \widetilde{P}_{t-1}}{a_t} \tag{128}$$

the decision rule can be restated as

$$\widetilde{P}_t^i - \widetilde{P}_t - \Upsilon_i(\widetilde{P}_{t-1}^i - \widetilde{P}_{t-1}) - \Upsilon_s^*(\widetilde{P}_{t-1}^{-i} - \widetilde{P}_{t-1}) = [\Upsilon_s^\pi \Omega^\pi + (\Upsilon_s' + \Upsilon_s'')(\Omega^y - 1)] \, a_t \tag{129}$$

In the first period of the monetary policy shock, this reduces to

$$\frac{\widetilde{P}_t^i - \widetilde{P}_t}{a_t} = \Omega_s^a \quad \text{where} \quad \Omega_s^a = \Upsilon_s^\pi \Omega^\pi + (\Upsilon_s' + \Upsilon_s'')(\Omega^y + 1) \tag{130}$$

Solving recursively

$$\mathbb{E}_t \left[\frac{\widetilde{P}_{t+1}^i - \widetilde{P}_{t+1}}{a_t} \right] = (\Upsilon_i + \rho_a)\Omega_s^a + \Upsilon_s^* \Omega_{-s}^a \tag{131}$$

This implies

$$\mathbb{E}_t \left[\frac{\widetilde{P}_{t+1}^i - \widetilde{P}_t^i}{a_t} \right] = \mathbb{E}_t \left[\frac{\widetilde{P}_{t+1} - \widetilde{P}_t}{a_t} \right] + (\Upsilon_s + \rho_a - 1)\Omega_s^a + \Upsilon_s^* \Omega_{-s}^a \tag{132}$$

Using (128)

$$\mathbb{E}_t \left[\widetilde{P}_{t+1}^i \right] - \widetilde{P}_t^i = [\rho \, \Omega^\pi + (\Upsilon_s + \rho_a - 1)\Omega_s^a + \Upsilon_s^* \Omega_{-s}^a] \, a_t \tag{133}$$

Finally, Ω^π solves the following identity (using expressions 128 and 146 and the definitions of Ω_s^a above)

$$\mathbb{E}_t \left[\widetilde{P}_{t+1} \right] - \widetilde{P}_t = \mathbb{E}_t \left[\frac{n^i (P^i)^{-\varphi} (\widetilde{P}_{t+1}^i - \widetilde{P}_t^i) + n^{-i} (P^{-i})^{-\varphi} (\widetilde{P}_{t+1}^{-i} - \widetilde{P}_t^{-i})}{P^{-\varphi}} \right] \tag{134}$$

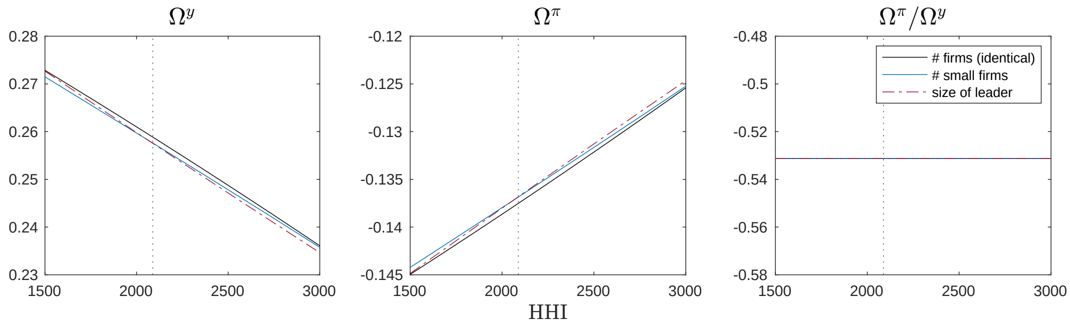
where

$$\Omega^y = \frac{(\rho - \phi_\pi)\Omega^\pi}{1 + \phi_y - \rho_a} \tag{135}$$

Looking at the left-hand panel in figure 14, the responsiveness of output to productivity shocks is declining as concentration increases.[66] The center panel indicates productivity shocks are also deflationary, which is a normal result in a New Keynesian setup. Looking at (78), it is clear the slope of the Phillips curve is only a function of parameters, as reflected in the right-hand panel of the figure.

[66]The results are consistent with Decker et al. (2020), which finds firms are becoming less responsive to the economic cycle.

Figure 14: Concentration and the Response to an Aggregate Productivity Shock

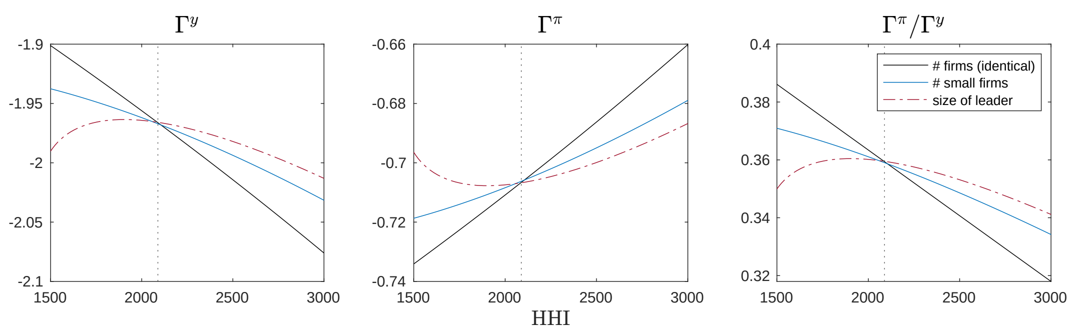


The x-axis displays the HHI and a move from left to right corresponds to an increase in concentration. The interpretation is analogous to figure 4. As concentration increases, firms less response to economic shocks. The ratio of the inflation and output reponse are a constant.

A.5 Differences in Nominal Price Adjustment Costs Across Firms

Goldberg and Hellerstein (2009) suggests large firms have greater price flexibility than small firms. This could be motivated in different ways. Adjusting prices may entail certain fixed costs, which would favor large firms. Managerial inattention at small firms could be greater. The the price adjustment costs are set so that γ_L and γ_S are 0.6 and 1.3 respectively. As figure 15 shows, the slope of the Phillips curve is much less sensitive to growing asymmetry in this case. The interpretation is simple. As large firms expand, the degree of aggregate price flexibility increases, which offsets the change in markup resulting from higher concentration.

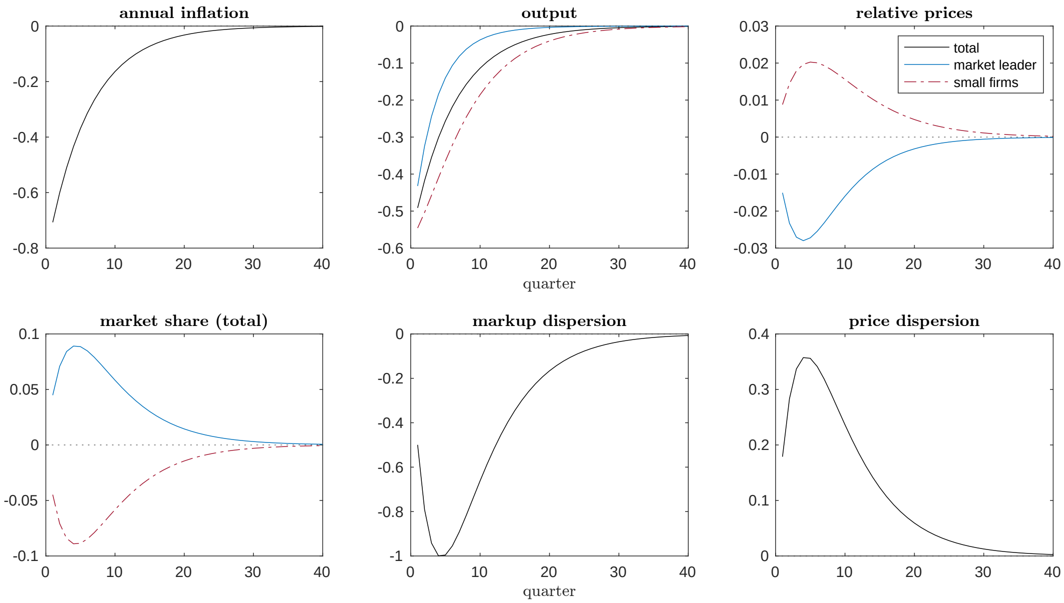
Figure 15: Concentration and the Aggregate Response to a Monetary Policy Shock ($\gamma_L = 0.6$ and $\gamma_S = 1.3$)



The underlying exercise and interpretation is the same as figure 4, except the price adjustment costs of small and large firms are modified. Large firms are assumed to have a significantly lower price adjustment cost where $\gamma_L = 0.6$ and $\gamma_S = 1.3$. This scenario indicates the change in the Phillips curve from the expansion of large firms is ambiguous if their prices are more flexibile.

A monetary policy shock is applied as before in figure 16, this time with a wedge in price adjustment costs. Because quadratic adjustment costs are lower for large firms, they set a lower relative price and gain market share. This also leads to compression in markups, which price dispersion increases. The outcomes are mostly opposite of the result in figure 7.

Figure 16: Baseline Impulse Response to Monetary Tightening ($\varepsilon_0 = 0.25$)



Here $\gamma_L = 0.6$ and $\gamma_S = 1.3$, The monetary policy shock is equivalent to a one percentage point increase in the nominal interest rate. The x-axis gives the quarter following the shock. The y-axis is scaled to give the deviation from the steady state.

A.6 Firm-Specific Shocks

A.6.1 Productivity of Large Firms

Technology shocks may affect small and large firms differently. Market leaders invest more in R&D and employee training and are often the first to benefit from new technologies. Some technology improvements could be general across sectors but specific to large firms, such as IT infrastructure. To explore this aspect, it is necessary to relate changes in marginal costs across large firms to aggregate output. First take that productivity shocks are different across firms

$$\mathcal{C}_{st} = \frac{1}{e^{a_{st}} \bar{a}_s P_t^{\alpha}} \left(\frac{z_t}{\alpha}\right)^{\alpha} \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha} \tag{136}$$

For simplicity, shocks to the small firm are set to zero ($a_{St} = 0$). Meanwhile, shocks to the large firm follow

$$a_{Lt} = \rho_a a_{Lt-1} + \xi_t \tag{137}$$

Accordingly, the prices of large firms are given by

$$\widetilde{P}_t^L - \widetilde{P}_t = \Upsilon_L^{\pi} \, \Omega'^{\pi} a_{Lt} + \Upsilon_L \, (\widetilde{P}_{t-1}^L - \widetilde{P}_{t-1}) + \Upsilon_L^{*} \, (\widetilde{P}_{t-1}^S - \widetilde{P}_{t-1}) + \Upsilon_L'(\Omega'^{y} a_{Lt} - a_{Lt}) + \Upsilon_L'' \Omega'^{y} a_{Lt} \tag{138}$$

while for small firms

$$\widetilde{P}_t^S - \widetilde{P}_t = \Upsilon_S^{\pi} \, \Omega'^{\pi} a_{St} + \Upsilon_S \, (\widetilde{P}_{t-1}^S - \widetilde{P}_{t-1}) + \Upsilon_S^{*} \, (\widetilde{P}_{t-1}^L - \widetilde{P}_{t-1}) + \Upsilon_S' \, \Omega'^{y} a_{Lt} + \Upsilon_S''(\Omega'^{y} a_{Lt} - a_{Lt}) \tag{139}$$

As before, each expression can be rearranged so that

$$\widetilde{P}_t^L - \widetilde{P}_t - \Upsilon_L(\widetilde{P}_{t-1}^L - \widetilde{P}_{t-1}) - \Upsilon_L^*(\widetilde{P}_{t-1}^S - \widetilde{P}_{t-1}) = [\Upsilon_L^\pi \Omega'^{\,\pi} + \Upsilon_L'(\Omega'^{\,y} - 1) + \Upsilon_L''\Omega'^{\,y}]\, a_{Lt} \tag{140}$$

$$\widetilde{P}_t^S - \widetilde{P}_t - \Upsilon_S(\widetilde{P}_{t-1}^S - \widetilde{P}_{t-1}) - \Upsilon_S^*(\widetilde{P}_{t-1}^L - \widetilde{P}_{t-1}) = [\Upsilon_S^\pi \Omega'^{\,\pi} + \Upsilon_S'\Omega'^{\,y} + \Upsilon_S''(\Omega'^{\,y} - 1)]\, a_{Lt} \tag{141}$$

Meaning in the first period, the shock is given by

$$\widetilde{P}_t^L - \widetilde{P}_t = \Omega_L^a a_{Lt} \quad \text{where} \quad \Omega_L^a = \Upsilon_L^\pi \Omega'^{\,\pi} + \Upsilon_L'(\Omega'^{\,y} - 1) + \Upsilon_L''\Omega'^{\,y} \tag{142}$$

$$\widetilde{P}_t^S - \widetilde{P}_t = \Omega_S^a a_{Lt} \quad \text{where} \quad \Omega_S^a = \Upsilon_S^\pi \Omega'^{\,\pi} + \Upsilon_S'\Omega'^{\,y} + \Upsilon_S''(\Omega'^{\,y} - 1) \tag{143}$$

Solving recursively

$$\mathbb{E}_t\left[\frac{\widetilde{P}_{t+1}^i - \widetilde{P}_{t+1}}{a_{Lt}}\right] = (\Upsilon_s + \rho_a)\Omega_s^a + \Upsilon_s^*\Omega_{\text{-}s}^a \tag{144}$$

This implies

$$\mathbb{E}_t\left[\frac{\widetilde{P}_{t+1}^i - \widetilde{P}_t^i}{a_{Lt}}\right] = \mathbb{E}_t\left[\frac{\widetilde{P}_{t+1} - \widetilde{P}_t}{a_{Lt}}\right] + (\Upsilon_s + \rho_a - 1)\Omega_s^a + \Upsilon_s^*\Omega_{\text{-}s}^a \tag{145}$$

Using (128)

$$\mathbb{E}_t\left[\widetilde{P}_{t+1}^i\right] - \widetilde{P}_t^i = [\rho_a\, \Omega'^{\,\pi} + (\Upsilon_s + \rho_a - 1)\Omega_s^a + \Upsilon_s^*\Omega_{\text{-}s}^a]\, a_{Lt} \tag{146}$$

Finally, Ω^π solves the following identity (using expressions 128 and 146 and the definitions of Ω_i^a above)

$$\mathbb{E}_t\left[\widetilde{P}_{t+1}\right] - \widetilde{P}_t = \mathbb{E}_t\left[\frac{n^i(P^i)^{-\varphi}(\widetilde{P}_{t+1}^i - \widetilde{P}_t^i) + n^{\text{-}i}(P^{\text{-}s})^{-\varphi}(\widetilde{P}_{t+1}^{\text{-}s} - \widetilde{P}_t^{\text{-}s})}{P^{-\varphi}}\right] \tag{147}$$

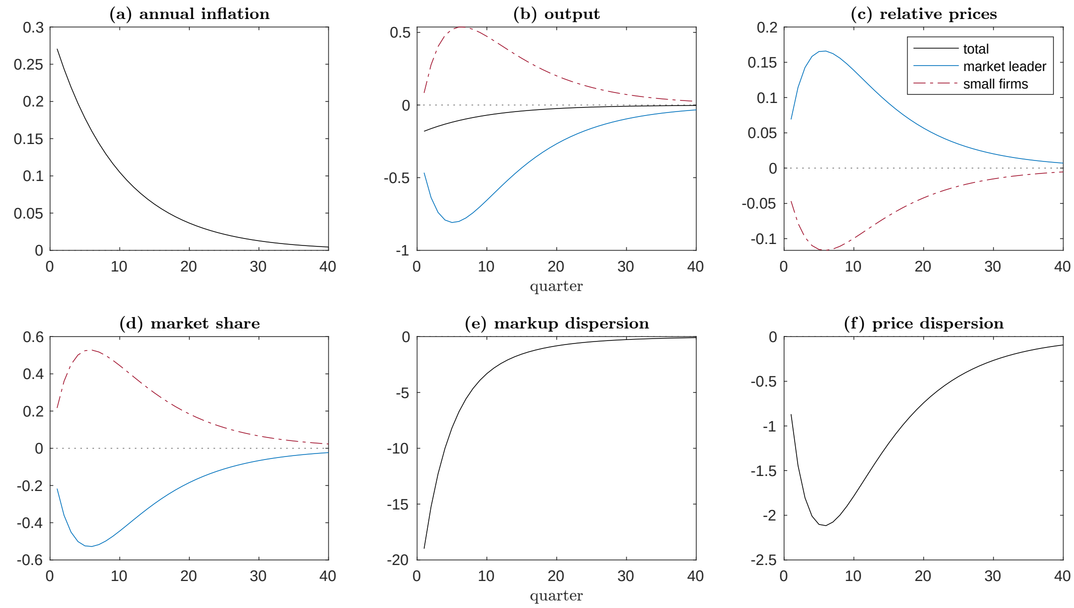
Figure 17 shows the impulse response following a productivity shock to large firms. There are general equilibrium effects – the shock is deflationary and increases aggregate output. This raises marginal costs for small firms. Also, the shock has a large effect on relative prices and markups. Therefore, there are noticable changes in market share and markup dispersion rises by around 30 percent. The shock also increases price dispersion, but the effect is much smaller.

A.6.2 Capital Costs of Small Firms

Cheng et al. (2023) finds firms exposed to 'superstars' exhibit weaker financial performance, greater riskiness, and are more likely to file for bankruptcy. This risk may translate into higher capital rental costs for small firms. The shock is described as follows. The firm's budget constraint is written

$$\Pi_{st} = (1 + \tau_t)p_{st}y_{st} - w_t\ell_{st} - e^{v_t}z_tk_{st} \tag{148}$$

Figure 17: Impulse Response to a Large Firm Productivity Shock ($\xi_0 = -1$)



A negative 1 percent productivity shock is applied to large firms. This has general equilibrium effects and there is an increase in inflation and decline in output. Becuase the shock is asymmetric, there is a large impact on relative prices and market share. Compression in the markups of large firms is particularly large and markup dispersion significantly falls. Given a positive shock to large firms, the opposite would hold.

where v_t is a shock on capital rental costs. This implies

$$\mathcal{C}_{st} = \frac{1}{\bar{a}_s P_t^{\alpha}} \left(\frac{e^{v_{st}} z_t}{\alpha} \right)^{\alpha} \left(\frac{w_t}{1-\alpha} \right)^{1-\alpha} \tag{149}$$

For simplicity, shocks to large firms are set to zero ($v_{Lt} = 0$). Meanwhile, shocks to small firms follow

$$v_{St} = \rho_v v_{St-1} + \zeta_t \quad \text{where} \quad \zeta_t \sim \mathcal{N}(0, \sigma_v) \tag{150}$$

The premium reduces the capital demanded by small firms

$$\tilde{k}_{Lt} = \tilde{p}_{St} + \tilde{y}_{St} - \tilde{z}_t - v_{St} \tag{151}$$

In turn, this affects overall capital demand

$$\tilde{z}_t = \widetilde{Y}_t + \widetilde{P}_t - n_S x_S v_{St} \tag{152}$$

For large firms, log-linear marginal costs become

$$\widetilde{\mathcal{C}}_{St} = \alpha \tilde{z}_t + (1-\alpha)\widetilde{w}_t - \alpha \widetilde{P}_t \tag{153}$$

$$= \widetilde{Y}_t - \alpha n_S x_S v_{St} \tag{154}$$

while for small firms

$$\widetilde{\mathcal{C}}_{Lt} = \alpha(\tilde{z}_t + v_t) + (1-\alpha)\widetilde{w}_t - \alpha\widetilde{P}_t \tag{155}$$

$$= \widetilde{Y}_t + \alpha(1 - n_S x_S)v_{St} \tag{156}$$

Aggregate output and inflation are assumed to have some elasticity to the shock

$$\widetilde{Y}_t = \Gamma'^{y} v_{St} \tag{157}$$

$$\tilde{\pi}_t = \Gamma'^{\pi} v_{St} \tag{158}$$

Noting that

$$\Gamma'^{\pi} = \frac{\widetilde{P}_t - \widetilde{P}_{t-1}}{v_{St}} \tag{159}$$

Accordingly, the prices of large firms are given by

$$\widetilde{P}^L_t - \widetilde{P}_t = \Upsilon_L\,(\widetilde{P}^L_{t-1} - \widetilde{P}_{t-1}) + \Upsilon^*_L\,(\widetilde{P}^S_{t-1} - \widetilde{P}_{t-1}) + \Upsilon'_L\,\widetilde{\mathcal{C}}_{Lt} + \Upsilon''_L\,\widetilde{\mathcal{C}}_{St} + \Upsilon^{\pi}_L\,\Omega^{\pi} v_{St} \tag{160}$$

where

$$\widetilde{\mathcal{C}}_{Lt} = (\Gamma'^{y} - \alpha n_S x_S)v_{St} \tag{161}$$

$$\widetilde{\mathcal{C}}_{St} = [\Gamma'^{y} + \alpha(1 - n_S x_S)]v_{St} \tag{162}$$

while for small firms

$$\widetilde{P}^S_t - \widetilde{P}_t = \Upsilon_S\,(\widetilde{P}^S_{t-1} - \widetilde{P}_{t-1}) + \Upsilon^*_S\,(\widetilde{P}^L_{t-1} - \widetilde{P}_{t-1}) + \Upsilon'_S\,\widetilde{\mathcal{C}}_{St} + \Upsilon''_S\,\widetilde{\mathcal{C}}_{Lt} + \Upsilon^{\pi}_S\,\Gamma'^{\pi} v_{St} \tag{163}$$

As before, each expression can be rearranged so that

$$\widetilde{P}^L_t - \widetilde{P}_t - \Upsilon_L(\widetilde{P}^L_{t-1} - \widetilde{P}_{t-1}) - \Upsilon^*_L(\widetilde{P}^S_{t-1} - \widetilde{P}_{t-1}) = [\Upsilon^{\pi}_L\Gamma'^{\pi} + (\Upsilon'_L + \Upsilon''_L)(\Gamma'^{y} - \alpha n_L x_L) + \alpha\Upsilon''_L]\,v_{St} \tag{164}$$

$$\widetilde{P}^S_t - \widetilde{P}_t - \Upsilon_S(\widetilde{P}^S_{t-1} - \widetilde{P}_{t-1}) - \Upsilon^*_S(\widetilde{P}^L_{t-1} - \widetilde{P}_{t-1}) = [\Upsilon^{\pi}_S\Gamma'^{\pi} + (\Upsilon'_S + \Upsilon''_S)(\Gamma'^{y} - \alpha n_L x_L) + \alpha\Upsilon'_S]\,v_{St} \tag{165}$$

Meaning in the first period, the shock is given by

$$\widetilde{P}^L_t - \widetilde{P}_t = \Gamma^v_L v_t \quad \text{where} \quad \Gamma^v_L = \Upsilon^{\pi}_L\Gamma'^{\pi} + (\Upsilon'_L + \Upsilon''_L)\Gamma'^{y} + \alpha\Upsilon''_L \tag{166}$$

$$\widetilde{P}^S_t - \widetilde{P}_t = \Gamma^v_S v_t \quad \text{where} \quad \Gamma^v_S = \Upsilon^{\pi}_S\Gamma'^{\pi} + (\Upsilon'_S + \Upsilon''_S)\Gamma'^{y} + \alpha\Upsilon'_S \tag{167}$$

Solving recursively

$$\mathbb{E}_t\left[\frac{\widetilde{P}^i_{t+1} - \widetilde{P}_{t+1}}{v_t}\right] = (\Upsilon_i + \rho_v)\Gamma^v_i + \Upsilon^*_i\Gamma^v_{\text{-}i} \tag{168}$$

This implies

$$\mathbb{E}_t\left[\frac{\widetilde{P}^i_{t+1}-\widetilde{P}^i_t}{v_t}\right]=\mathbb{E}_t\left[\frac{\widetilde{P}_{t+1}-\widetilde{P}_t}{v_t}\right]+(\Upsilon_i+\rho_v-1)\Gamma^v_i+\Upsilon^*_i\Gamma^v_{\text{-}i} \tag{169}$$

Using (159)

$$\mathbb{E}_t\left[\widetilde{P}^i_{t+1}\right]-\widetilde{P}^i_t=\left[\rho_v\Gamma'^{\pi}+(\Upsilon_i+\rho_v-1)\Gamma^v_i+\Upsilon^*_i\Gamma^v_{\text{-}i}\right]v_t \tag{170}$$

Finally, Γ'^{π} solves the identity (using expressions 159 and 170 and the definitions of Γ^v_i above)

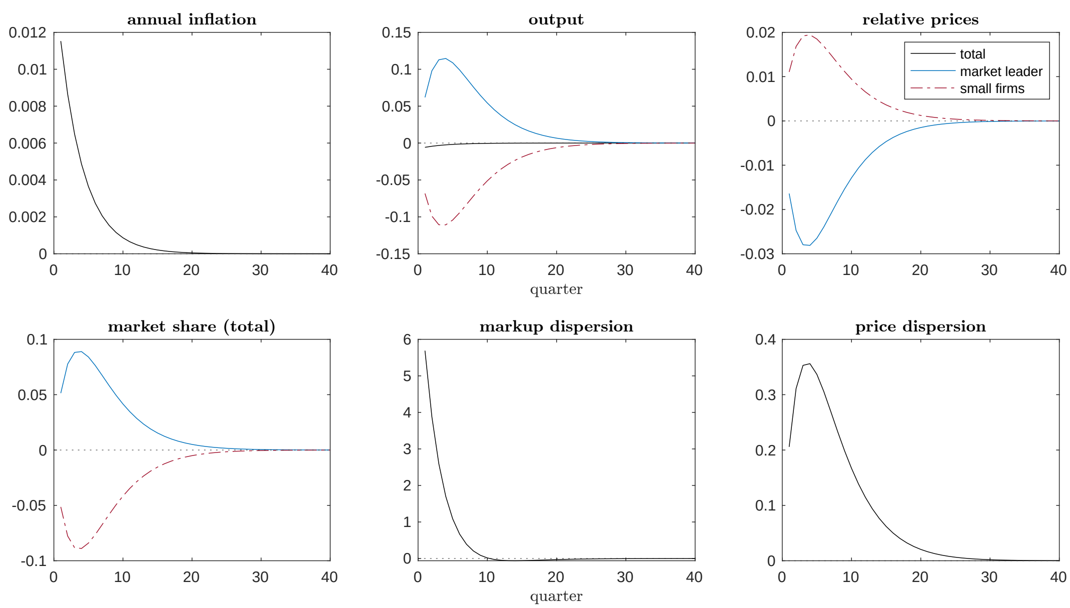
$$\mathbb{E}_t\left[\widetilde{P}_{t+1}\right]-\widetilde{P}_t=\mathbb{E}_t\left[\frac{n^i(P^i)^{-\varphi}(\widetilde{P}^i_{t+1}-\widetilde{P}^i_t)+n^{\text{-}i}(P^{\text{-}i})^{-\varphi}(\widetilde{P}^{\text{-}i}_{t+1}-\widetilde{P}^{\text{-}i}_t)}{P^{-\varphi}}\right] \tag{171}$$

where

$$\Gamma'^{y}=\frac{(\rho-\phi_\pi)\Gamma'^{\pi}}{1+\phi_y-\rho_v} \tag{172}$$

The response to the shock is given in figure 18. While the shock does not impact inflation and aggregate output, it has a meaningful impact on market share and markup dispersion.

Figure 18: Impulse Response to a Small Firm Capital Cost Shock ($\zeta_0 = 1$)



There is a 1 percent shock to the capital rental costs of small firms. Unlike most other shocks, this capital cost shock does not have a significant impact on aggregate inflation or output. Since general equilibrium effects are weak, the efficiency of large firms is not impeded and they benefit from a relative price advantage. Since large firms match the price increase of small firms to some degree, this leads to higher markup dispersion.

A.7 Comparing the Standard NK Model with Price Staggering

How do the results for markup and price dispersion presented earlier compare to the standard New Keynesian model with price staggering? The model is implemented using Dynare modifying the replication package for Galí (2015) chapter 3.[67] The implementation proposed in Galí matches the main outcomes from the baseline model. The settings in table 9 give the same equilibrium markup (0.14) and slope for the Phillips curve (0.36). All other values are identical to table 1.

Table 9: Alternative Parameter Values

Parameter	Value	Description
σ	8.1	Elasticity of substitution across goods
θ	0.65	Probability firm keeps the same price

The standard deviation of log prices can be determined as follows. In each period of the shock, some fraction $1-\theta$ of firms can reset their price. This means in period t a share θ^t of firms will never reset their price. For all prices $\boldsymbol{P}_t^* = \{\widetilde{P}_0, \widetilde{P}_1^*, \widetilde{P}_2^*, ..., \widetilde{P}_t^*\}$, indexed by k, their respective weights are given by $\eta = \{\omega_0, \omega_1, \omega_2, ..., \omega_t\}$ where

$$\omega_0 = \theta^t \quad \text{and} \quad \omega_k = (1-\theta)\theta^{t-k} \quad \text{for} \quad 0 < k \leq t \tag{173}$$

Since the aggregate price index moves in each period, relative prices are given by

$$\boldsymbol{p}_t^* = \boldsymbol{P}_t^* - \widetilde{P}_t \tag{174}$$

where $\widetilde{P}_t$ is the aggregate price index. The set of corresponding markups is similarly

$$\boldsymbol{\mu}_t^* = \boldsymbol{P}_t^* - \widetilde{\boldsymbol{\mathcal{C}}}_t \tag{175}$$

To solve for the optimal reset price P^* in each period, the relation between inflation and prices is given by

$$\widetilde{P}_t = \theta\widetilde{P}_{t-1} + (1-\theta)\widetilde{P}_t^* \quad \implies \quad \tilde{\pi}_t = \frac{1-\theta}{\theta}(\widetilde{P}_t^* - \widetilde{P}_t) \quad \text{since} \quad \tilde{\pi}_t = \widetilde{P}_t - \widetilde{P}_{t-1} \tag{176}$$

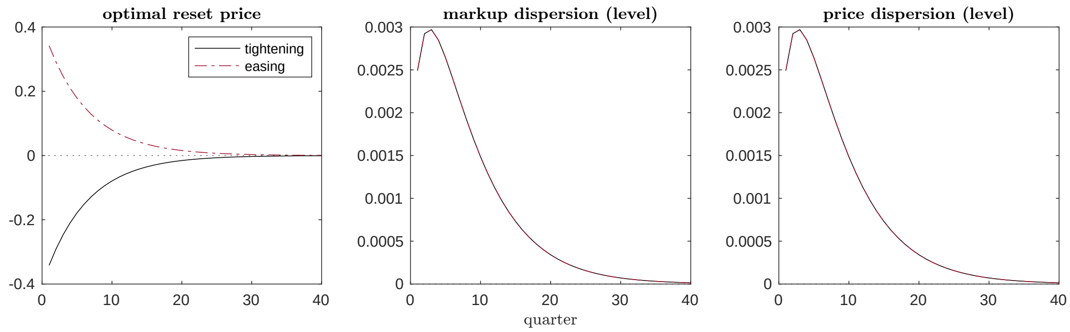
This is sufficient to both derive the reset price and calculate the weighted standard deviation of log prices and markups. Both the monetary and productivity shocks are implemented

The results for the monetary shock are presented in figure 19. Because there is no price or markup dispersion in the steady state, both are presented in levels (using log markups and log prices). Output and inflation are identical to the baseline results in figure 7. The initial effect of the shock on markup and price dispersion grows since only a fraction $1-\theta$ of firms can reset their price. The change in dispersion over time relates to two factors: (i) the size of the price reset and (ii) movement of the aggregate price index. Given monetary tightening, a resetting firm will choose a price below the aggregate price index. This increases dispersion. Now take that the firm does not reset its price again. First, the aggregate price index will gradually converge to the reset price, reducing price dispersion. After this point, it will continue to move below the reset price, increasing dispersion.

Unlike the baseline model, both monetary tightening and easing increase markup and price dispersion (see figure 19). There is no price dispersion in equilibrium, so this is expected. Still, results in Sheremirov (2020) suggest dispersion in regular prices and inflation are positively correlated, meaning a deflationary

[67] Refer to Galí (2015) for details on how Calvo pricing is implemented. Dynare is a software program designed to solve dynamic stochastic general equilibrium models (Adjemian et al., 2021).

Figure 19: Impulse Response to a Monetary Shock (Standard NK Model)



The figure shows the response of prices and markups in a model with Calvo pricing. For a 1 percent decrease in the nominal interest rate, there is an increase in the dispersion of log markups and log prices. The same applies if there is a negative shock with a 1 percent increase.

shock should also lead to price compression. This is not the case. In addition, Calvo prices implies an excessive level of price dispersion. In Sheremirov (2020), a 1 percentage point increase in annual inflation raises the standard deviation of log prices by 0.050 where the model returns almost 11x the appropriate level.[68] Table 10 presents the corresponding estimates.

Table 10: OLS Regression of Price Dispersion on Inflation Following a Productivity Shock (Simulated Data)

Price dispersion	NK Model (1)	Baseline (2)
Inflation	0.612***	0.027***
	(0.054)	(0.003)
Constant	-0.001***	0.069***
	(0.000)	(0.000)
R-squared	0.769	0.616

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[68] The coefficient reported above omits industry as a control. It falls to 0.026 when controlling for industry.