Industry Concentration and Aggregate Price Dynamics

Overview:

The inflation episode following Covid-19 reflects the confluence of several factors: swings in consumer demand, supply-chain bottlenecks, and expansionary fiscal and monetary policies. Corporate profits appear as one of the main contributors to the initial inflation surge and this paper develops a general equilibrium framework for aggregate price dynamics around industry competition. It accounts for differences in pricing power across firms, cross-price effects, and firm-specific shocks. The model builds upon a set of established facts. Industry leaders are usually much larger than other firms and charge a higher markup. They focus on preserving market share and their pricing behavior differs: they limit the pass-through of idiosyncratic cost shocks, but are strategic and match price changes by rival firms. Meanwhile, trailing firms are generally much smaller and set prices monopolistically. On this basis, the framework yields several key results. First, due to strategic complementarity in pricing, the implied cost pass-through for industry leaders after an aggregate shock is around 25 percent higher than for an idiosyncratic shock, which aligns with evidence from Gödl-Hanisch and Menkhoff (2023). Second, due to differences in firms' demand schedules, aggregate shocks have an uneven impact and the model explains differences in business cycle fluctuations across firms. Finally, if a negative productivity shock affects small firms more, industry leaders raise prices, resulting in 'excess' profits. In this case, the additional markup distortion amplifies the adverse impact of the shock by around 25%.

1. Introduction

There has been a trend increase in industry concentration in the United States over the past few decades and markups appear higher as well (De Loecker et al., 2020). This paper is motivated by concerns rising pricing power contributed to the recent inflation bout following the Covid-19 pandemic. Profits explain around one-third of domestic price growth between mid-2020 and mid-2023 and the recent inflation episode has rekindled a long-standing debate on whether inflation is driven by expectations or pricing power (Cagan, 1979).[1] Before the 1970s, many economists believed slack demand would lead prices to fall. The simultaneous rise of unemployment and prices (or 'stagflation') challenged this perception and expectations were later viewed as the main driver of inflation. As a result, models for aggregate price dynamics tend to treat pricing power as peripheral. This paper puts greater emphasis on market structure and develops a general equilibrium framework where only a few firms compete within industries. It shows that changes in concentration affect the pass-through of cost shocks across small and large firms. Furthermore, strategic interactions between firms affect how they respond to changes in monetary policy, demand conditions, and import competition.

Macroeconomic models describing aggregate price dynamics typically assume monopolistic competition across identical firms. Starting with the observation that a few firms account for the majority of sales within most industries, a growing body of research indicates market position affects pricing behavior.[2] 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 impact of economic shocks, this paper embeds a nested CES demand system featuring asymmetric firms into a New Keynesian framework with forward-looking agents. The demand system connects the pricing behavior of individual firms to their market position. The calibrated model makes a set of predictions in line with empirical evidence, both in aggregate and

[1] The period between 2020Q2 and 2023Q2 in the NIPA tables (1.15) shows profits account for 38 percent of the price increase among domestic companies when looking at a unit of real gross value added. Labor compensation contributed to 30 percent of the increase and non-labor costs contributed 32 percent. See the appendix (section A.3) for further discussion.

[2] As will be discussed in section 2.2, 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. Furthermore, Gödl-Hanisch and Menkhoff (2023) finds most variation in the pass-through is within (rather than between) 4-digit industries.

at the firm level. It also helps evaluate how competition shocks affect inflation and quantifies the associated economic losses.

Models for the aggregate economy frequently use quasi-kinked demand, e.g. Kimball (1995), to explain why firms limit the pass-through of cost shocks. In this case, the second derivative of the price elasticity of demand is negative with respect to the firm's *own* price, making large price increases costly compared to small ones. Instead, I consider a nested CES specification that adds strategic interaction between firms of different sizes. With strategic complementarity in pricing, 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 and these forces offset to varying degrees. Therefore the nature of shocks matters, i.e. if they are uniform across firms, uneven, or idiosyncratic. The assumption that shocks are truly aggregate may not hold in practice. As highlighted in Gabaix (2011), idiosyncratic shocks to top firms explain a large share of total variation in output growth. Along with the demand schedule, the degree of nominal price rigidity may differ across firms.[3] The model presented here links the pass-through to three factors: the 'aggregate' nature of shocks; their expected persistence; and the strength of strategic complementarity between firms.

I specify quadratic price adjustment costs and firms smooth their price adjustments. As a consequence, price dispersion only reflects real rigidities, i.e. differences in the demand schedule across firms. The responses to different shocks are compared to studies looking at small and large firms over the business and financial cycles, most prominently Crouzet and Mehrotra (2020). Generally, the model aligns closely with observed outcomes. The analysis also draws on Baqaee et al. (2021), who argue shocks have first-order effects on efficiency and welfare when they act on existing market distortions. In other words, demand for goods from efficient and inefficient producers changes with their relative prices. This affects the allocative efficiency of the economy following shocks. If shocks are uneven, unaffected firms may exploit their market power and raise prices, leading to efficiency losses and 'excess' profits. As mentioned, profits explain much of the initial jump in inflation in 2020. The model makes a similar prediction for a demand shock, but the level of concentration does not significantly influence this result. On the other hand, concentration is very relevant when shocks are uneven across firms.

[3] While omitted from the baseline, an extension allows for different price rigidities across firms.

There is a growing literature connecting oligopoly competition and aggregate price dynamics. Wang and Werning (2022) develop a general equilibrium model around an industry structure. This paper is similar but emphasizes heterogeneity in shocks, which leads to two distinct results: first, a nested CES system predicts large differences in the pass-through when comparing idiosyncratic and aggregate shocks; second, cross-price effects amplify shocks when they are uneven across firms. The setup is closest to Heise et al. (2022), which uses import competition to explain low inflation over the 2000s and 2010s. Heise et al. looks at competition between domestic and foreign firms, whereas this paper compares large and small firms and incorporates general equilibrium effects between them. Some of the intuitions are also similar to Guimaraes and Sheedy (2011), which uses strategic interaction between retailers to explain sales. In isolation, retailers would reduce the number of sales following a monetary easing – yet with strategic substitutability retailers maintain the number of sales relatively constant. The nested CES specification used here also implies that own- and cross-price effects frequently offset.

The analysis 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 4 along with an overview of the solution method. The calibration and results are discussed in section 5. Results include changes in pass-through, price dynamics following shocks, the contribution of profits to inflation, and changes in allocative efficiency following shocks. Section 6 concludes with a discussion of the policy implications and future directions for research.

2. Changes in Industry and Product Market Structure

This section provides a set of stylized facts on market structure. Along with the distribution of market share, differences in markups across firms 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, which depresses 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 since households favor goods with low markups and not those with low production costs.

2.1. 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).[4] More recent studies find large differences in productivity across firms within an industry (Cunningham et al., 2023). There is substantial evidence markets in the United States have become more concentrated over recent decades and that productivity dispersion 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).[5] 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) find 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 within industries appears the main driver of this trend, not the expansion of firms into new industries. Autor et al. (2020) find top firms have expanded their primary business lines while participation across industries decreased.

2.2. Measuring Local Product Market Concentration

The geographic dimension is also important and there is an ongoing debate on whether concentration in local product markets increased or decreased.[6] 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

[4] 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).

[5] 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.

[6] These studies rely on retail data, which have several limitations. Many services, intermediate goods, and major durable purchases are absent from retail data. This extends to housing costs, healthcare, private education, and other significant outlays.

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 regional product markets. Shimomura and Thisse (2012) analyze the consequences for consumer welfare.

Despite mixed evidence on the trends, local product market concentration in the United States is higher than commonly appreciated. Benkard et al. (2021) use a market research survey covering around 25,000 consumers per year between 1994 and 2019 and extract all questions relating to brands purchased, dividing them into goods that are closely substitutable. On this basis, 44 percent of product markets have an HHI above 2500 over the sample period. This is higher than most estimates circulating in the literature and meets the US Horizontal Merger Guidelines criterion for "highly concentrated." The same estimates indicate the top two firms in a market control 55-60 percent of sales on average. Other studies support this view. 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. Furthermore, the leading firm usually had a much larger market share than others and charged a higher markup.[7] Affeldt et al. (2021) look at concentration in Europe through the lens of antitrust markets. Examining European Commission 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.

2.3. The Distribution of Market Share in the European Union

The *EU Merger Control Database* compiled by Affeldt et al. (2018) allows for an analysis of firm characteristics across well-defined market segments. 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.[8] The market share of the largest firm exceeds 30 percent in more

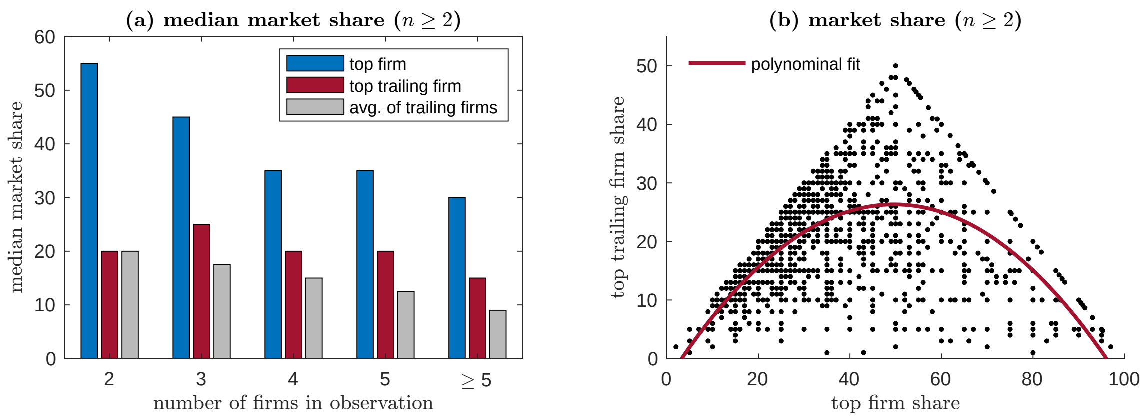
[7] Hottman et al. (2016) find the leader's markup is 24 to 100 percent higher than the sector average, depending on the markup estimation.

[8] Each case contains the name of the target firm and its potential acquirer, their market shares across different regions, 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.

than one-half of antitrust markets and exceeds 50 percent in almost one-quarter. The median share for the top firm is 40 percent. The appendix (section A.2) includes a full set of summary statistics.

The market leader is typically much larger than other firms. Figure 1 presents the main 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 gives the joint distribution of market share for the market leader and top trailing firm whenever both are reported. The top trailing firm tends to be significantly smaller than the 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.[9] In addition, the top two firms control around 63 percent of the market on average and the median is similar at 61 percent. This may not generalize to the United States; still, the findings are consistent with Benkard et al. (2021), Buzzell (1981), and Mongey (2017).

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 is taken across all corresponding observations. 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 the appendix (section A.2). 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 polynomial gives the conditional expectation. The prediction ($y = -0.012x^2 + 1.213x - 3.788$) is very close to what smoothing methods return.

2.4. 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

[9] 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.

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 the same firms also expanded (Baqaee & Farhi, 2019; Barkai, 2020; De Loecker et al., 2020).[10] 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 are problematic and papers have pointed out other weaknesses as well.[11] Despite some ambiguity on the basic facts, the literature has offered a variety of explanations for rising markups.

First, network effects could be more prominent than in the past, particularly on digital platforms (OECD, 2022). Top managers may be increasingly adept at 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. Alternatively, Amiti and Heise (2021) highlights the role of import penetration, which may lead smaller domestic firms to exit markets. 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) attribute 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 in the United States.

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)

[10] 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.

[11] 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).

attribute weakness in physical investment to intangible capital. On this point, Tambe et al. (2020) find superstar firms accumulated substantial digital capital, which explains much of their apparent productivity advantage. Furthermore, markup estimates often exclude indirect costs (e.g. marketing, payments to management). Traina (2018) finds markups have been relatively flat since the mid-1980s when these are included. Rising markups could also reflect changing 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 where owner-employees and pass-through income are prevalent (Cooper et al., 2015). Due to these ambiguities, the analysis here focuses on markup dispersion rather than changes in the aggregate markup over time.

3. Firm Size and Pricing Behavior

Market position can 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, the model treats them as connected.

3.1. 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 and 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 terms of pricing power.

Exploring price dynamics with heterogeneous firms requires a more complicated functional form. Atkeson and Burstein (2008) outline the nested CES specification used here, which was first proposed in Dornbusch (1987). It combines a discrete CES aggregator, representing all firms within an 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.[12]

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 own- and cross-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.[13] Amiti et al. (2019) use Belgian manufacturing data, which gives a more representative sample. They also employ a research design that better controls for potential endogeneity 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, which aligns with the nested CES prediction. Furthermore, large firms behave strategically while small firms do not.[14] Dedola et al. (2021) and Bruine De Bruin et al. (2023) also report similar results. The evidence supporting this specification is therefore robust, although some caution is due given potential reporting bias.

3.2. 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

[12]As an alternative, Hottman et al. (2016) develops a specification where firms produce a number of closely substitutable varieties, which leads to the cannibalization of own sales from price changes.

[13]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, i.e. the downward part of the 'U' and the upward part of the 'hump,' where firms limit their pass-through and become more strategic as market share increases. Monopoly levels of concentration are never considered.

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

costs, (iv) managerial inattention and misalignment of incentives, (v) fear of alienating customers, and (vi) uncertainty around the duration of shocks.[15] Firm size appears relevant in all these cases. For example, price increases by large firms might receive wider media attention.[16] Alternatively, managers at small firms often balance multiple tasks, leading to greater managerial inattention. Studies looking at pricing behavior across firms usually find size is relevant. 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.[17] 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) obtain similar results for Canada, as do Stokman and Hoeberichts (2006) for the Netherlands. 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 nominal price rigidities. Small firms adjust their prices by greater margins, albeit less frequently. Gopinath and Itskhoki (2010) suggest most variation in price adjustment costs takes place at highly disaggregated levels, i.e. individual industries. Finally, uniform pricing policies drive the frequency of price adjustments (DellaVigna & Gentzkow, 2019).[18]

Price leadership and strategic interaction affect pricing as well. A comparison of experimental

[15]The role of sales in price movements is well documented (Klenow & Malin, 2010; Kryvtsov & Vincent, 2021). On the other hand, Kehoe and Midrigan (2015) argue 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 indicates retailers maintain substantial price flexibility. Casual observation, along with empirical evidence, suggests large firms are more adept at price discrimination through sales (Katz, 2019).

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

[17]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 by Goldberg and Hellerstein suggests a high degree of flexibility, equal to that of consumer goods.

[18]While the analysis here focuses on price dynamics within an industry, there is a long-standing literature looking at how differences in price adjustment speeds across industries affect 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 compared to a model where price frictions are uniform.

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) argue 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) relate 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).

3.3. 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, due to data limitations, both the basic facts on the financial accelerator and their interpretation remain subject to debate. For example, Ottonello and Winberry (2020) identify firms with low default risk as those most responsive to monetary shocks. Meanwhile, Pérez-Orive and Timmer (2023) find 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. Wages appear particularly important in this context and large firms may exercise substantial power over labor markets (Azar et al., 2022). Mertens and Mottironi (2023) link growth in the markups of large firms to wage compression.[19] Bargaining power

[19] Large firms usually offer a wage premium, even when controlling for skills (Gibson & Stillman, 2009). This might be

among workers and employers likely varies over the business cycle, as highlighted in Lombardi et al. (2023). Large firms may also need to account for labor market externalities. 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.

4. A New Keynesian Model with Asymmetric Competition

The framework here 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 standard, the firm side has three distinct elaborations: The first and most important is a nested CES demand system with asymmetric firms. The second is the addition of firm-specific marginal cost shocks. The third is firm-specific pricing frictions.[20] Nominal price rigidities arise from Rotemberg adjustment costs.

The modeling approach draws on the literature and emphasizes heterogeneity across several dimensions. The firm size and productivity distributions are highly skewed within industries. Industry leaders have a much larger market share and a higher degree of pricing power than trailing firms. The literature also suggests leading firms have some degree of buyer power in factor markets and among suppliers. Franzoni et al. (2023) provides evidence for rationing by suppliers during the Covid pandemic, which predominately affected small firms. For this reason, firm-specific cost shocks are included along with aggregate shocks. These capture factors outside the model, such as bargaining power in labor negotiations or price increases by key suppliers. Various evidence suggests large firms set prices more frequently than small firms and the model allows for firm-specific price adjustment costs. Finally, several papers connect low inflation over the 2010s to stronger import competition (Auer & Fischer, 2010; Heise et al., 2022).[21] I include imports to look at how small and large firms

one reason workers are more willing to accept cuts over downturns.

[20]Differences in the expected persistence of shocks across firms can be implemented as well.

[21]Similar to this paper, the study by Heise et al. (2022) uses a nested CES demand system to look at price dynamics. 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.

respond to foreign price shocks.

This section has four parts: The first part describes the basic setup of households and firms. It is followed by a discussion of nested CES demand and the contribution of own- and cross-price effects to pricing behavior. The next two parts (4.3 and 4.4) cover the solution for flexible and sticky prices respectively. Because the solution for identical firms tends to be straightforward, this is typically included as part of the exposition. The solution for asymmetric firms is relegated to the appendix since the derivations often require a recursive approach.

4.1. Households and Firms

Household utility is a function of consumption C and labor L

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

subject to the budget constraint

$$P_t C_t + B_t \leq W_t L_t + R^n_{t-1} B_{t-1} + P_t \Pi_t + T_t \tag{2}$$

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. The demand shock χ_t is given by

$$\chi_t = e^{\frac{d_t}{1-\rho_d}} \quad \text{where} \quad d_t = \rho_d \, d_{t-1} + \eta_t \quad \text{and} \quad \eta_t \sim \mathcal{N}(0, \sigma_d) \tag{3}$$

The optimality condition for labor implies

$$P_t C_t = W_t \tag{4}$$

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

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

Price adjustment costs are rebated to households and trade is balanced. The resource constraint is therefore

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

Monetary policy follows a Taylor rule

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

where ϕ_π and ϕ_y determine the strength of the monetary policy response to deviations in inflation and 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 within an industry each produce a variety of an intermediate good. There are diminishing returns to labor

$$y_{ijt} = e^{a_t} \bar{a}_{ij} \ell_{ijt}^{1-\alpha} \tag{9}$$

where ℓ labor and $\bar{a}$ is a firm-specific productivity level. The parameter α represents the capital share in production. Although aggregate capital is fixed, it moves freely between firms and the rental rate varies. 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 reflects only labor costs

$$\Pi_{ijt} = p_{ijt} y_{ijt} - w_t \ell_{ijt} \quad \text{where} \quad w_t = \frac{W_t}{P_t} \tag{11}$$

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

$$\mathcal{C}_{ijt} = \frac{1}{e^{a_t}\bar{a}_{ij}} \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha} \tag{12}$$

Differences in marginal costs across firms relate solely to their productivity level, which is time-invariant. Firm-specific productivity shocks are introduced in the appendix (section A.6).

4.2. Nested CES Demand

The production structure consists of a nested two-level CES aggregator consisting of industry- and firm-level output.[22] The specification follows Atkeson and Burstein (2008) and Shimomura and Thisse (2012), where the latter is a specific case of the former. The general case is discussed first.

4.2.1. *General Case*

The nested CES specification of Atkeson and Burstein (2008) 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).

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

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

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

[22] 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 CES form

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

Using relative prices, the demand schedule for each firm is written as

$$y_{ijt} = p_{ijt}^{-\varphi} \left[\sum_{i=1}^{n} p_{ijt}^{1-\varphi} \right]^{\frac{\varphi-\sigma}{1-\varphi}} Y_t \quad (16)$$

The price elasticity of demand is therefore

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

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

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 than different goods.[23]

4.2.2. Nested CES with Asymmetric Firms and Foreign Competition

Following Shimomura and Thisse (2012), I specify an asymmetric setup where a sector has a mix of large and small firms. Firms are divided by class $s \in \{L, S\}$ into large (L) and small (S). Foreign imports (F) are also introduced. Domestic firms do not observe the pricing decision of foreign firms and treat it as exogenous. Import prices are assumed to follow

$$p_{Ft} = \rho_f p_{Ft-1} + \epsilon_t \quad \text{where} \quad \epsilon_t \sim \mathcal{N}(0, \sigma_f) \quad (19)$$

[23]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.

Within each class, firms are identical. The industry-level price index becomes

$$p_{jt} = \Big[\underbrace{(p^{i}_{sjt})^{1-\varphi}}_{\text{own price}} + \underbrace{(n_s - 1)(p^{-i}_{sjt})^{1-\varphi} + n_{\text{-}s}(p^{-i}_{\text{-}sjt})^{1-\varphi}}_{\text{rival prices}} + \underbrace{n_F(p_{Fjt})^{1-\varphi}}_{\text{imports}}\Big]^{\frac{1}{1-\varphi}} \tag{20}$$

where $i \in \{a, b\}$ denotes the firm making the pricing decision (a) and domestic rivals (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 'market leader') is assumed so that $n_L = 1$. The leader faces multiple smaller rivals where $n_S > 1$.[24] The large firm dominates the market and faces a lower price elasticity of demand. Since its market share depends on the actions of its rivals, it will anticipate how small and foreign firms set their prices as part of its optimization problem

4.2.3. 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 of demand with respect to prices, results from the firm's own price and is generally negative. As a result, small price increases may lead to a disproportionate drop in demand, incentivizing firms to limit the pass-through of cost shocks. The presence of a finite number of firms also induces 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 effects are typically omitted when firms are identical, but they are important if asymmetries are present or there is a mix of idiosyncratic and aggregate shocks.

4.2.3.1 The Price Elasticity of Demand and Its Curvature

The price elasticity of demand is defined as Ψ^i_t. Ueda (2023) explains the relation to markups in a

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

simple way. Take a one-period profit maximization problem where the budget constraint for firm i is

$$\Pi_t^i = \left(p_t^i - \mathcal{C}_t^i\right) y_t^i \tag{21}$$

Defining the markup μ_t^i as price over marginal cost, the solution for the optimal price can be expressed in terms of the price elasticity of demand

$$p_t^i = \frac{\Psi_t^i}{\Psi_t^i + 1}\mathcal{C}_t^i \quad \Longleftrightarrow \quad \mu_t^i = \frac{\Psi_t^i}{\Psi_t^i + 1} \tag{22}$$

Next, I define the own-price superelasticity

$$\Psi_t^{i,i} \equiv \frac{\partial \Psi_t^i}{\partial \log(p_t^i)} \tag{23}$$

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 pass-through of marginal costs reflects the co-movement of markups and prices. This given by

$$\Psi_t^{\mu^i} \equiv \frac{\partial \log(\mu_t^i)}{\partial \log(p_t^i)} = \frac{\Psi_t^{i,i}}{\Psi_t^i(\Psi_t^i + 1)} \tag{24}$$

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

$$\mathcal{P}_t^i \equiv \frac{1}{1 + \Psi_t^{\mu^i}} \tag{25}$$

The cross-price superelasticity with respect to a competitor is given by

$$\Psi_t^{i,-i} \equiv \frac{\partial \Psi_t^i}{\partial \log(p_t^{-i})} \tag{26}$$

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

$$\mathcal{B}_t^i \equiv \frac{\partial \log(p_t^i)}{\partial \log(p_t^{-i})} = \frac{\Psi_t^{i,-i}}{\Psi_t^i(\Psi_t^i + 1)} \tag{27}$$

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

4.2.3.2 Asymmetric Nested CES Case

Given asymmetric firms, where the industry-level price index follows (20), the price elasticity of demand is

$$\Psi^{i}_{st} = (\varphi - \sigma)\left(\frac{p^{i}_{sjt}}{p_{jt}}\right)^{1-\varphi} - \varphi \tag{28}$$

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

$$\Psi^{i,i}_{st} = (\varphi - \sigma)(1-\varphi)\frac{(n_s - 1)(p^{i}_{sjt}p^{-i}_{sjt})^{1-\varphi} + n_{-s}(p^{i}_{sjt}p^{-i}_{-sjt})^{1-\varphi} + n_F(p^{i}_{sjt}p_{Fjt})^{1-\varphi}}{p_{jt}^{2-2\varphi}} \tag{29}$$

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

$$\Psi^{i,-i}_{st} = -(\varphi - \sigma)(1-\varphi)\frac{(n_s - 1)(p^{i}_{sjt}p^{-i}_{sjt})^{1-\varphi} + n_{-s}(p^{i}_{sjt}p^{-i}_{-sjt})^{1-\varphi} + n_F(p^{i}_{sjt}p_{Fjt})^{1-\varphi}}{p_{jt}^{2-2\varphi}} \tag{30}$$

This last expression can be divided into three components:

$$\Psi'^{i,-i}_{st} = -(\varphi - \sigma)(1-\varphi)\frac{(n_s - 1)(p^{i}_{sjt}p^{-i}_{sjt})^{1-\varphi}}{p_{jt}^{2-2\varphi}} \quad \text{(elasticity to the price of same size firms)} \tag{31}$$

$$\Psi''^{i,-i}_{st} = -(\varphi - \sigma)(1-\varphi)\frac{n_{-s}(p^{i}_{sjt}p^{-i}_{-sjt})^{1-\varphi}}{p_{jt}^{2-2\varphi}} \quad \text{(elasticity to the price of other size firms)} \tag{32}$$

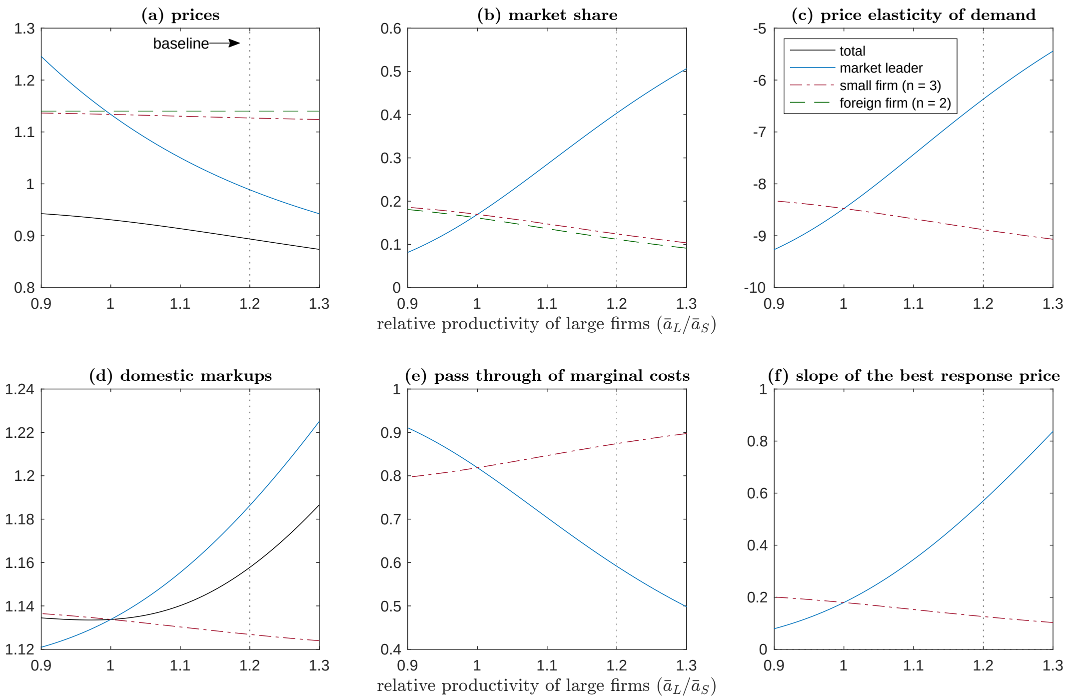
$$\Psi'''^{i,-i}_{st} = -(\varphi - \sigma)(1-\varphi)\frac{n_F(p^{i}_{sjt}p_{Fjt})^{1-\varphi}}{p_{jt}^{2-2\varphi}} \quad \text{(elasticity to the price of foreign firms)} \tag{33}$$

The first component ($\Psi'^{i,-i}$) represents the cross-price superelasticity to other firms of the same size. These firms will choose the same price as the firm making the pricing decision and separating this term simplifies some of the subsequent analysis. The second term ($\Psi''^{i,-i}$) is the cross-price superelasticity to firms that are a different size. The final term ($\Psi'''^{i,-i}$) is the cross-price superlasticity to foreign prices. Own- and cross-price superelasticities perfectly offset with nested CES demand

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

If firms are identical, these forces perfectly offset and the price elasticity of demand is linear given an aggregate shock. Asymmetry in firm size and/or shocks is needed for a nested CES specification to meaningfully differ from the standard CES specification.[25] Still, nested CES has the advantage of greater flexibility since the price elasticity of demand varies with the type of shock and should be used if firms face a mix of idiosyncratic and aggregate shocks.

Figure 2: 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 an 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 markup (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).

Figure 2 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 ($n_S = 3$). In equilibrium, the market share of firms is set by their relative efficiency ($\bar{a}$). This lowers marginal costs and translates into a

[25] 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.

price advantage. The vertical dotted lines show the baseline calibration. The x-axis displays the relative productivity of the large firm (i.e. the market leader). Moving from left to right, 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. The market share of each small firm is around 12 percent.[26] Therefore, they face highly elastic demand and cannot achieve a high markup. Furthermore, they do not respond to price adjustments by other firms and fully pass through cost shocks. The opposite is true of the market leader. In the baseline calibration, it passes through around 65 percent of 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 show price dynamics remain highly tractable with 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.4.1 in the appendix includes some further discussion on solving for the price elasticity of demand.

4.3. Flexible Price Equilibrium

This section gives the solution method for the flexible price equilibrium when cross-price effects are present.[27] While numerical methods are preferred, an approach using log-linearization is included for illustration. The dynamic problem is more complicated, but follows the same approach. In the absence of price adjustment costs or nominal rigidities, firms optimize their profits as follows

$$\max_{p^i_{st}} \quad \Pi^i_{st} = \left(p^i_{st} - \mathcal{C}^i_{st} \right) y^i_{st} \tag{34}$$

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

[26] Note small firms are generally treated as less efficient than the market leader. The instance where they have an efficiency advantage is included for illustration only.

[27] 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. See the appendix (section A.4.1) for further discussion.

4.3.1. *Identical Firms*

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

$$\frac{\partial \Pi_t}{\partial p_t} = 0 \quad \Longrightarrow \quad \left(1 - \frac{\mathcal{C}_t}{p_t}\right)\left(\frac{\varphi - \sigma}{n} - \varphi\right) = -1 \tag{35}$$

Solving for the price is simple in this case

$$p_t^* = \frac{(n-1)\varphi + \sigma}{(n-1)\varphi + \sigma - n}\mathcal{C}_t^* \tag{36}$$

Here, 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

$$\frac{\partial \mu_t^*}{\partial n} = \frac{\sigma - \varphi}{[(n-1)\varphi + \sigma - n]^2} \quad < 0 \quad \text{given} \quad \varphi > \sigma \tag{37}$$

Accordingly, greater concentration is associated with rising markups.

4.3.2. *Asymmetric Firms*

The solution to the firm's optimization problem under asymmetric oligopoly ($n \geq 2$) proceeds as follows: Going back to the profit maximization problem faced by the firm[28]

$$\frac{\partial \Pi_{st}}{\partial p_{st}^i} = 0 \quad \Longrightarrow \quad \left(1 - \frac{\mathcal{C}_{st}}{p_{st}^i}\right)\underbrace{\left[(\varphi - \sigma)\left(\frac{p_{st}^i}{p_{jt}}\right)^{1-\varphi} - \varphi\right]}_{\Psi_{st}^i} = -1 \tag{38}$$

Solving prices requires inverting the demand function

$$p_{st}^i = \frac{\Psi_{st}^i}{\Psi_{st}^i + 1}\mathcal{C}_{st} \tag{39}$$

The optimal price can be solved numerically or approximated using undetermined coefficients. Log-linearizing and taking a first-order Taylor expansion around the symmetric equilibrium price

[28] Industries are identical and their index is dropped from the notation.

gives the following relationship

$$\tilde{p}^{i}_{st} = \underbrace{\frac{\Psi^{i}_{s}(\Psi^{i}_{s}+1)\mathcal{C}_{s}}{v_{s}}}_{1+\Omega'_{s}}\widetilde{\mathcal{C}}_{st} + \underbrace{\frac{\Psi''^{\,i,\text{-}i}\mathcal{C}_{s}}{p^{\text{-}i}_{s}\,v_{s}}}_{\Omega^{*}_{s}}\tilde{p}^{\text{-}i}_{\text{-}st} + \underbrace{\frac{\Psi'''^{\,i,\text{-}i}\mathcal{C}_{s}}{p_{F}\,v_{s}}}_{\Omega^{F}_{s}}\tilde{p}_{Ft} \tag{40}$$

$$\text{where}\quad v_{s} = p^{i}_{s}(\Psi^{i}_{s}+1)^{2} - (\Psi^{i,i}+\Psi'^{\,i,\text{-}i}_{s})\mathcal{C}_{s}/p^{i}_{s}$$

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

$$\tilde{p}^{i}_{st} = (1+\Omega'_{s})\,\widetilde{\mathcal{C}}_{st} + \Omega^{*}_{s}\,\tilde{p}^{\text{-}i}_{\text{-}st} + \Omega^{F}_{s}\,\tilde{p}_{Ft} \tag{41}$$

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

$$\tilde{p}^{i}_{st} = \frac{1+\Omega'_{s}}{1-\Omega^{*}_{s}\Omega^{*}_{\text{-}s}}\widetilde{\mathcal{C}}_{st} + \frac{\Omega^{*}_{s}(1+\Omega'_{\text{-}s})}{1-\Omega^{*}_{s}\Omega^{*}_{\text{-}s}}\widetilde{\mathcal{C}}_{\text{-}st} + \frac{\Omega^{F}_{s}+\Omega^{*}_{s}\Omega^{F}_{\text{-}s}}{1-\Omega^{*}_{s}\Omega^{*}_{\text{-}s}}\tilde{p}_{Ft} \tag{42}$$

Markups and market share are determined using (17) and (39) respectively. While the method of undetermined coefficients is accurate around an initial point (e.g. p^{*}), the nested CES specification is non-linear and a numerical solution is generally preferable when searching for the steady state price. This is less of an issue when solving the dynamic problem since shocks are relatively small and the system remains close to the steady state.

4.4. Price Dynamics with Nominal Rigidities

Price adjustment frictions are specified using quadratic costs, as in Rotemberg (1982).[29] For the standard 3-equation New Keynesian model, this can give the same first-order solution as Calvo pricing.[30] Solving all components of the model requires several steps, which are outlined as follows:

[29] 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.

[30] 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) find a baseline New Keynesian model using Rotemberg pricing better fits observed price dynamics at the zero lower bound compared to an equivalent specification with Calvo pricing. Similarly, Oh (2020) finds Rotemberg pricing better fits the data when looking at uncertainty shocks.

The first part of this section states the firm's problem. The first-order solution gives each firm's decision rule. Next, changes in firm-specific marginal costs are related to aggregate shocks. The final part derives the slope of the Phillips curve. This section focuses on the main steps and the appendix (section A.4) provides a more comprehensive overview of the solution.

4.4.1. *The Firm's Optimization Problem*

The dynamic model introduces Rotemberg price adjustment costs, which are rebated to households

$$\frac{\Theta_s}{2}\left(\frac{P^i_{st}}{P^i_{st-1}}-1\right)^2 y_{jt} \quad \text{where} \quad \Theta_s=\gamma_s x_s \Theta \tag{43}$$

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 per unit sales is equal to the weight they put on the price adjustment cost. To examine how differences in adjustment costs across firms affect outcomes, a 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

$$\mathcal{L}=\mathbb{E}_t\sum_{k=0}^{\infty}\Lambda_{t+k}\left[\left(p_{st+k}-\mathcal{C}_{st+k}\right)y_{st+k}-\frac{\Theta_s}{2}\left(\pi_{t+k}\frac{p_{st+k}}{p_{st+k-1}}-1\right)^2 P_{jt+k}y_{jt+k}\right] \tag{44}$$

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

$$\Lambda_{t+k}=\beta^k\frac{P_t}{P_{t+k}}\frac{C_t}{C_{t+k}} \tag{45}$$

With identical industries, the FOC with respect to p^i_{st} yields

$$0=p^i_{st}y^i_{st}+\left(p^i_{st}-\mathcal{C}^i_{st}\right)y^i_{st}\Psi^i_{st}-\Theta_s Y_t\left\{\left(\pi_t\frac{p^i_{st}}{p^i_{st-1}}-1\right)\pi_t\frac{p^i_{st}}{p^i_{st-1}}+\beta\mathbb{E}_t\left[\left(\pi_{t+1}\frac{p^i_{st+1}}{p^i_{st}}-1\right)\pi_{t+1}\frac{p^i_{st+1}}{p^i_{st}}\right]\right\} \tag{46}$$

The FOC is log-linearized and terms are collected using undetermined coefficients to find the decision rule for each firm

$$\tilde{p}^{i}_{st} = \Gamma_s\, \tilde{p}^{i}_{st-1} + \,(1+\Gamma'_s)\, \widetilde{\mathcal{C}}^{\,i}_{st} + \,\Gamma^{*}_s\, \tilde{p}^{-i}_{-st} + \Gamma^{F}_s\, \tilde{p}_{Ft} + \widehat{\Gamma}_s\, \tilde{\pi}_t \tag{47}$$

In the expression above, the term for similar-size rivals is already incorporated on the left-hand side (since $\tilde{p}^{i}_{st} = \tilde{p}^{-i}_{st}$).[31] The decision rule is a function of past prices, marginal costs, rival prices, competition from imports, and inflation. The rival's decision rule gives the best reply

$$\tilde{p}^{i}_{st} = \underbrace{\frac{\Gamma_s}{1-\Gamma^{*}_s\Gamma^{*}_{-s}}}_{\Upsilon_s} \tilde{p}^{i}_{st-1} + \underbrace{\frac{\Gamma^{*}_s\Gamma_{-s}}{1-\Gamma^{*}_s\Gamma^{*}_{-s}}}_{\Upsilon^{*}_s} \tilde{p}^{-i}_{-st-1} + \underbrace{\frac{1+\Gamma'_s}{1-\Gamma^{*}_s\Gamma^{*}_{-s}}}_{\Upsilon'_s} \widetilde{\mathcal{C}}^{\,i}_{st} + \underbrace{\frac{\Gamma^{*}_s(1+\Gamma'_{-s})}{1-\Gamma^{*}_s\Gamma^{*}_{-s}}}_{\Upsilon''_s} \widetilde{\mathcal{C}}^{\,-i}_{-st} + \underbrace{\frac{\Gamma^{F}_s+\Gamma^{*}_s\Gamma^{F}_{-s}}{1-\Gamma^{*}_s\Gamma^{*}_{-s}}}_{\Upsilon^{F}_s} \tilde{p}_{Ft} + \underbrace{\frac{\widehat{\Gamma}_s+\Gamma^{*}_s\widehat{\Gamma}_{-s}}{1-\Gamma^{*}_s\Gamma^{*}_{-s}}}_{\Upsilon^{\pi}_s} \tilde{\pi}_t \tag{48}$$

The corresponding terms are collected into the Υ's for convenience where

$$\Upsilon_s = \frac{(\psi_s+\beta\Theta_s\Upsilon^{*}_s)\Upsilon^{*}_{-s}+\Theta_s}{\kappa_s-\beta\Theta_s\Upsilon_s} \qquad \text{(own past price)} \tag{49}$$

$$\Upsilon^{*}_s = \frac{(\psi_s+\beta\Theta_s\Upsilon^{*}_s)\Upsilon_{-s}}{\kappa_s-\beta\Theta_s\Upsilon_s} \qquad \text{(rival past price)} \tag{50}$$

$$\Upsilon'_s = \frac{(\psi_s+\beta\Theta_s\Upsilon^{*}_s)\Upsilon''_{-s}-(p^{i}_s)^{-\varphi}p_j^{\varphi-\sigma}\Psi^{i}_s\mathcal{C}^{\,i}_s}{\kappa_s-\beta\Theta_s(\Upsilon_s+\rho)} \qquad \text{(own marginal cost)} \tag{51}$$

$$\Upsilon''_s = \frac{(\psi_s+\beta\Theta_s\Upsilon^{*}_s)\Upsilon'_{-s}}{\kappa_s-\beta\Theta_s(\Upsilon_s+\rho)} \qquad \text{(rival marginal cost)} \tag{52}$$

$$\Upsilon^{F}_s = \frac{(\psi_s+\beta\Theta_s\Upsilon^{*}_s)\Upsilon^{F}_{-s}+\omega_s}{\kappa_s-\beta\Theta_s(\Upsilon_s+\rho)} \qquad \text{(import price)} \tag{53}$$

$$\Upsilon^{\pi}_s = \frac{(\psi_s+\beta\Theta_s\Upsilon^{*}_s)\Upsilon^{\pi}_{-s}-\Theta_s(1-\rho\beta)}{\kappa_s-\beta\Theta_s(\Upsilon_s+\rho)} \qquad \text{(inflation)} \tag{54}$$

[31] Log deviations are defined $\tilde{x}_t = \log\left(\frac{x_t}{x}\right)$. Time subscripts are dropped for the steady state.

The convenience terms κ, ψ, and ω are defined as[32]

$$\kappa_s = \Theta_s + \beta\Theta_s - (p_s^i)^{1-\varphi} p_j^{\varphi-\sigma} \left[\left(1 - \frac{\mathcal{C}_s}{p_s^i}\right) \frac{\Psi_s^{i,i} + \Psi_s'^{\,i,-i}}{p_s^i} + \Psi_s^i \frac{\mathcal{C}_s}{p_s^i} \right] \tag{55}$$

$$\psi_s = (p_s^i)^{1-\varphi} p_j^{\varphi-\sigma} \left(1 - \frac{\mathcal{C}_s}{p_s^i}\right) \frac{\Psi_s''^{\,i,-i}}{p_{-s}^{-i}} \tag{56}$$

$$\omega_s = (p_s^i)^{1-\varphi} p_j^{\varphi-\sigma} \left(1 - \frac{\mathcal{C}_s}{p_s^i}\right) \frac{\Psi_s'''^{\,i,-i}}{p_F} \tag{57}$$

In the solution for the Y's above, the term ρ refers generically to the persistence of the shock in question (ρ_d, ρ_a, ρ_m, or ρ_f). The steps behind the derivation are provided in the appendix (section A.4.2). The system consists of 12 unknowns and 12 equations, which are solved numerically. It is also necessary to relate exogenous shocks in the economy to changes in marginal costs for firms and inflation. Again, this is solved using undetermined coefficients. For the monetary policy shock m

$$(i) \quad \tilde{\pi}_t = \Gamma^{\pi} m_t \qquad\qquad (ii) \quad \widetilde{Y}_t = \Gamma^{y} m_t \tag{58}$$

noting that marginal costs move in line with aggregate output. The solution for the undetermined coefficients Γ^{π} and Γ^{y} are covered in the following section as well.

4.4.2. The Relationship Between Marginal Costs and Aggregate Shocks

Wages and output share a simple relationship. Real wages are given by the household labor-leisure trade-off

$$w_t = C_t \quad \Longrightarrow \quad \widetilde{w}_t = \widetilde{Y}_t \tag{59}$$

The log-linear marginal cost for each firm is

$$\widetilde{\mathcal{C}}_{st} = (1-\alpha)\widetilde{w}_t - a_t \tag{60}$$

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

Therefore

$$\widetilde{\mathcal{C}}_{st} = (1-\alpha)\widetilde{Y}_t - a_t \tag{61}$$

Accordingly, marginal costs are a function of aggregate output and the productivity shock. Firm-specific productivity shocks are discussed in the appendix (section A.6).

4.4.3. Aggregate Shocks with Identical Firms

This section connects three of the main shocks (monetary policy, demand, and productivity) 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 the appendix (section A.5). For 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.

4.4.3.1 Monetary Policy Shocks and the Phillips Curve

The monetary policy shock acts on demand through the household Euler equation. Log-linearizing and using the resource constraint (6)

$$\widetilde{Y}_t = \mathbb{E}_t\left[\widetilde{Y}_{t+1} + \widetilde{P}_{t+1}\right] - \widetilde{P}_t - \widetilde{R}^n_t \tag{62}$$

In log-linear form, the Taylor rule is

$$\widetilde{R}^n_t = m_t + \phi_\pi \tilde{\pi}_t + \phi_y \widetilde{Y}_t \tag{63}$$

Adding this to the household Euler equation for bonds gives

$$\widetilde{Y}_t = \mathbb{E}_t\left[\widetilde{Y}_{t+1} + \tilde{\pi}_{t+1}\right] - m_t - \phi_\pi \tilde{\pi}_t - \phi_y \widetilde{Y}_t \tag{64}$$

Replacing $\widetilde{Y}$ and $\tilde{\pi}$ yields the aggregate demand relationship

$$\Gamma^y m_t = \rho_m(\Gamma^y + \Gamma^\pi)m_t - m_t - \phi_\pi \Gamma^\pi m_t - \phi_y \Gamma^y m_t \tag{65}$$

$$\implies \Gamma^\pi = \frac{(1+\phi_y-\rho_m)\Gamma^y + 1}{\rho_m - \phi_\pi} \tag{66}$$

With identical firms, there is no variation in relative prices and the log-linearized aggregate supply relationship is

$$\Upsilon^{\pi}\tilde{\pi}_t = \Upsilon'\tilde{\mathcal{C}}_t^{*} \tag{67}$$

where the solutions for Υ^{π} and Υ' are

$$(i) \quad \Upsilon^{\pi} = \frac{\Theta}{n}(1-\rho_m\beta) \quad \text{and} \quad (ii) \quad \Upsilon' = n^{\frac{\varphi-\sigma}{1-\varphi}}(p^*)^{1-\sigma}\left(\varphi - \frac{\varphi-\sigma}{n}\right)\frac{\mathcal{C}^*}{p^*} \tag{68}$$

Using (58), the monetary policy shock enters as

$$\Upsilon^{\pi}\Gamma^{\pi}m_t = \Upsilon'(1-\alpha)\Gamma^{y}m_t \quad \Longrightarrow \quad \Gamma^{\pi} = (1-\alpha)\frac{\Upsilon'}{\Upsilon^{\pi}}\Gamma^{y} \tag{69}$$

This gives aggregate demand (66) and aggregate supply (69) where the Γ^{π} and Γ^{y} are the unknowns. Solving the coefficients gives the reaction of output and inflation to a monetary policy shock and the ratio of Γ^{π} and Γ^{y} gives the slope of the Phillip curve

$$\frac{\Gamma^{\pi}}{\Gamma^{y}} = (1-\alpha)\frac{n^{\frac{1-\sigma}{1-\varphi}}(p^*)^{-\sigma}\left(\varphi-(\varphi-\sigma)/n\right)\mathcal{C}^*}{\Theta(1-\rho_m\beta)} \tag{70}$$

To see how the parameters affect the slope, it is simple to take the limit cases. Setting $n = 1$ gives

$$\frac{\Gamma^{\pi}}{\Gamma^{y}} = (1-\alpha)\frac{\sigma(p^*)^{-\sigma}\mathcal{C}^*}{\Theta(1-\rho_m\beta)} \quad \text{where} \quad p^* = \frac{\sigma}{\sigma-1}\mathcal{C}^* \tag{71}$$

In the baseline calibration, the elasticity of substitution across goods $\sigma = 1$. If there is just one firm, the markup becomes infinite and the slope of the Phillips curve goes to zero. In this case, monetary policy is completely non-neutral. As the number of firms $n \to \infty$, then

$$\frac{\Gamma^{\pi}}{\Gamma^{y}} = (1-\alpha)\frac{\varphi(p^*)^{-\sigma}\mathcal{C}^*}{\Theta(1-\rho_m\beta)} \quad \text{where} \quad p^* = \frac{\varphi}{\varphi-1}\mathcal{C}^* \tag{72}$$

In this case, the slope of the Phillips curve implies some trade-off between inflation and output. Lower Rotemberg adjustment costs steepen the slope of the Phillips curve. When prices are fully flexible, i.e. $\Theta = 0$, the slope 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.

Although the solution for asymmetric firms is more complicated, it again relies on solving undetermined coefficients. The change in price for each firm is nested within the change industry price index (where $\tilde{\pi}_{jt} = \tilde{\pi}_t$ given identical industries)

$$\tilde{\pi}_{t+1} = \mathbb{E}_t \left[\frac{n_s(P_s)^{-\varphi}(\widetilde{P}_{st+1} - \widetilde{P}_{st}) + n_{\text{-}s}(P_{\text{-}s})^{-\varphi}(\widetilde{P}_{\text{-}st+1} - \widetilde{P}_{\text{-}st}) + n_F(P_F)^{-\varphi}(\widetilde{P}_{Ft+1} - \widetilde{P}_{Ft})}{P^{-\varphi}} \right] \tag{73}$$

Expected future inflation is a function of the monetary policy shock

$$\mathbb{E}_t \left[\tilde{\pi}_{t+1}\right] = \rho_m \Gamma^{\pi} m_t \tag{74}$$

The change in price for each firm is also related to the monetary policy shock

$$\mathbb{E}_t \left[\widetilde{P}_{st+1}\right] - \widetilde{P}_{st} = \left[\rho_m \Gamma^{\pi} + (\Upsilon_s + \rho_m - 1)\Gamma^m_s + \Upsilon^*_s \Gamma^m_{\text{-}s}\right] m_t \tag{75}$$

where

$$\Gamma^m_s = \Upsilon^{\pi}_s \Gamma^{\pi} + (\Upsilon'_s + \Upsilon''_s)(1-\alpha)\Gamma^y \tag{76}$$

Aggregate demand (66) provides the second equation determining the system. Combining expressions, the only unknowns are Γ^{π} and Γ^y after some cancellation. The monetary policy shock assumes no change in foreign relative prices so that $\tilde{p}^f_t = 0$ and $\tilde{\pi}^f_t = \tilde{\pi}_t$. The appendix covers changes in foreign prices (section A.5.4).

4.4.3.2 Demand Shock

For the demand shock, the coefficients relating the shock to aggregate output and inflation are

$$(i) \quad \widetilde{Y}_t = \Phi^y d_t \qquad\qquad (ii) \quad \tilde{\pi}_t = \Phi^{\pi} d_t \tag{77}$$

The log-linearized household Euler equation for bonds is

$$\widetilde{Y}_t = \mathbb{E}_t \left[\widetilde{Y}_{t+1} + \tilde{\pi}_{t+1} - \frac{d_{t+1}}{1-\rho_d} \right] + \frac{d_t}{1-\rho_d} - \phi_\pi \tilde{\pi}_t - \phi_y \widetilde{Y}_t \tag{78}$$

After solving for expectations, the aggregate demand relationship is similar to (66)

$$\Phi^y d_t = \rho_d(\Phi^y + \Phi^\pi)d_t + d_t - \phi_\pi \Phi^\pi d_t - \phi_y \Phi^y d_t \tag{79}$$

$$\implies \Phi^\pi = \frac{(1+\phi_y - \rho_d)\Phi^y - 1}{\rho_d - \phi_\pi} \tag{80}$$

With identical firms, the aggregate supply relationship establishes

$$\Phi^\pi = (1-\alpha)\frac{Y'}{Y^\pi}\Phi^y \tag{81}$$

This leaves two equations and two unknowns. The solutions to the demand and monetary policy shocks are similar, although the aggregate demand relationships in (66) and (80) differ.

4.4.3.3 Aggregate Productivity Shock

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

$$(i) \quad \widetilde{Y}_t = \Omega^y a_t \qquad\qquad (ii) \quad \tilde{\pi}_t = \Omega^\pi a_t \tag{82}$$

Compared to the other shocks, the aggregate demand relationship changes somewhat. Combining the household Euler equation and the Taylor rule gives

$$\Omega^\pi = \frac{(1+\phi_y - \rho_a)}{\rho_a - \phi_\pi}\Omega^y \tag{83}$$

Aggregate supply establishes

$$\Omega^\pi = \frac{Y'}{Y^\pi}[(1-\alpha)\Omega^y - 1] \tag{84}$$

Again there are two equations and two unknowns, which gives the solution for Ω^π and Ω^y.

5. Calibrated Model and Main Results

This section covers the main results. The first part presents the calibration and associated target values along with the resulting Phillips curve. The second part covers the pass-through and compares aggregate and idiosyncratic shocks. The third part describes the dynamic response to aggregate productivity and monetary policy shocks across firms along with the contribution of profits to inflation following a demand shock. The final part covers firm-specific shocks. It looks at how these shocks affect the allocation of demand across firms and quantifies the associated efficiency costs.[33]

5.1. Model Calibration

The baseline calibration is given in table 1 and is matched to industry characteristics. The model is solved at a quarterly frequency. The time discount factor and the capital share of income use standard values. 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.

Table 1: Baseline Parameter Values

Parameter	Value	Description
β	0.99	Household time discount
$1-\alpha$	0.70	Labor returns to scale
σ	1	Elasticity of substitution across goods
φ	10	Elasticity of substitution across varieties
Θ	125	Rotemberg price adjustment costs
ϕ_π	1.50	Monetary policy inflation reaction
ϕ_y	0.125	Monetary policy output gap reaction
n_L	1	Number of large firms in an industry
n_S	3	Number of small firms in an industry
n_F	2	Number of foreign firms in an industry
ρ	0.85	Persistence of shocks
p_F	1.14	Price of foreign imports (steady state)
$\bar{a}_L/\bar{a}_S$	1.2	Relative productivity of large firms
γ_L/γ_S	1	Relative price adjustment costs

Target moments include the distribution of market share across large and small firms, the pass-

[33] Differences in Rotemberg adjustment costs across large and small firms are covered in the appendix (section A.7).

through, and the best response price (see tables 2 and 3).[34] 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 some mismatch in the markup of large and small firms. The parameter for the price adjustment cost Θ is equivalent to a 35 percent reset probability under Calvo pricing.[35] This appears consistent with the data. Large and small firms are assumed to have the same price adjustment costs in the baseline ($\gamma_s = 1$).

Table 2: Industry-Level Targets

	Large firms		Small firms		
Description	Target	Value	Target	Value	Source
Market share	0.40	0.40	0.15	0.13	Affeldt et al. (2018)
Pass-through	0.50	0.58	0.80	0.87	Amiti et al. (2019)
Slope of best response price	0.60	0.58	0.12	0.10	Ibid.
Markup ($\mu - 1$)	0.24	0.19	0.16	0.13	Hottman et al. (2016)

The market shares in table 2 are based on an analysis of the EU Merger Control database of Affeldt et al. (2018). The large firm target takes the average/median market share observed for large firms. The small firm target is based on the average market share of all trailing firms, but a lower value is acceptable since around 15 percent of market share is unreported. The slope of the best response price and the pass-through are from Amiti et al. (2019). The model does not fully match the level of markups reported in Hottman et al. (2016), but the relative gap is the same. 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 upper 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 (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.

[34] The pass-through is taken from table 2 column 4 of Amiti et al. (2019) and the best-response price is from column 7. The markups 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.

[35] 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.

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

Table 3: Aggregate Targets

Description	Target (range)	Value	Source
Targeted			
Median industry HHI (incl. foreign firms)	2045 - 2360	2340	Benkard et al. (2021)
Aggregate markup ($\mu - 1$)	0.13 - 0.16	0.16	See appendix[36]
Import penetration in manufacturing	0.19 - 0.23	0.21	Hale et al. (2019)
Slope of the Phillips curve	0.20 - 0.33	0.23	Tetlow (2022)
Implied			
Price dispersion (std. dev.)	–	0.07	–
Markup dispersion (std. dev.)	–	0.03	–

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. There are many estimates of price dispersion in the literature, but few apply directly to the model environment. Abbott (1989) appears 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 multiple studies looking at dispersion in consumer prices 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) find the standard deviation of normalized prices for identical goods is 19 percent while this rises to 25 percent for closely substitutable goods.[37] 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.

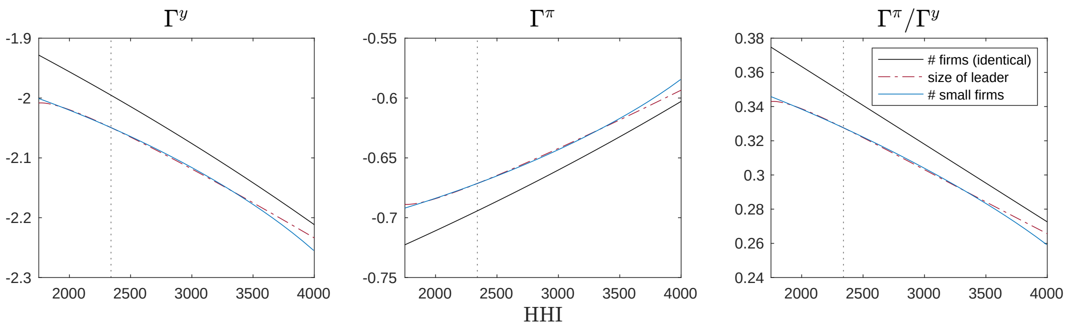
5.1.1. Concentration and the Slope of the Phillips Curve

The Phillips curve describes the relationship between inflation and output. Wang and Werning (2022) look at how higher concentration affects the slope and figure 3 presents a similar set of results. The left-hand panel 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

[37] Similarly, Böheim et al. (2021) find a coefficient of variation around 0.12 comparing online prices across retailers in Austria

presented in the right panel. Moving from left to right along the x-axis corresponds to an increase in concentration. This is evaluated in four ways: (i) identical firms where the number n changes; (ii) the baseline calibration where the productivity of the leader $\bar{a}_L$ shifts; (iii) the baseline calibration where the number of small firms n_S changes; and (iv), a change in the number of foreign firms on the market. Each change leads to a different allocation of market share, e.g. between the market leader and other firms or between domestic and foreign firms. The vertical dotted line shows the HHI implied by the baseline calibration.

Figure 3: 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 four cases are (i) identical firms where n decreases, (ii) the baseline calibration where the productivity of the leader improves and its market share increases, (iii) the baseline calibration where n_S decreases, and (iv) the baseline calibration where n_F decreases.

The results are close to those presented in Wang and Werning (2022). In their study, a naïve oligopoly model closely matches a more sophisticated model with strategic complementarity and firm heterogeneity. The same could be said here. When looking at a range of plausible values for the HHI, different forms of concentration all lead to flattening of the slope of the Phillips curve. The scenarios with firm heterogeneity both include foreign firms, which explains the downward shift observed in the slope compared to the scenario with identical firms. Meanwhile, an increase in concentration across either margin – the expansion of large firms or exit by small firms – flattens the slope of the Phillips curve. While it is tempting to link higher concentration to the observed flattening of the Philips Curve, even modest change requires a large increase in concentration in the context of the model.[38] In part, this is a consequence of the parameterization. Large and small firms face the same price adjustment costs in the baseline. Firm-specific adjustment costs are explored in the appendix (section A.7). It is also a consequence of the model structure, which abstracts from

[38]A decrease in the slope of the Philips curve by 0.01 implies an increase in the HHI of more than 200 points. The change in HHI estimated by Benkard et al. (2021) is around 300 points.

differences in concentration across industries.

5.1.2. *The Pass-Through for Idiosyncratic and Aggregate Cost Shocks*

While the 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 section 4.4.1, but two adjustments are necessary. In the decision rule 48, the cross-price elasticities are set so that $\Psi'^{\,i,\text{-}i}_{st} = 0$ and

$$\Psi''^{\,i,\text{-}i}_{st} = -(\varphi-\sigma)(1-\varphi)\frac{(n_s-1)(p^i_{1jt}p^{\text{-}i}_{1jt})^{1-\varphi} + n_{\text{-}s}(p^i_{1jt}p^{\text{-}i}_{2jt})^{1-\varphi}}{p^2_{jt}} \tag{85}$$

The Υ's are re-estimated accordingly. The log deviation in prices is given by

$$(i)\quad \tilde{p}^i_{st} = \Upsilon_s\,\tilde{p}^i_{st-1} + \Upsilon^*_s\,\tilde{p}^{\text{-}i}_{\text{-}st-1} + \Upsilon'_s\,\widetilde{\mathcal{C}}^{\,i}_{st} \quad \text{and} \quad (ii)\quad \tilde{p}^{\text{-}i}_{\text{-}st} = \Upsilon_{\text{-}s}\,\tilde{p}^{\text{-}i}_{\text{-}st-1} + \Upsilon^*_{\text{-}s}\,\tilde{p}^i_{st-1} + \Upsilon''_{\text{-}s}\,\widetilde{\mathcal{C}}^{\,i}_{\text{-}st} \tag{86}$$

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

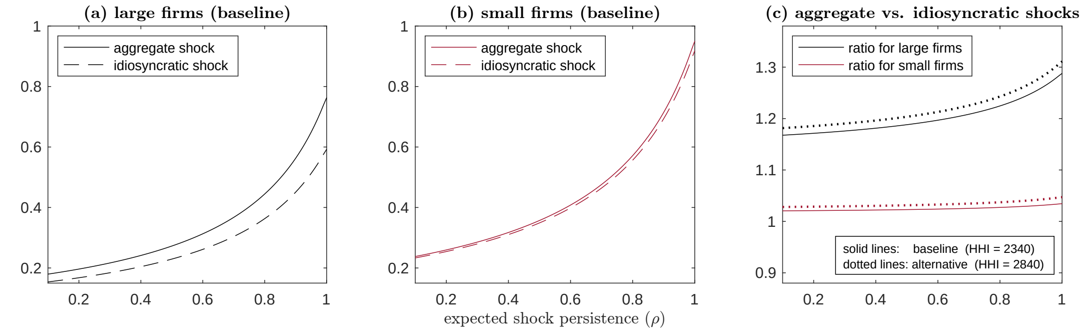
$$\mathcal{P} = \frac{\sum_{t=1}^{t=t^*}\tilde{p}^i_{st}}{\sum_{t=1}^{t=t^*}\widetilde{\mathcal{C}}^{\,i}_{st}}$$

where t^* is large enough to ensure both variables revert to their steady state.[39] The model is re-estimated over a range of values for the expected shock persistence.

The pass-through following a cost shock for large and small firms is presented in figure 4. Expectations play a role because firms weigh the future benefit of adjusting prices against the costs of doing so. When cost shocks are temporary, firms prefer relatively small adjustments (see the left-hand and center panels). If changes in costs are permanent, the pass-through increases. The pass-through is lower for large firms due to strategic complementarity with foreign firms. A permanent shock has near complete pass-through for both small and large firms when foreign firms are omitted. Along with changes in the expected persistence of the shock, it matters if shocks are perceived as idiosyncratic or

[39] Setting $t^* = 1000$ ensures this margin is extremely small and indistinguishable from 0. In practice, the pass-through is only observed over a limited period and the appendix (section A.4.3) presents the same results for the first eight quarters of the shock.

Figure 4: The Pass-Through of Cost Shocks (Full Time Horizon)



The x-axis displays the expected persistence of the shock. In the left and center panels, the y-axis gives the pass-through, which is 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) in the right-hand panel modifies the baseline so that $n_S = 2$ and $p_F = 1.17$. This increases the market share of the leading firm to 43 percent and significantly lowers the pass-through of idiosyncratic shocks.

aggregate. For large firms, the difference is significant – around 25 percent when $\rho = 0.9$ (right-hand panel). This appears consistent with Gödl-Hanisch and Menkhoff (2023), which finds the differences in pass-through between idiosyncratic and aggregate shocks is around 30 percent.[40] This result is also supported by Dedola et al. (2021) and Lafrogne-Joussier et al. (2023).[41] Along with the baseline, the right-hand panel in figure 4 includes an alternative scenario with higher concentration. As the HHI rises, both own- and cross-price effects become more prominent, widening the gap for the pass-through.

5.2. The Dynamic Response to Aggregate Shocks

This section looks at price dynamics following each of the shocks included in the model and draws comparisons with the empirical literature. Impulse responses are measured as the percent deviation from the steady state. The productivity shock is discussed first, followed by the monetary policy shock and the import price shock. With quadratic adjustment costs, dispersion arises solely from the cross-section of firms. This contrasts with most models incorporating Calvo price frictions, where dispersion arises from price staggering. Excepting the import price shock, foreign prices are assumed to track domestic inflation.

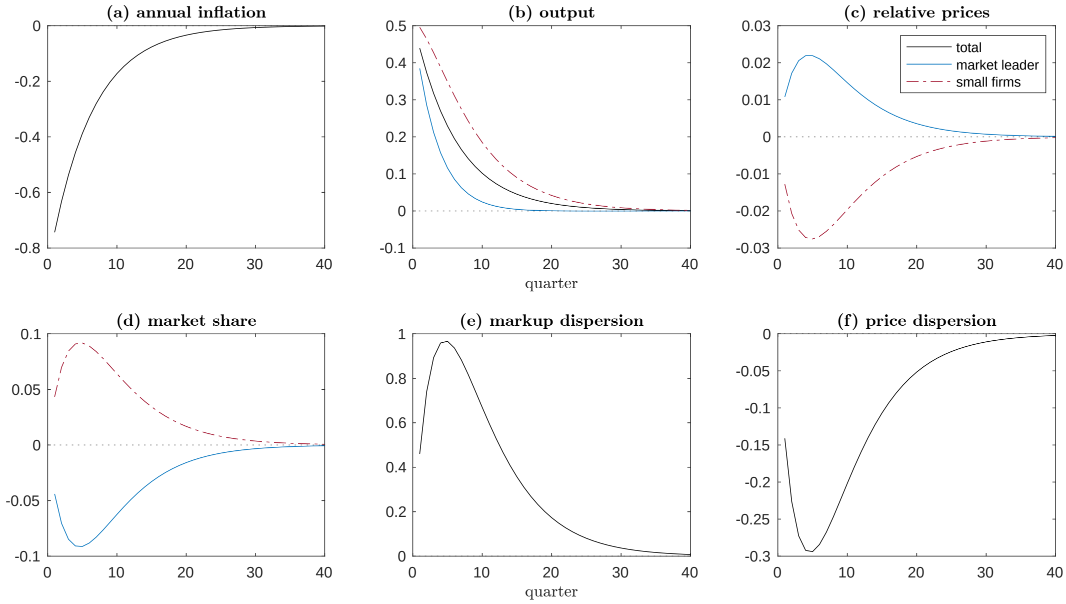
[40]The level of pass-through depends on the persistence of the shock. Bruine De Bruin et al. (2023) find the average pass-through following the Covid-19 shock was 60 percent.

[41]In addition, Lafrogne-Joussier et al. (2023) compares the pass-through for a shock to energy prices and a shock to the price of imported inputs. In the former case, the pass-through is near 100 percent whereas it is 30 percent for the latter. They also find the pass-through is higher for positive cost shocks than negative shocks.

5.2.1. *Productivity Shock*

Figure 5 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 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. The gap in relative prices relates to differences in pricing power and 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 price compression. Differences in relative prices also explain the reallocation of market share towards small firms.

Figure 5: Baseline Impulse Response to a Positive Productivity Shock ($\xi_0 = 1$)



The initial shock increases aggregate productivity by one percent. The x-axis gives the number of quarters following the shock. The y-axis gives the deviation from the steady state. Inflation drops and output expands. While wages and capital rental costs increase, efficiency is also higher. The latter effect dominates and marginal costs drop. Small firms pass their savings to consumers and cut their relative prices more than large firms. This reduces price dispersion since small firms have a higher price in equilibrium. 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.[42] 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 0.028 percent. The results indicate small firms are more sensitive to the business cycle, which is consistent

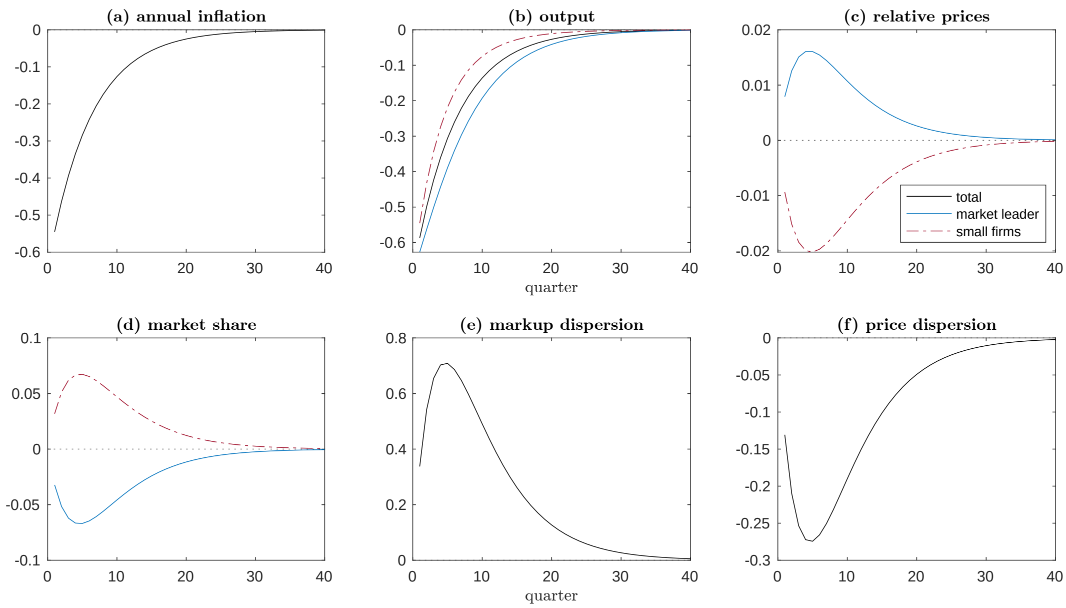
[42]Sheremirov (2020) also observes the Calvo model overstates the co-movement of price dispersion with inflation by a factor of 15 and a similar analysis is included in the appendix (section A.8).

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. 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 ($= 3.1/2.5 - 1$).

5.2.2. Monetary Policy Shock

Given the simplicity of the model, monetary tightening is analogous to a negative demand shock. Figure 6 presents the dynamic response to a one percentage point increase in the annualized interest rate. Both aggregate inflation and output decline in response to the shock. 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 are more sensitive. 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. Given monetary easing, the results are fully symmetric.

Figure 6: 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 number of quarters following the shock. The y-axis gives the deviation from the steady state. Inflation drops by around 0.7 percent in the first period. The evolution of relative prices among small and large firms results from differences in pricing behavior. Marginal costs fall in line with output. 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 both charge a higher markup and increase it 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.[43] 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 variance of log markups from a 1 percentage point increase in the interest rate is 0.001, matching what Meier and Reinelt report. 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.[44] It is possible differences in the price elasticity of demand across firms are confounded by other factors, such as financial constraints or price adjustment costs.[45]

5.2.3. Import Price Shock

Heise et al. (2022) show import competition played an important role in the concentration trend in the United States. The rise in prices following the Covid shock likely reflected weaker competition from imports along with other factors. Auer et al. (2021) finds evidence for strategic complementarity between domestic and foreign products following a rapid appreciation of the Swiss Franc in 2015. Other studies indicate US producers increased retail prices following tariffs on Chinese competitors (Cavallo et al., 2021; Flaaen et al., 2020). Imports make up around 20 percent of the consumption basket in the model. The import price shock tests how strategic complementarity between domestic and foreign producers affects firm-level and aggregate outcomes. The competition channel is somewhat novel since most models use lower foreign input costs to explain why domestic producers cut prices.[46]

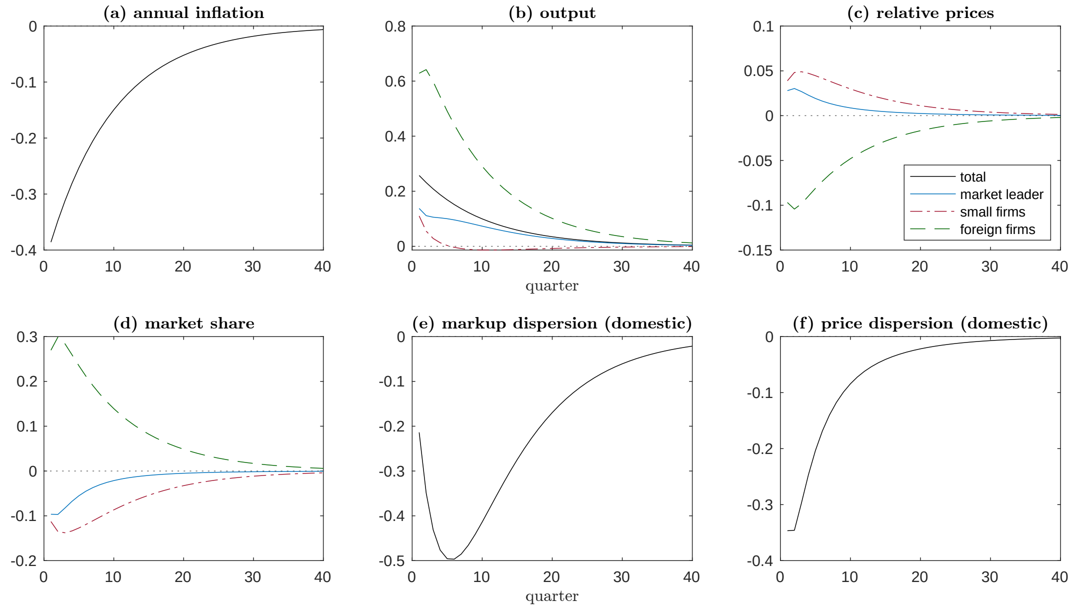
[43] Price dispersion is measured using the weighted standard deviation of log prices in each time period, where the market share of each firm gives the weight. Log markups are similarly used to measure markup dispersion.

[44] Crouzet and Mehrotra (2020) 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 can compensate for industry-specific shocks whereas small firms are more exposed.

[45] 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.7 in the appendix).

[46] In the context of the model, marginal costs for producers go up since demand increases with lower prices. These general equilibrium effects dampen the response of domestic prices to foreign competition.

Figure 7: Baseline Impulse Response to Deflation in Import Prices ($\epsilon_0 = 0.25$)



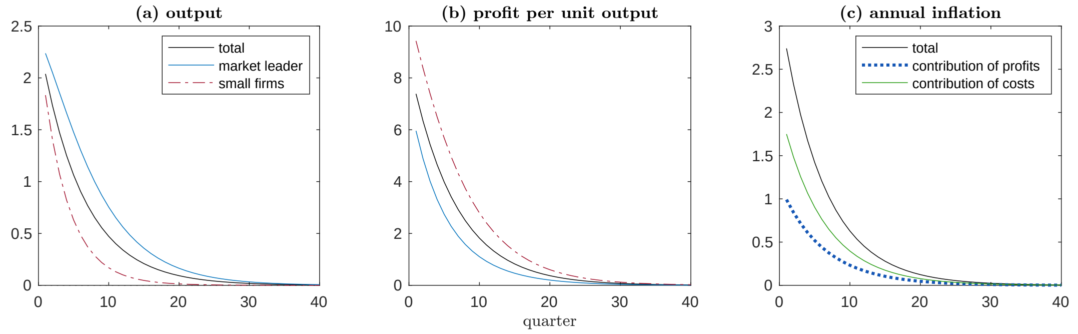
The import price shock is equivalent to an initial one percentage point decrease in import price inflation. The x-axis gives the number of quarters following the shock. The y-axis gives the deviation from the steady state. Inflation drops by around 0.4 percent in the first period. This is larger than the weight of imports in the price basket since domestic competition leads to price cuts.

Figure 7 shows the impact of a 1 percent deflationary shock to import prices. Because lower foreign prices elicit a strategic response from domestic firms, the deflationary effect of the shock is amplified by around 35-40 percent when looking at overall price inflation. The resulting decrease in aggregate prices has a positive effect on demand. Main outcomes largely align with those observed in Auer et al. (2021). The study suggests an approximate 5 percent decline in import CPI resulted in a 4.3 percent (or one percentage point) increase in the share of imports in household expenditures at the one year horizon. Given a shock of a similar magnitude – a decline in the import price index by 5 percent – the model predicts a 4 percent shift in market share towards foreign firms. The results also suggest that small firms are more sensitive to import competition than large firms – consistent with the evidence in Amiti et al. (2019).

5.2.4. Demand Shock

US national accounts show real disposable personal income increased by 6.4 percent year-on-year in 2020, the largest increase since 1984. Most of this increase was due to fiscal stimulus. At the same time, consumer spending redirected towards durable goods, leading to a mismatch between demand and supply. These developments are consistent with a demand shock. Higher corporate profitability appears one symptom of this. While the inflation of the 1970s resulted from de-anchored inflation expectations, the current episode has more in common with a surge in demand-driven inflation in the 1950s. A comparison of inflation episodes is included in the appendix (section A.3).

Figure 8: Baseline Impulse Response to a Positive Demand Shock ($\eta_0 = 1$)



The x-axis gives the number of quarters following the shock. The y-axis gives the deviation from the steady state. The left-hand panel gives the deviation in aggregate output. The center panel gives the change in the profit margin on each unit of sales. The right-hand panel gives the contribution of profits to inflation.

Figure 8 summarizes the effect of a demand shock on key outcomes.[47] The output gap is positive and the profit margin significantly widens following the shock (left and center panel). As a result, total profits explain more than one-third of inflation (right panel). This is consistent with the overall contribution of profits to domestic price growth in the United States over the 2021-23 period: 38 percent. Still, the contribution of profits to inflation is relatively constant over time in the model whereas it was front-loaded in practice – profits appeared to jump in the third quarter of 2020. Subsequently, rising costs explain almost all growth in prices. As suggested by Glover et al. (2023), firms may have anticipated future cost increases and raised prices in advance. While I cannot test this hypothesis, I look at whether concentration affects the contribution of profits to inflation. To do this, I run an alternative scenario with monopolistic competition within industries and find the contribution of profits to inflation is lower in the baseline. As large firms consolidate the market, they absorb higher costs and this erodes their profit margin. In fact, the overall response of inflation to a demand shock is smaller in the baseline economy compared to the monopolistic alternative – around 20 percent lower.

[47]The IRFs for other variables are included in the appendix (section A.5.2).

5.3. Firm-Specific Shocks

This section considers cost shocks that only affect small firms. These shocks are economy-wide and have general equilibrium effects. To give one example of such a shock, Franzoni et al. (2023) provide evidence of rationing among suppliers during the Covid-19 shock. Suppliers favored larger customers and small firms experienced longer backlogs. Their study suggests (i) supply backlogs were associated with rising industry CPI, (ii) trailing firms within an industry were more exposed to supply chain backlogs, and (iii) leading firms raised their markups following the shock. The model looks at how these effects can amplify inflation and allows for some quantification of the resulting economic losses.

Figure 9 shows the impulse response following a productivity shock to small firms. There are general equilibrium effects. The shock is inflationary and reduces aggregate output, which lowers marginal costs for all firms. This allows large firms to set a lower relative price and they gain market share. Still, large firms do not cut prices as much as their costs fall and markup dispersion rises by around 20 percent. Compared to a benchmark economy where all firms are monopolistic, inflation is around 10 percent higher. This appears relatively small, but cross-price and general equilibrium effects offset – for example the fall in output (and thereby marginal costs) is smaller when firms are monopolistic. The following section looks at how firm-specific shocks affect the allocative efficiency of the economy.

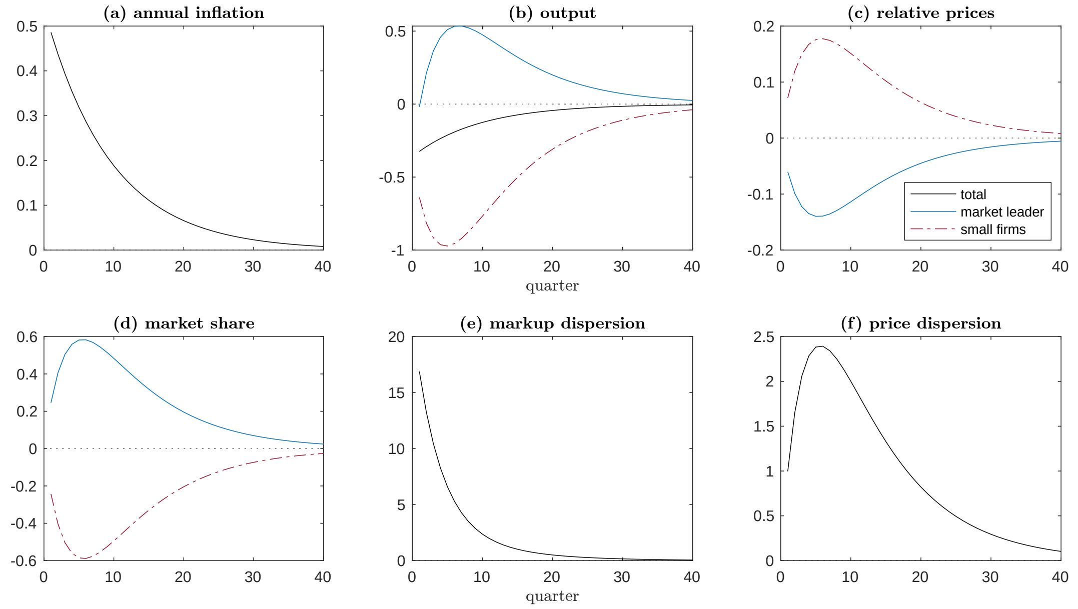
5.3.1. Measuring Allocative Efficiency

Large and small firms have different productivity levels in the steady state. Therefore, the reallocation of demand across firms following shocks affects aggregate productivity. To measure this, the change in productivity A is divided into two components:

$$(i) \quad \frac{A_t^w}{A} = e^{a_t} \qquad (ii) \quad \frac{A_t^b}{A} = \frac{y_{St} n_S \bar{a}_S + y_{Lt} n_L \bar{a}_L}{y_S n_S \bar{a}_S + y_L n_L \bar{a}_L} \qquad \text{where} \quad A = y_S n_S \bar{a}_S + y_L n_L \bar{a}_L \tag{87}$$

where A^w gives the change in productivity holding market share constant, often called the 'within' component. The change from the reallocation of market share A^b, or the 'between' component, is more interesting since it reflects differences in pricing behavior.

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

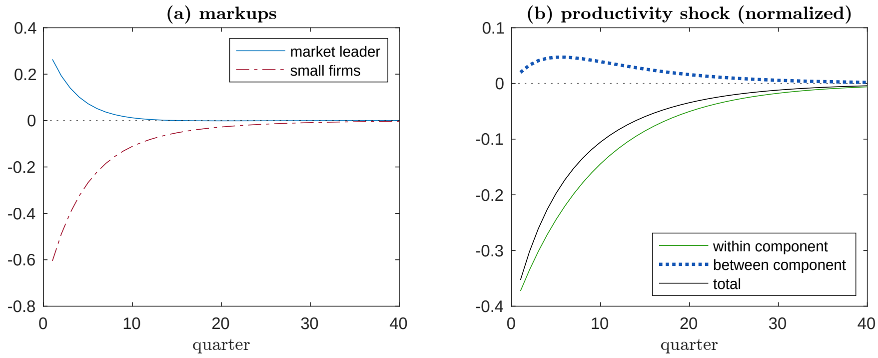


A negative 1 percent productivity shock is applied to small firms. This has general equilibrium effects and there is an increase in inflation and decline in output. Because the shock is firm-specific, there is a large impact on relative prices and market share. Large firms raise their markup and markup dispersion significantly increases. Given a positive shock to small firms, the opposite would hold.

Looking at the between component, the monetary tightening and productivity shocks from the previous sections both lead to efficiency losses. It is evident large firms lose market share in figures 5 and 6. Since they are the most efficient producers, this affects aggregate productivity – yet the effect is somewhat trivial when shocks are aggregate. The productivity shock results in a cumulative output gain of 2.9 percentage points. Reallocation to small firms lowers this by 0.1 percentage points and the total cumulative output gain is 2.8 percent. For monetary policy tightening, the cumulative output loss amounts to 3.4 percentage points of potential, mostly from the within component. Again, around 0.1 percentage points is explained by reallocation across firms. While these losses are a second-order concern, shocks may affect firms unequally. In this case, the contribution of dynamic reallocation to aggregate productivity becomes more prominent, as will be discussed.

Figure 10 gives the response of markups and aggregate productivity to a shock affecting small firms alone. General equilibrium effects are present since the shock equally impacts small firms in all industries. Reallocation to large firms partially offsets the loss from the shock and figure 10 shows how aggregate productivity evolves: Following the shock, small firms are forced to raise their prices. Due to strategic complementarity, large firms raise their prices in response and also benefit from lower costs (since output falls). The loss from the within component is 4.1 percentage points of

Figure 10: Impulse Response Given a Negative Productivity Shock to Small Firms ($\xi_0 = -1$)



A one percent productivity shock is applied to small firms. Small firms cut their markup by less than large firms when facing a comparable shock. The relative price of small firms increases and demand shifts towards large firms. This reallocation partially offsets the static losses resulting from the shock.

potential output. The between component offsets this adding 0.9 percentage point of potential output, meaning the net impact of the shock is around 3.2 percentage points. Still, this offsetting effect could be larger in a counterfactual sense. If strategic complementarity were absent, i.e. firms were purely monopolistic, the dynamic gain would be 40 percent larger: 1.5 percentage points.[48] The 0.6 percentage point difference reflects the 'cost' of market power in the model, making the shock almost 25 percent worse (= 3.2/2.6 - 1). This is one potential mechanism explaining why some firms may have earned 'excess' profits following the Covid shock.

6. Discussion of Results

6.1. Policy Implications and Further Extensions

With higher inflation, there are indications the pass-through has recently increased (Amiti et al., 2023).[49] This is consistent with the model's predictions and highlights the role of strategic complementarity in price setting. This suggests the aggregate nature of shocks is highly relevant. For example, shocks to energy prices have a high pass-through (Lafrogne-Joussier et al., 2023). Since these shocks unambiguously affect all firms, pricing complementarities are strong.[50] With rising concentration, strategic complementarity becomes relevant when shocks only affect a subset of firms.

[48]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 $n_L = 600$, $n_S = 2900$, and $n_F = 2000$. This eliminates both own-price effects and strategic complementarity since each firm's market share is negligible. Still, the gap in productivity remains.

[49]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. With higher inflation, the Phillips curve has steepened (Hobijn et al., 2023).

[50]An unexpected jump in the pass-through may have additional consequences. While the model here is completely forward-looking, inflation expectations likely have a backward-looking component.

This relates to the debate on so-called 'greedflation' – the idea large corporates exploited inflation to exercise market power (Franzoni et al., 2023; 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 or productivity shocks, which might have been the case following the Covid pandemic.[51] This is much less the case with aggregate shocks where large firms absorb cost increases to some extent.

The results also suggest large firms disproportionately benefit from monetary easing. While the change in their profit margins is somewhat lower compared to small firms, they gain market share and this increases their pricing power. The results contribute to a literature arguing low interest rates 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 affect R&D as well, allowing market leaders to pull ahead. Liu et al. (2019) argue low rates widened the gap between firms at the innovation frontier and those behind, discouraging competition and market entry.[52] The model here also suggests small firms benefit from monetary tightening. While higher interest rates may improve the competition environment, the consequences require further elaboration. A VAR analysis by 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. Such an extension would be useful and Kharroubi and Smets (2024) develop a framework along these lines.

Several further extensions appear useful as well. The analysis focuses on aggregate efficiency but not household welfare. With CES preferences, households gain utility from the presence of multiple varieties and they may prefer to allocate their income across varieties despite the efficiency costs. Heterogeneity across industries – in terms of market structure, sensitivity to cost shocks, and price adjustment frictions – could further enrich the results. Since the solution method is computationally efficient, solving a general equilibrium model with heterogeneous industries appears feasible. Finally, there is a literature looking at what price basket the central bank should target. The results in this

[51] More generally, small firms appear more exposed to shocks because they exert less buyer power in factor markets.

[52] 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.

paper suggest the optimal price basket would tilt more towards small firms since their pricing reflects underlying costs to a greater extent and because they also set the tone of competition within the economy.

6.2. Conclusion

This paper embeds an industry structure featuring strategic interaction between firms within a standard New Keynesian framework. The setup aligns with three key empirical findings: industry leaders usually control a significant share of the market; they charge higher markups; and their pricing behavior reflects some degree of strategic complementarity. There are several implications. First, rising concentration has a somewhat counter-intuitive effect. Industry leaders focus on preserving market share and limit the pass-through of idiosyncratic cost shocks, leading to greater price stability. Fluctuations are largely absorbed by profits, with the downside the markup 'tax' is relatively high. This leads to a second point. As the market share of leading firms increases, strategic complementarity strengthens. This leads to a significant increase in the cost pass-through following aggregate shocks, which may raise household inflation expectations. Third, the response of inflation to shocks depends on their aggregate nature and the strength of competition. This would explain why the pass-through for energy price shocks appears high in many estimates: an increase in energy prices unambiguously affects all firms, resulting in strong cross-price effects. Fourth, small firms may be more sensitive to cost shocks. The model helps evaluate whether strategic complementarity is economically relevant in this case. Under specific circumstances, e.g. a negative productivity shock affecting small firms more than large firms, strategic behavior may generate sizable efficiency losses, amplifying the adverse impact of the shock by around 25 percent. Firm exit and hysteresis in markups may further amplify the losses. Finally, price dynamics in the model match observed outcomes, which suggests firm heterogeneity plays an important role in explaining price dispersion.

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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.[53] 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.[54] In addition, many partnerships and S-corporations are set up as investment vehicles. Returns 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 in 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.

[53]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.

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

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 the change to 6 percentage points of GDP. Further excluding portfolio income reduces it to 4 percentage points of GDP. By this measure, accounting profits went from around 11 percent of GDP in the 1980s to 15 percent in the 2010s.[55] A shift-share decomposition indicates the majority of the change is explained by S-corporations and partnerships. It takes the following form

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

where X is total income over a time period, subdivided by type of entity i and weighted by their share of total receipts ω_i. The first component – the 'within' category – holds weights constant. The change in profitability is positive for all types of incorporation by this measure. Next, the 'between' component describes the change in weights, which is negative for C-corporations and sole proprietorships. Finally, the 'dynamic' component gives the interaction of the two components. For example, S-corporations both grew and became more profitable over time.

While large public companies are somewhat more profitable than in the past, they explain a smaller share of total activity. They accounted for more than 80 percent of activity in the 1980s and this share dropped to around 60 percent over the 2010s. S-corporation and partnerships both expanded and explain most of the overall increase in corporate profitability. Ownership of S-corporations is often highly concentrated with 2-3 owners for the median firm. This may affect patterns of investment and how profits are distributed. Many studies looking at corporate profitability over time use the 1980s as their starting point. Studies looking at longer time periods suggest this period witnessed abnormally low returns and may not serve as an appropriate benchmark.

[55] As a rule of thumb, net receipts are around 2.2x GDP. CBO data for households indicate a corresponding increase of 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 (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 records. 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.

Table 4: Corporate Profitability by Form of Incorporation, 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

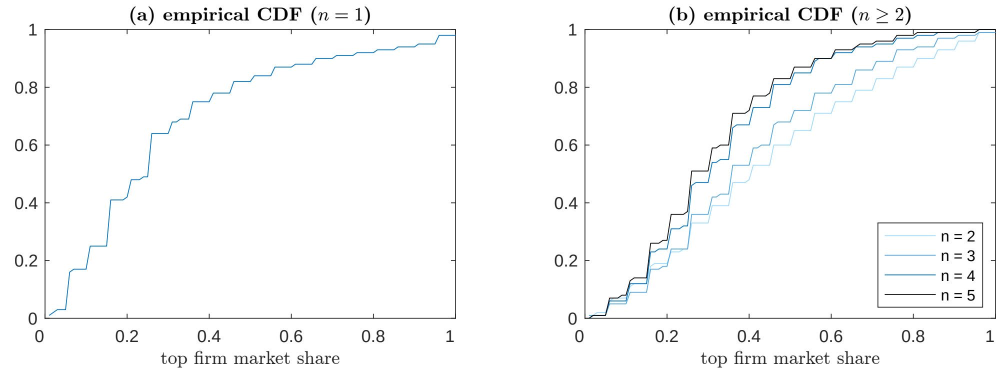
Δ Within	Between	Dynamic	Total
0.018	-0.005	0.008	0.020
0.008	-0.010	-0.002	-0.004
0.004	0.004	0.007	0.016
0.001	0.003	0.004	0.009
0.004	-0.003	-0.002	0.000

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 this 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 11 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.

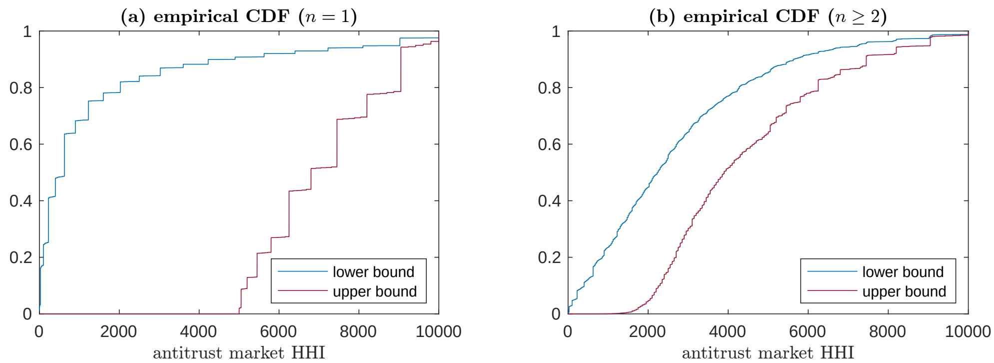
Figure 11: Cumulative Distribution of Top Market Shares Across Antitrust Markets



Source: Affeldt et al. (2018)

Affeldt et al. calculate HHIs for each market.[56] The lower bound HHI assigns a value of zero to all unattributed market share. Otherwise, it is calculated in the normal way. The upper bound for the post-merger HHI adds the square of all residual market share. In other words, the residual market share is treated as one missing competitor. The corresponding CDFs are given in figure 12.

Figure 12: Distribution of HHIs Across Antitrust Markets



Source: Affeldt et al. (2018)

In the left-hand panel of figure 12, market share is only reported for the post-merger entity and most is treated as a residual. The resulting gap between the lower and upper bound is large. The lower bound estimate in the right-hand panel is more interesting. It suggests the HHI is above 2000 in the median antitrust market, at least when multiple firms are reported.[57] This threshold is significant

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

[57]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.

since the EU guidelines on horizontal mergers flag potential competition concerns for higher levels of concentration. Furthermore, almost one-quarter of markets 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**

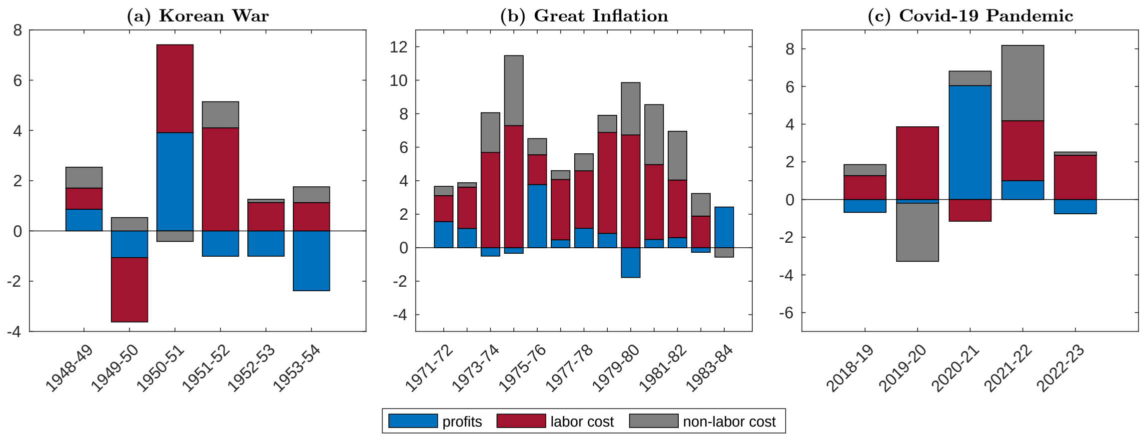
Source: Affeldt et al. (2018).

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. A Comparison of Past and Present Inflation Episodes in the United States

As commentators have pointed out, the jump in inflation following Covid shares some similarities with the inflation of the 1950s.[58] During the Second World War, the United States severely rationed consumer goods. With the outbreak of the Korean War, fears rationing would be reintroduced led US consumers to bring consumption forward. The resulting demand shock generated rapid price growth. When it became evident the scale of economic mobilization for the Korean War would be limited, inflation expectations dropped and inflation quickly normalized. With the Covid pandemic, consumer spending quickly reoriented from services to goods. At least in good producing sectors, mismatches between supply and demand allowed firms to raise prices. Unlike the Korean War episode, demand remained elevated following the Covid shock. While real household disposable income dropped strongly in 2022, households continued to draw on savings. Still, there are indications domestic price growth normalized by the end of the second quarter of 2023, dropping to 2 percent year-on-year.

Figure 13: Contribution to Price Growth Among Domestic Companies (Annual Percent Change)



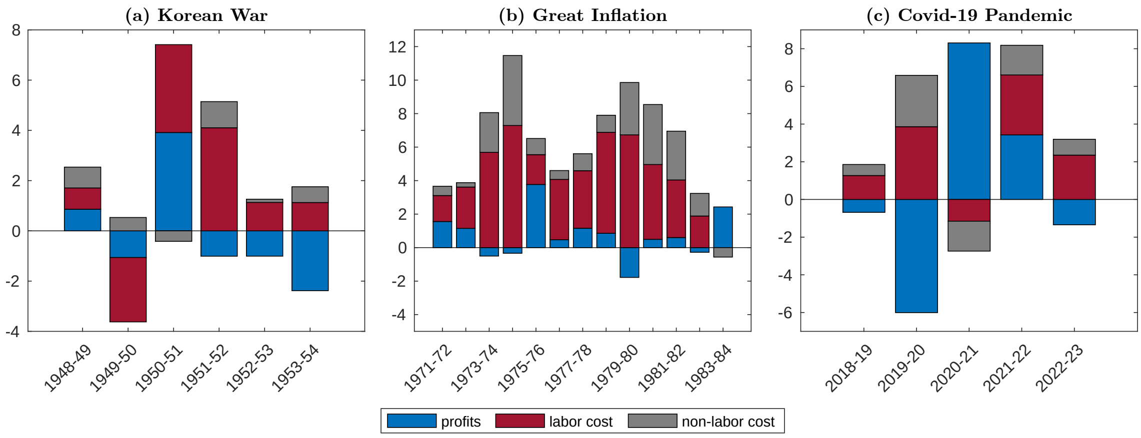
The three episodes represent the largest inflation spikes in the United States since 1950. The bars give the contribution of each component to overall price growth among domestic non-financial companies (based on NIPA table 1.15). Annual growth is measured from the end of the second quarter of each year.

Palazzo (2023) shows that government interventions and debt refinancing by firms affected the

[58] https://www.cfr.org/article/what-korean-war-era-reveals-about-feds-inflation-dilemma

reporting of profits. He proposes holding net taxes and net interest (both components of non-labor costs) constant. Using the adjustments proposed by Palazzo, profits explain around 25 percent of price growth between 2019 and 2023Q3. This remains 2x their normal contribution to price growth. Without this adjustment, profits account for 40 percent of price growth. Arguably, the unadjusted data better reflect the true contribution of profits to price growth: First, taxes and subsidies have reverted to their normal level. Second, net interest expenses show a declining trend before the Covid-19 pandemic and later realizations consistent with the trend.

Figure 14: Adjusted Price Growth Among Domestic Companies (Annual Percent Change)



The Covid-19 inflation episode is adjusted following Palazzo (2023). Non-labor costs attributed to tax and subsidies are linearly interpolated between 2019Q4 and 2022Q1 while net interest expenses are held constant at their 2019Q4 levels. In this case, profits account for around 25 percent of price growth between 2019 and 2023Q3 while non-labor costs make up 22 percent. The initial surge in inflation between 2020-21 is still explained by profits.

A.4. Nested CES Demand

A.4.1. Solving the Flexible Price Equilibrium

The method of undetermined coefficients is solved around the point where all firms are identical. As figure 15 makes clear, it is 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 their pricing behavior is non-linear.[59]

Table 6 gives the pricing rules when firms are identical. The Ω's are the same as in (42). The Υ's collect the coefficients for the firm's own marginal cost (Υ') and the marginal cost of its rival (Υ''). The difference between large and small firms in terms of pricing behavior is already apparent. Large

[59] While a higher-order Taylor approximation would be more accurate, 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 15: Comparison of Solution Methods in the Flexible Price Equilibrium

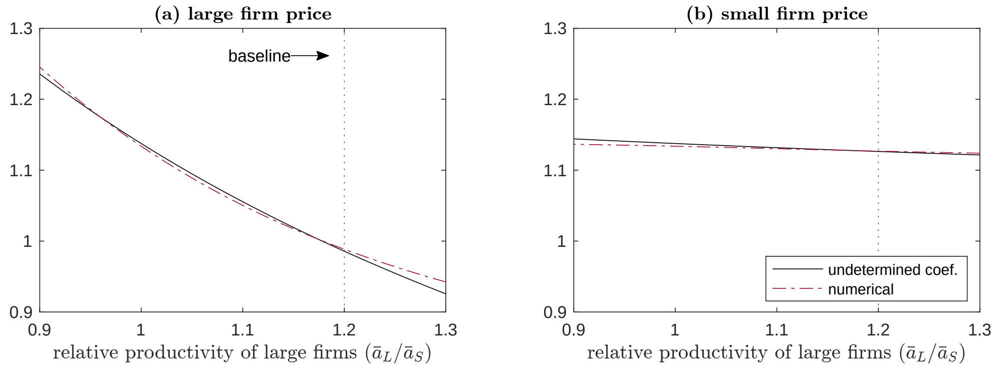


Table 6: Estimated Decision Rules at p^*

	Ω'	Ω^*	Υ'	Υ''
Large firms	-0.224	0.183	0.786	0.163
Small firms	-0.116	0.069	0.895	0.055

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.

A.4.2. Solving the Dynamic Problem

With Rotemberg adjustment costs, the profit maximization problem becomes

$$\mathbb{E}_t \sum_{k=0}^{\infty} \Lambda_{t+k} \left[\left(p_{sjt+k} - \mathcal{C}_{sjt+k}\right) y_{sjt+k} - \frac{\Theta_s}{2} \left(\pi_{t+k} \frac{p_{sjt+k}}{p_{sjt+k-1}} - 1 \right)^2 P_{t+k} Y_{t+k} \right] \tag{88}$$

The FOC with respect to p_{sjt} gives

$$\begin{aligned} 0 = p_{sjt} y_{sjt} \left[1 + \Psi^i_{st} \left(1 - \frac{\mathcal{C}_{sjt}}{p_{sjt}} \right) \right] - \Theta_s \left(\pi_t \frac{p_{sjt}}{p_{sjt-1}} - 1 \right) \pi_t \frac{p_{sjt}}{p_{sjt-1}} Y_t \ldots \\ + \beta \Theta_s \mathbb{E}_t \left[\frac{C_t}{C_{t+1}} \left(\pi_{t+1} \frac{p_{sjt+1}}{p_{sjt}} - 1 \right) \pi_{t+1} \frac{p_{sjt+1}}{p_{sjt}} Y_{t+1} \right] \end{aligned} \tag{89}$$

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

A.4.2.1 Identical Firms

Using (15) and noting that

$$p_{jt} = n^{\frac{1}{1-\varphi}} p_{sjt} \tag{90}$$

where the solution for p_{sjt} is given by (36). The FOC of the pricing equation (44) becomes

$$0 = p_{st}^{1-\varphi} p_{jt}^{\varphi-\sigma} Y_t \left[1 + \left(\frac{\varphi - \sigma}{n} - \varphi\right)\left(1 - \frac{\mathcal{C}_{st}}{p_{st}}\right)\right] - \frac{\Theta}{n}\left(\pi_t \frac{p_{st}}{p_{st-1}} - 1\right)\pi_t \frac{p_{st}}{p_{st-1}} Y_t \ldots \tag{91}$$

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

$$= n^{\frac{\varphi-\sigma}{1-\varphi}} p_s^{1-\sigma}\left[1 + \left(\frac{\varphi-\sigma}{n} - \varphi\right)\left(1 - \frac{\mathcal{C}_{st}}{p_{st}}\right)\right] - \frac{\Theta}{n}\left(\pi_t - 1\right)\pi_t + \frac{\beta\Theta}{n}\mathbb{E}_t\left[\Lambda_{t+1}\left(\pi_{t+1} - 1\right)\pi_{t+1}\right] \tag{92}$$

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

$$0 = n^{\frac{\varphi-\sigma}{1-\varphi}} p_s^{1-\sigma}\left(\varphi - \frac{\varphi-\sigma}{n}\right)\frac{\mathcal{C}_s}{p_s}\tilde{\mathcal{C}}_{st} - \frac{\Theta}{n}\tilde{\pi}_t + \frac{\beta\Theta}{n}\tilde{\pi}_{t+1} \quad \text{where} \quad p_s = \frac{(n-1)\varphi + \sigma}{(n-1)\varphi + \sigma - n}\mathcal{C}_s \tag{93}$$

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

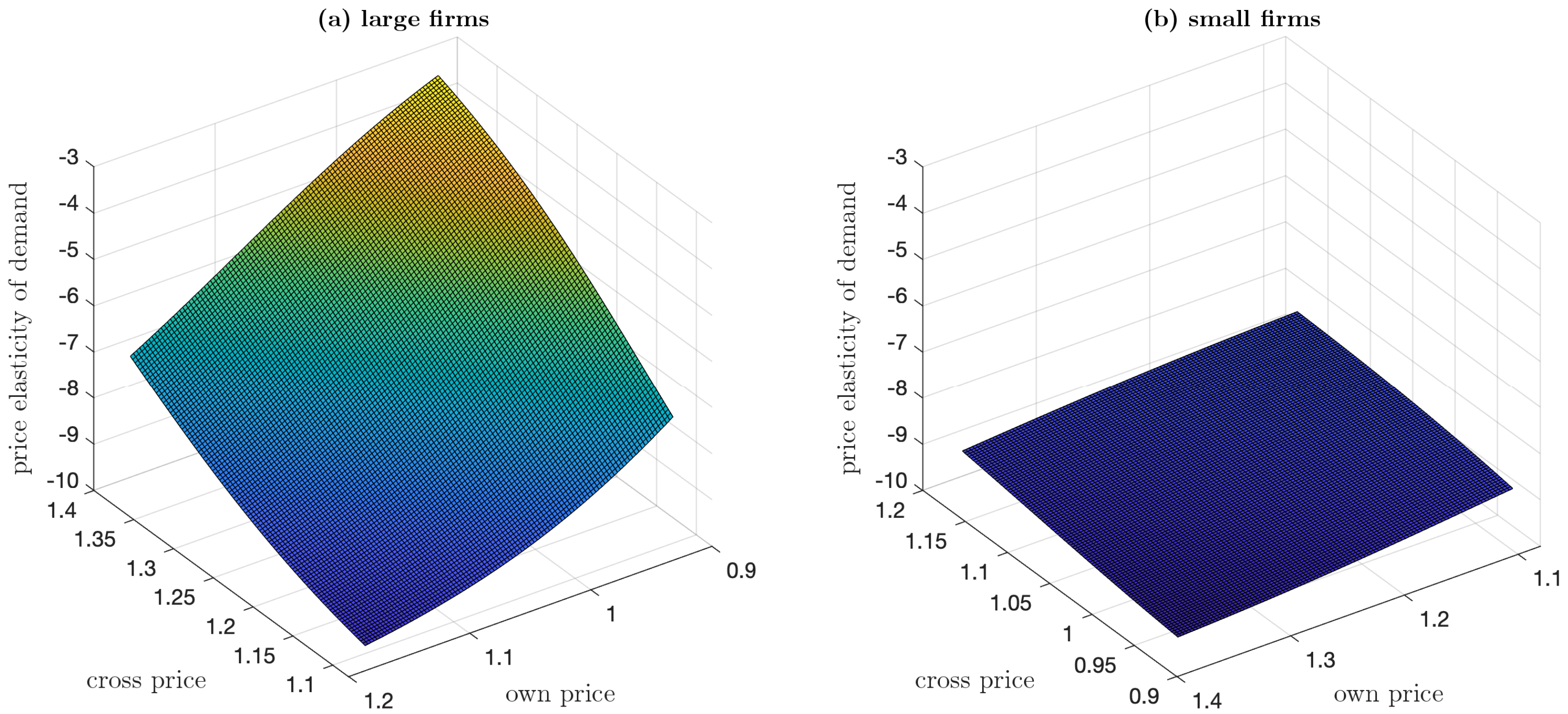
$$\Gamma^y = \frac{\Theta(1-\rho_m\beta)/n}{n^{\frac{\varphi-\sigma}{1-\varphi}} p_s^{1-\sigma}\left(\varphi - (\varphi-\sigma)/n\right)\mathcal{C}_s/p_s}\Gamma^\pi \tag{94}$$

where (66) gives the second equation. The elasticity of inflation to the productivity shock is similarly

$$\Omega^y = \frac{\Theta(1-\rho_m\beta)/n}{n^{\frac{\varphi-\sigma}{1-\varphi}} p_s^{1-\sigma}\left(\varphi - (\varphi-\sigma)/n\right)\mathcal{C}_s/p_s}\Omega^\pi + 1 \tag{95}$$

where (83) gives the second equation needed to solve the system.

Figure 16: The Price Elasticity of Demand Across Relative Prices



Each surface displays the price elasticity of demand for large and small firms across combinations or own and rival prices. 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 to own- or cross-price effects.

A.4.2.2 Asymmetric Firms

The FOC with respect to p_{st}^i gives

$$
\begin{aligned}
0 = p_{st}^i y_{st}^i &\left[1 + \left((\varphi - \sigma)\left(\frac{p_{st}^i}{p_{jt}}\right)^{1-\varphi} - \varphi\right)\left(1 - \frac{\mathcal{C}_{st}^i}{p_{st}^i}\right)\right] \dots \\
&- \Theta_s\left(\pi_t \frac{p_{st}^i}{p_{st-1}^i} - 1\right)\pi_t \frac{p_{st}^i}{p_{st-1}^i} Y_t + \beta\Theta_s \mathbb{E}_t\left[\frac{C_t}{C_{t+1}}\left(\pi_{t+1}\frac{p_{st+1}^i}{p_{st}^i} - 1\right)\pi_{t+1}\frac{p_{st+1}^i}{p_{st}^i} Y_{t+1}\right]
\end{aligned}
\tag{96}
$$

Using (15) and dividing through by Y_t this becomes

$$
\begin{aligned}
0 = (p_{st}^i)^{1-\varphi} p_{jt}^{\varphi-\sigma} &\left[1 + \Psi_{st}^i\left(1 - \frac{\mathcal{C}_{st}^i}{p_{st}^i}\right)\right] - \Theta_s\left(\pi_t \frac{p_{st}^i}{p_{st-1}^i} - 1\right)\pi_t \frac{p_{st}^i}{p_{st-1}^i} \dots \\
&+ \beta\Theta_s \mathbb{E}_t\left[\left(\pi_{t+1}\frac{p_{st+1}^i}{p_{st}^i} - 1\right)\pi_{t+1}\frac{p_{st+1}^i}{p_{st}^i}\right]
\end{aligned}
\tag{97}
$$

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

$$
\begin{aligned}
0 = {} & (1-\varphi)(p_s^i)^{-\varphi} p_j^{\varphi-\sigma}\left[1 + \Psi_s^i\left(1 - \frac{\mathcal{C}_s^i}{p_s^i}\right)\right]\tilde{p}_s^i \dots \\
&+ (\varphi-\sigma)(p_s^i)^{1-\varphi} p_j^{2\varphi-\sigma-1}\left[1 + \Psi_s^i\left(1 - \frac{\mathcal{C}_s^i}{p_s^i}\right)\right]\left[n_s (p_s^i)^{-\varphi}\tilde{p}_{st}^i + n_{-s}(p_{-s}^{-i})^{-\varphi}\tilde{p}_{-st}^{-i} + p_F^{-\varphi}\tilde{p}_{Ft}\right] \dots \\
&+ (p_s^i)^{1-\varphi} p_j^{\varphi-\sigma}\left[\left(1 - \frac{\mathcal{C}_j^i}{p_s^i}\right)\left[\frac{\Psi_s^{i,i} + \Psi_s'^{\,i,-i}}{p_s^i}\tilde{p}_{st}^i + \frac{\Psi_s''^{\,i,-i}}{p_{-s}^{-i}}\tilde{p}_{-st}^{-i} + \frac{\Psi_{st}'''^{\,i,-i}}{p_{Ft}}\tilde{p}_{Ft}\right] - \Psi_s^i \frac{\mathcal{C}_j^i}{p_s^i}(\widetilde{\mathcal{C}}_{st}^i - \tilde{p}_{st}^i)\right] \dots \\
&- \Theta_s(\tilde{\pi}_t^i + \tilde{p}_{st}^i - \tilde{p}_{st-1}^i) + \beta\Theta_s\mathbb{E}_t\left[\tilde{\pi}_{t+1}^i + \tilde{p}_{st+1}^i - \tilde{p}_{st}^i\right]
\end{aligned}
\tag{98}
$$

In the steady state

$$
\Psi_s^i = -\left(1 - \frac{\mathcal{C}_s^i}{p_s^i}\right)^{-1} \quad \Longrightarrow \quad 1 + \Psi_s^i\left(1 - \frac{\mathcal{C}_s^i}{p_s^i}\right) = 0
\tag{99}
$$

so the first two terms of (98) can be ignored

$$0 = (p_s^i)^{1-\varphi} p_j^{\varphi-\sigma} \left[\left(1 - \frac{\mathcal{C}_j^i}{p_s^i}\right) \left[\frac{\Psi_s^{i,i} + \Psi_s^{\prime\, i,\text{-}i}}{p_s^i} \tilde{p}_{st}^i + \frac{\Psi_s^{\prime\prime\, i,\text{-}i}}{p_{\text{-}s}^{\text{-}i}} \tilde{p}_{\text{-}st}^{\text{-}i} + \frac{\Psi_{st}^{\prime\prime\prime\, i,\text{-}i}}{p_{Ft}} \tilde{p}_{Ft} \right] - \Psi_s^i \frac{\mathcal{C}_j^i}{p_s^i} (\widetilde{\mathcal{C}}_{st}^i - \tilde{p}_{st}^i) \right] \dots$$
$$- \Theta_s(\tilde{\pi}_t^i + \tilde{p}_{st}^i - \tilde{p}_{st-1}^i) + \beta \Theta_s \mathbb{E}_t \left[\tilde{\pi}_{t+1}^i + \tilde{p}_{st+1}^i - \tilde{p}_{st}^i \right] \tag{100}$$

Expression 100 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

$$\tilde{p}_{st}^i = \Upsilon_s \, \tilde{p}_{st-1}^i + \Upsilon_s^* \, \tilde{p}_{\text{-}st-1}^{\text{-}i} + \Upsilon_s^{\prime} \, \widetilde{\mathcal{C}}_{st}^i + \Upsilon_s^{\prime\prime} \, \widetilde{\mathcal{C}}_{\text{-}st}^{\text{-}i} + \Upsilon_s^F \, \tilde{p}_{Ft} + \Upsilon_s^{\pi} \, \tilde{\pi}_t \tag{101}$$

Rival firms follow

$$\tilde{p}_{\text{-}st}^{\text{-}i} = \Upsilon_{\text{-}s} \, \tilde{p}_{\text{-}st-1}^{\text{-}i} + \Upsilon_{\text{-}s}^* \, \tilde{p}_{st-1}^i + \Upsilon_{\text{-}s}^{\prime} \, \widetilde{\mathcal{C}}_{\text{-}st}^{\text{-}i} + \Upsilon_{\text{-}s}^{\prime\prime} \, \widetilde{\mathcal{C}}_{\text{-}st}^i + \Upsilon_{\text{-}s}^F \tilde{p}_{Ft} + \Upsilon_{\text{-}s}^{\pi} \tilde{\pi}_t \tag{102}$$

Given some shock, expected prices in the next period are

$$\mathbb{E}_t \left[\tilde{p}_{st+1}^i \right] = \Upsilon_s \, \tilde{p}_{st}^i + \Upsilon_s^* (\Upsilon_{\text{-}s} \, \tilde{p}_{\text{-}st-1}^{\text{-}i} + \Upsilon_{\text{-}s}^* \, \tilde{p}_{st-1}^i + \Upsilon_{\text{-}s}^{\prime} \, \widetilde{\mathcal{C}}_{\text{-}st}^{\text{-}i} + \Upsilon_{\text{-}s}^{\prime\prime} \, \widetilde{\mathcal{C}}_{st}^i + \Upsilon_{\text{-}s}^F \tilde{p}_{Ft} + \Upsilon_{\text{-}s}^{\pi} \tilde{\pi}_t) \dots$$
$$+ \rho \left[\Upsilon_s^{\prime} \, \widetilde{\mathcal{C}}_{st}^i + \Upsilon_s^{\prime\prime} \, \widetilde{\mathcal{C}}_{\text{-}st}^{\text{-}i} + \Upsilon_s^F \, \tilde{p}_{Ft} + \Upsilon_s^{\pi} \, \tilde{\pi}_t \right] \tag{103}$$

where ρ is the persistence of the shock. This suggests

$$\Upsilon_s = \frac{(\psi_s + \beta \Theta_s \Upsilon_s^*) \Upsilon_{\text{-}s}^* + \Theta_s}{\kappa_s - \beta \Theta_s \Upsilon_s} \tag{104}$$

$$\Upsilon_s^* = \frac{(\psi_s + \beta \Theta_s \Upsilon_s^*) \Upsilon_{\text{-}s}}{\kappa_s - \beta \Theta_s \Upsilon_s} \tag{105}$$

$$\Upsilon_s^{\prime} = \frac{(\psi_s + \beta \Theta_s \Upsilon_s^*) \Upsilon_{\text{-}s}^{\prime\prime} - (p_s^i)^{-\varphi} p_j^{\varphi-\sigma} \Psi_s^i \mathcal{C}_s^i}{\kappa_s - \beta \Theta_s (\Upsilon_s + \rho)} \tag{106}$$

$$\Upsilon_s^{\prime\prime} = \frac{(\psi_s + \beta \Theta_s \Upsilon_s^*) \Upsilon_{\text{-}s}^{\prime}}{\kappa_s - \beta \Theta_s (\Upsilon_s + \rho)} \tag{107}$$

$$\Upsilon_s^F = \frac{(\psi_s + \beta \Theta_s \Upsilon_s^*) \Upsilon_{\text{-}s}^F + \omega_s}{\kappa_s - \beta \Theta_s (\Upsilon_s + \rho)} \tag{108}$$

$$\Upsilon_s^{\pi} = \frac{(\psi_s + \beta \Theta_s \Upsilon_s^*) \Upsilon_{\text{-}s}^{\pi} - \Theta_s (1 - \rho \beta)}{\kappa_s - \beta \Theta_s (\Upsilon_s + \rho)} \tag{109}$$

where

$$\kappa_s = \Theta_s + \beta\Theta_s - (p_s^i)^{1-\varphi} p_j^{\varphi-\sigma} \left[\left(1 - \frac{\mathcal{C}_s}{p_s^i}\right) \frac{\Psi^{i,i} + \Psi_s'^{\,i,-i}}{p_s^i} + \Psi^i \frac{\mathcal{C}_s}{p_s^i} \right] \tag{110}$$

$$\psi_s = (p_s^i)^{1-\varphi} p_j^{\varphi-\sigma} \left(1 - \frac{\mathcal{C}_s}{p_s^i}\right) \frac{\Psi_s''^{\,i,-i}}{p_{-s}^{-i}} \tag{111}$$

$$\omega_s = (p_s^i)^{1-\varphi} p_j^{\varphi-\sigma} \left(1 - \frac{\mathcal{C}_s}{p_s^i}\right) \frac{\Psi_s'''^{\,i,-i}}{p_F} \tag{112}$$

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

$$\tilde{x}_{st}^i = \frac{\Psi_s^{i,i} + \Psi_s'^{\,i,-i}}{(\varphi-\sigma) p_s^i} \tilde{p}_{st}^i + \frac{\Psi_s''^{\,i,-i}}{(\varphi-\sigma) p_{-s}^{-i}} \tilde{p}_{-st}^{-i} + \frac{\Psi_s'''^{\,i,-i}}{(\varphi-\sigma) p_F} \tilde{p}_{Ft} \tag{113}$$

Output for each firm is equal to

$$\tilde{y}_{st}^i = \tilde{x}_{st}^i + \widetilde{Y}_t + \widetilde{P}_t - \tilde{p}_{st}^i \tag{114}$$

Table 7: Estimated Decision Rules (Baseline Calibration)

	Υ	Υ^*	Υ'	Υ''	Υ^F	Υ^π
Large firms	0.768	0.020	0.104	0.013	0.020	-0.287
Small firms	0.773	0.005	0.157	0.002	0.005	-0.278

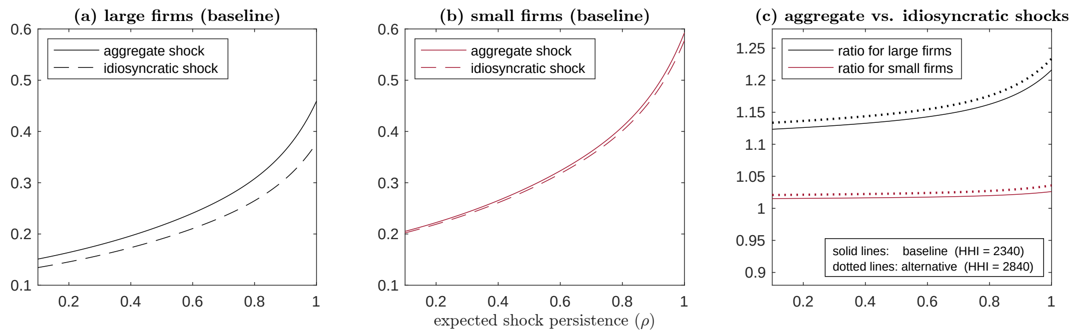
A.4.3. The Pass-Through of Cost Shocks

The pass-through is measured over the first eight periods of the shock

$$\mathcal{P} = \frac{\sum_{t=1}^{t=8} \tilde{p}_{st}^i}{\sum_{t=1}^{t=8} \widetilde{\mathcal{C}}_{st}^i}$$

Compared to the estimates presented in figure 4, this change in the time horizon significantly lowers the observed pass-through. The difference between the aggregate and idiosyncratic regimes remains similar as shown in the right-hand panel of figure 17.

Figure 17: The Pass-Through of Cost Shocks (Two Year Horizon)



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) in the right-hand panel modifies the baseline so that $\bar{a}_L = 0.89$. This increases the market share of the leading firm to 43 percent and significantly lowers the pass-through of idiosyncratic shocks.

A.5. Aggregate Shocks with Asymmetric Firms

A.5.1. Monetary Policy Shock

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

$$\widetilde{Y}_t = \Gamma^y m_t \tag{115}$$

$$\tilde{\pi}_t = \Gamma^\pi m_t \tag{116}$$

The decision rule for each firm can be written

$$\widetilde{P}_{st} - \widetilde{P}_t = \Upsilon_s^\pi \Gamma^\pi m_t + \Upsilon_s \left(\widetilde{P}_{st-1} - \widetilde{P}_{t-1}\right) + \Upsilon_s^* \left(\widetilde{P}_{\text{-}st-1} - \widetilde{P}_{t-1}\right) + \left(\Upsilon_s' + \Upsilon_s''\right)(1-\alpha)\Gamma^y m_t \tag{117}$$

The log-linearized price index is

$$\widetilde{P}_t = \frac{n_s (P_s)^{-\varphi} \widetilde{P}_{st} + n_{\text{-}s} (P_{\text{-}s})^{-\varphi} \widetilde{P}_{\text{-}st} + (P_F)^{-\varphi} \widetilde{P}_{Ft}}{P^{-\varphi}} \tag{118}$$

while (66) 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

$$\Gamma^\pi = \frac{\widetilde{P}_t - \widetilde{P}_{t-1}}{m_t} \tag{119}$$

the decision rule can be restated as

$$\widetilde{P}_{st} - \widetilde{P}_t - \Upsilon_s(\widetilde{P}_{st-1} - \widetilde{P}_{t-1}) - \Upsilon_s^*(\widetilde{P}_{\text{-}st-1} - \widetilde{P}_{t-1}) = \left[\Upsilon_s^\pi \Gamma^\pi + (\Upsilon_s' + \Upsilon_s'')(1-\alpha)\Gamma^y\right] m_t \tag{120}$$

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

$$\frac{\widetilde{P}_{st} - \widetilde{P}_t}{m_t} = \Gamma_s^m \quad \text{where} \quad \Gamma_s^m = \Upsilon_s^\pi \Gamma^\pi + (\Upsilon_s' + \Upsilon_s'')(1-\alpha)\Gamma^y \tag{121}$$

Recognizing the recursive nature of the problem

$$\mathbb{E}_t\left[\frac{\widetilde{P}_{st+1} - \widetilde{P}_{t+1}}{m_t}\right] = \Upsilon_s \Gamma_s^m + \rho_m \Gamma_s^m + \Upsilon_s^* \Gamma_{\text{-}s}^m \tag{122}$$

This implies

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

Using (119)

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

Accordingly, the following identity and (66) jointly determine Γ^π and Γ^y along with (119) and (124) and the definition of Γ_i^m

$$\mathbb{E}_t\left[\widetilde{P}_{t+1}\right] - \widetilde{P}_t = \mathbb{E}_t\left[\frac{n_s(P_s)^{-\varphi}(\widetilde{P}_{st+1} - \widetilde{P}_{st}) + n_{\text{-}s}(P_{\text{-}s})^{-\varphi}(\widetilde{P}_{\text{-}st+1} - \widetilde{P}_{\text{-}st})}{P^{-\varphi} - (P_F)^{-\varphi}}\right] \tag{125}$$

A.5.2. *Demand Shock*

The solution is the same as the monetary policy shock. The aggregate demand relation is given by (80). Aggregate supply is

$$\rho_d \Phi^{\pi} m_t = \mathbb{E}_t \left[\frac{n_s (P_s)^{-\varphi} (\widetilde{P}_{st+1} - \widetilde{P}_{st}) + n_{\text{-}s} (P_{\text{-}s})^{-\varphi} (\widetilde{P}_{\text{-}st+1} - \widetilde{P}_{\text{-}st})}{P^{-\varphi} - (P_F)^{-\varphi}} \right] \tag{126}$$

where

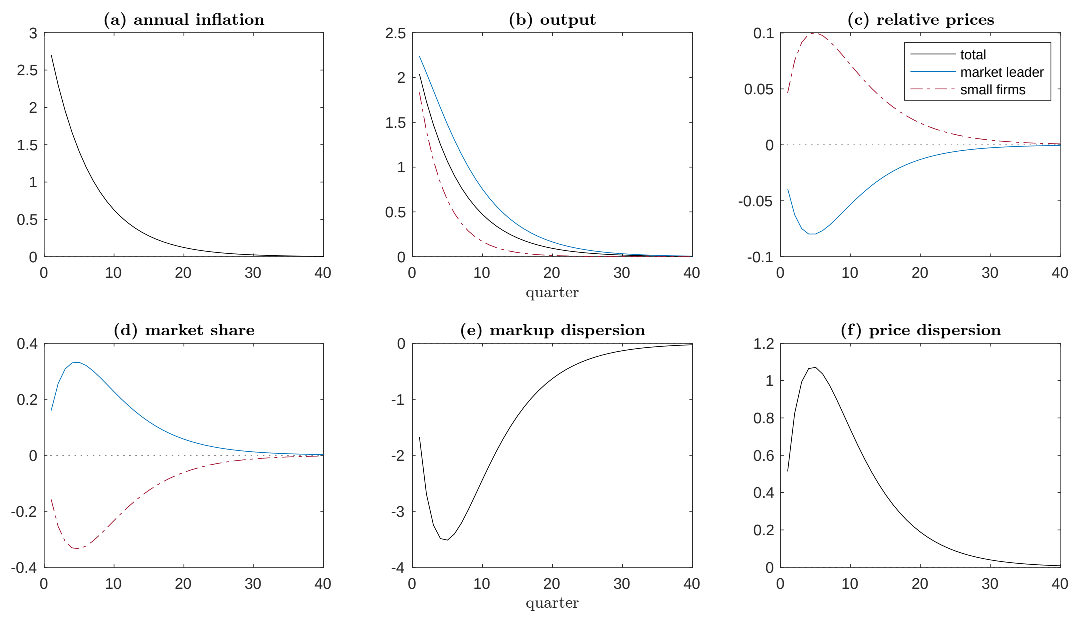
$$\mathbb{E}_t \left[\widetilde{P}_{st+1} \right] - \widetilde{P}_{st} = \left[\rho_d \Phi^{\pi} + (\Upsilon_s + \rho_d - 1) \Phi^d_s + \Upsilon^*_s \Phi^d_{\text{-}s} \right] d_t \tag{127}$$

and

$$\Phi^d_s = \Upsilon^{\pi}_s \Phi^{\pi} + (\Upsilon'_s + \Upsilon''_s)(1 - \alpha) \Phi^y \tag{128}$$

As with the monetary policy shock, this equation and (80) reduce the system to two equations and two unknowns: Φ^{π} and Φ^{y}.

Figure 18: Baseline Impulse Response to a Positive Demand Shock ($\eta_0 = 1$)



Source:

A.5.3. Aggregate Productivity Shock

The decision rule for each firm can be written in terms of the price level

$$\widetilde{P}_{st} - \widetilde{P}_t = \Upsilon_s^{\pi}\,\Omega^{\pi} a_t + \Upsilon_s\left(\widetilde{P}_{st-1} - \widetilde{P}_{t-1}\right) + \Upsilon_s^{*}\left(\widetilde{P}_{\text{-}st-1} - \widetilde{P}_{t-1}\right) + \left(\Upsilon_s' + \Upsilon_s''\right)\left((1-\alpha)\Omega^{y} - 1\right)a_t \tag{129}$$

where

$$\Omega^{\pi} = \frac{\widetilde{P}_t - \widetilde{P}_{t-1}}{a_t} \tag{130}$$

The decision rule can be restated as

$$\widetilde{P}_{st} - \widetilde{P}_t - \Upsilon_i(\widetilde{P}_{st-1} - \widetilde{P}_{t-1}) - \Upsilon_s^{*}(\widetilde{P}_{\text{-}st-1} - \widetilde{P}_{t-1}) = \left[\Upsilon_s^{\pi}\Omega^{\pi} + (\Upsilon_s' + \Upsilon_s'')((1-\alpha)\Omega^{y} - 1)\right] a_t \tag{131}$$

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

$$\frac{\widetilde{P}_{st} - \widetilde{P}_t}{a_t} = \Omega_s^{a} \quad \text{where} \quad \Omega_s^{a} = \Upsilon_s^{\pi}\Omega^{\pi} + (\Upsilon_s' + \Upsilon_s'')((1-\alpha)\Omega^{y} - 1) \tag{132}$$

Solving recursively

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

This implies

$$\mathbb{E}_t\left[\frac{\widetilde{P}_{st+1} - \widetilde{P}_{st}}{a_t}\right] = \mathbb{E}_t\left[\frac{\widetilde{P}_{t+1} - \widetilde{P}_{t}}{a_t}\right] + (\Upsilon_s + \rho_a - 1)\Omega_s^{a} + \Upsilon_s^{*}\Omega_{\text{-}s}^{a} \tag{134}$$

Using (130)

$$\mathbb{E}_t\left[\widetilde{P}_{st+1}\right] - \widetilde{P}_{st} = \left[\rho_a\,\Omega^{\pi} + (\Upsilon_s + \rho_a - 1)\Omega_s^{a} + \Upsilon_s^{*}\Omega_{\text{-}s}^{a}\right] a_t \tag{135}$$

Finally, Ω^{π} solves the following identity (using expressions 83, 130, and 135 and the definitions of Ω_s^a above)

$$\mathbb{E}_t\left[\widetilde{P}_{t+1}\right]-\widetilde{P}_t=\mathbb{E}_t\left[\frac{n_s(P_s)^{-\varphi}(\widetilde{P}_{st+1}-\widetilde{P}_{st})+n_{\text{-}s}(P_{\text{-}s})^{-\varphi}(\widetilde{P}_{\text{-}st+1}-\widetilde{P}_{\text{-}st})}{P^{-\varphi}-(P_F)^{-\varphi}}\right] \tag{136}$$

A.5.4. Import Price Shock

The elasticities of output and domestic/imported inflation to the foreign price shock are

$$(i)\quad \tilde{\pi}_t^d=\Theta^d\tilde{p}_{Ft}\qquad (ii)\quad \tilde{\pi}_t^f=\Theta^f\tilde{p}_{Ft}\qquad (iii)\quad \widetilde{Y}_t=\Theta^y\tilde{p}_{Ft} \tag{137}$$

Noting

$$\tilde{\pi}_t\approx\left[1-\left(\frac{P_F}{P}\right)^{1-\varphi}\right]\tilde{\pi}_t^d+\left(\frac{P_F}{P}\right)^{1-\varphi}\tilde{\pi}_t^f\quad\Longrightarrow\quad\Theta^{\pi}\approx\left[1-\left(\frac{P_F}{P}\right)^{1-\varphi}\right]\Theta^d+\left(\frac{P_F}{P}\right)^{1-\varphi}\Theta^f \tag{138}$$

Putting foreign inflation in terms of relative prices

$$\tilde{p}_{Ft}-\tilde{p}_{Ft-1}=\tilde{\pi}_t^f-\tilde{\pi}_t\quad\Longrightarrow\quad\tilde{p}_{Ft}-\tilde{p}_{Ft-1}\approx\left[1-\left(\frac{P_F}{P}\right)^{1-\varphi}\right]\left(\tilde{\pi}_t^f-\tilde{\pi}_t^d\right) \tag{139}$$

$$\Longrightarrow\quad\tilde{p}_{Ft}-\tilde{p}_{Ft-1}\approx\left[1-\left(\frac{P_F}{P}\right)^{1-\varphi}\right]\left(\tilde{\pi}_t^f-\Theta^d\tilde{p}_{Ft}\right) \tag{140}$$

Rearranging terms

$$\begin{aligned}
\tilde{p}_{Ft}-\tilde{p}_{Ft-1}&\approx\left(1+\Theta^d\left[1-\left(\frac{P_F}{P}\right)^{1-\varphi}\right]\right)^{-1}\left(\left[1-\left(\frac{P_F}{P}\right)^{1-\varphi}\right]\tilde{\pi}_t^f-\left[1-\left(\frac{P_F}{P}\right)^{1-\varphi}\right]\Theta^d\tilde{p}_{Ft-1}\right)\\
&\approx\left(1+\Theta^d\left[1-\left(\frac{P_F}{P}\right)^{1-\varphi}\right]\right)^{-1}\left(\tilde{\pi}_t^f-\tilde{\pi}_{t-1}-\left(\frac{P_F}{P}\right)^{1-\varphi}\left(\tilde{\pi}_t^f-\tilde{\pi}_{t-1}^f\right)\right)\\
&\approx\left(\Theta^d\left[1-\left(\frac{P_F}{P}\right)^{1-\varphi}\right]\right)^{-1}\left(\tilde{\pi}_t-\tilde{\pi}_{t-1}-\left(\frac{P_F}{P}\right)^{1-\varphi}\left(\tilde{\pi}_t^f-\tilde{\pi}_{t-1}^f\right)\right)\\
&\approx\frac{1}{\Theta^d}\left(\tilde{\pi}_t^d-\tilde{\pi}_{t-1}^d\right)
\end{aligned}$$

$$\implies \Theta^d \approx 1 \tag{141}$$

Using (138)

$$\Theta^\pi \approx 1 - \left(\frac{P_F}{P}\right)^{1-\varphi} + \left(\frac{P_F}{P}\right)^{1-\varphi} \Theta^f \tag{142}$$

The shock is set so that

$$\mathbb{E}_t \left[\tilde{p}_{Ft+1}\right] = \rho_f \tilde{p}_{Ft} \tag{143}$$

The decision rule for each firm can be written

$$\widetilde{P}_{st} - \widetilde{P}_t = \Upsilon_s^\pi \Theta^\pi \tilde{p}_{Ft} + \Upsilon_s \left(\widetilde{P}_{st-1} - \widetilde{P}_{t-1}\right) + \Upsilon_s^* \left(\widetilde{P}_{\text{-}st-1} - \widetilde{P}_{t-1}\right) + (\Upsilon_s' + \Upsilon_s'')(1-\alpha)\Theta^y \tilde{p}_{Ft} + \Upsilon_s^F \tilde{p}_{Ft}$$

where

$$\Theta^\pi = \frac{\widetilde{P}_t - \widetilde{P}_{t-1}}{\tilde{p}_{Ft}} \tag{144}$$

The decision rule can be restated as

$$\widetilde{P}_{st} - \widetilde{P}_t - \Upsilon_i(\widetilde{P}_{st-1} - \widetilde{P}_{t-1}) - \Upsilon_s^*(\widetilde{P}_{\text{-}st-1} - \widetilde{P}_{t-1}) = \left[\Upsilon_s^\pi \Theta^\pi + (\Upsilon_s' + \Upsilon_s'')(1-\alpha)\Theta^y + \Upsilon_s^F\right] \tilde{p}_{Ft} \tag{145}$$

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

$$\frac{\widetilde{P}_{st} - \widetilde{P}_t}{\tilde{p}_{Ft}} = \Theta_s^* \quad \text{where} \quad \Theta_s^* = \Upsilon_s^\pi \Theta^\pi + (\Upsilon_s' + \Upsilon_s'')(1-\alpha)\Theta^y + \Upsilon_s^F \tag{146}$$

Solving recursively

$$\mathbb{E}_t \left[\frac{\widetilde{P}_{st+1} - \widetilde{P}_{t+1}}{\tilde{p}_{Ft}}\right] = (\Upsilon_s + \rho_f)\Theta_s^* + \Upsilon_s^* \Theta_{\text{-}s}^* \tag{147}$$

Subtracting (146) from both sides

$$\mathbb{E}_t\left[\frac{\widetilde{P}_{st+1}-\widetilde{P}_{st}}{\tilde{p}_{Ft}}\right]=\mathbb{E}_t\left[\frac{\widetilde{P}_{t+1}-\widetilde{P}_t}{\tilde{p}_{Ft}}\right]+(\Upsilon_s+\rho_f-1)\Theta_s^*+\Upsilon_s^*\Theta_{-s}^* \tag{148}$$

Using (144)

$$\mathbb{E}_t\left[\widetilde{P}_{st+1}\right]-\widetilde{P}_{st}=\left[\rho_f\,\Theta^\pi+(\Upsilon_s+\rho_f-1)\Theta_s^*+\Upsilon_s^*\Theta_{-s}^*\right]\tilde{p}_{Ft} \tag{149}$$

The change in domestic inflation is

$$\mathbb{E}_t\left[\tilde{\pi}_{t+1}\right]=\mathbb{E}_t\left[\frac{n_s(P_s)^{-\varphi}(\widetilde{P}_{st+1}-\widetilde{P}_{st})+n_{-s}(P_{-s})^{-\varphi}(\widetilde{P}_{-st+1}-\widetilde{P}_{-st})+(P_F)^{-\varphi}\,\tilde{\pi}^f_{t+1}}{P^{-\varphi}}\right] \tag{150}$$

As before, Θ^π solves this identity (using expressions 144 and 149 and the definitions of Θ_s^* above) where

$$\Theta^y=\frac{(\rho_f-\phi_\pi)\Theta^\pi}{1+\phi_y-\rho_f} \tag{151}$$

A.6. Firm-Specific Shocks

A.6.1. Productivity of Small Firms

First, take that productivity shocks are different across firms

$$\mathcal{C}_{st}=\frac{1}{e^{a_{st}}\bar{a}_s}\left(\frac{w_t}{1-\alpha}\right)^{1-\alpha} \tag{152}$$

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

$$a_{St}=\rho_a a_{St-1}+\xi_t \tag{153}$$

Accordingly, the prices of small firms are given by

$$\widetilde{P}_{St} - \widetilde{P}_t = \Upsilon_L^{\pi}\,\Omega^{\pi} a_{St} + \Upsilon_S\,(\widetilde{P}_{St-1} - \widetilde{P}_{t-1}) + \Upsilon_S^{*}\,(\widetilde{P}_{Lt-1} - \widetilde{P}_{t-1}) + \Upsilon_S'(\Omega^{y} a_{St} - a_{St}) + \Upsilon_S''\Omega^{y} a_{St} \tag{154}$$

while for large firms

$$\widetilde{P}_{Lt} - \widetilde{P}_t = \Upsilon_S^{\pi}\,\Omega^{\pi} a_{Lt} + \Upsilon_L\,(\widetilde{P}_{Lt-1} - \widetilde{P}_{t-1}) + \Upsilon_L^{*}\,(\widetilde{P}_{St-1} - \widetilde{P}_{t-1}) + \Upsilon_L'\,\Omega^{y} a_{St} + \Upsilon_L''(\Omega^{y} a_{St} - a_{St}) \tag{155}$$

As before, each expression can be rearranged so that

$$\widetilde{P}_{St} - \widetilde{P}_t - \Upsilon_S(\widetilde{P}_{St-1} - \widetilde{P}_{t-1}) - \Upsilon_S^{*}(\widetilde{P}_{Lt-1} - \widetilde{P}_{t-1}) = \left[\Upsilon_S^{\pi}\Omega^{\pi} + \Upsilon_S'(\Omega^{y} - 1) + \Upsilon_S''\Omega^{y}\right] a_{St} \tag{156}$$

$$\widetilde{P}_{Lt} - \widetilde{P}_t - \Upsilon_L(\widetilde{P}_{Lt-1} - \widetilde{P}_{t-1}) - \Upsilon_L^{*}(\widetilde{P}_{St-1} - \widetilde{P}_{t-1}) = \left[\Upsilon_L^{\pi}\Omega^{\pi} + \Upsilon_L'\Omega^{y} + \Upsilon_L''(\Omega^{y} - 1)\right] a_{St} \tag{157}$$

Meaning in the first period, the shock is given by

$$\widetilde{P}_{St} - \widetilde{P}_t = \Omega_S^{a} a_{St} \quad \text{where} \quad \Omega_S^{a} = \Upsilon_S^{\pi}\Omega^{\pi} + \Upsilon_S'(\Omega^{y} - 1) + \Upsilon_S''\Omega^{y} \tag{158}$$

$$\widetilde{P}_{Lt} - \widetilde{P}_t = \Omega_S^{a} a_{St} \quad \text{where} \quad \Omega_L^{a} = \Upsilon_L^{\pi}\Omega^{\pi} + \Upsilon_L'\Omega^{y} + \Upsilon_L''(\Omega^{y} - 1) \tag{159}$$

Solving recursively

$$\mathbb{E}_t\left[\frac{\widetilde{P}_{st+1} - \widetilde{P}_{t+1}}{a_{St}}\right] = (\Upsilon_s + \rho_a)\Omega_s^{a} + \Upsilon_s^{*}\Omega_{-s}^{a} \tag{160}$$

This implies

$$\mathbb{E}_t\left[\frac{\widetilde{P}_{st+1} - \widetilde{P}_{st}}{a_{St}}\right] = \mathbb{E}_t\left[\frac{\widetilde{P}_{t+1} - \widetilde{P}_{t}}{a_{St}}\right] + (\Upsilon_s + \rho_a - 1)\Omega_s^{a} + \Upsilon_s^{*}\Omega_{-s}^{a} \tag{161}$$

Using (130)

$$\mathbb{E}_t\left[\widetilde{P}_{st+1}\right] - \widetilde{P}_{st} = [\rho_a\,\Omega^{\pi} + (\Upsilon_s + \rho_a - 1)\Omega_s^{a} + \Upsilon_s^{*}\Omega_{-s}^{a}]\, a_{St} \tag{162}$$

Finally, Ω^{π} solves the following identity (using expressions 130 and 162 and the definitions of Ω_i^a above)

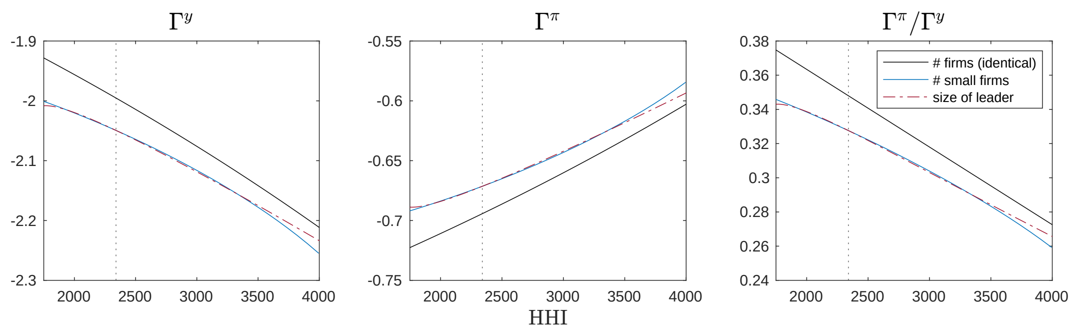
$$\mathbb{E}_t\left[\widetilde{P}_{t+1}\right]-\widetilde{P}_t=\mathbb{E}_t\left[\frac{n_s(P_s)^{-\varphi}(\widetilde{P}_{st+1}-\widetilde{P}_{st})+n_{\text{-}s}(P_{\text{-}s})^{-\varphi}(\widetilde{P}_{\text{-}st+1}-\widetilde{P}_{\text{-}st})}{P^{-\varphi}}\right] \tag{163}$$

The solution for a shock to large firms is similar.

A.7. Differences in Nominal Price Adjustment Costs Across Firms

Goldberg and Hellerstein (2009) suggest large firms have greater price flexibility than small firms. This could be explained in several ways. Fixed costs could be lower for large firms. Managerial inattention at small firms could be greater. The price adjustment costs are set so that γ_L and γ_S are 0.8 and 1.25 respectively. As figure 19 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.

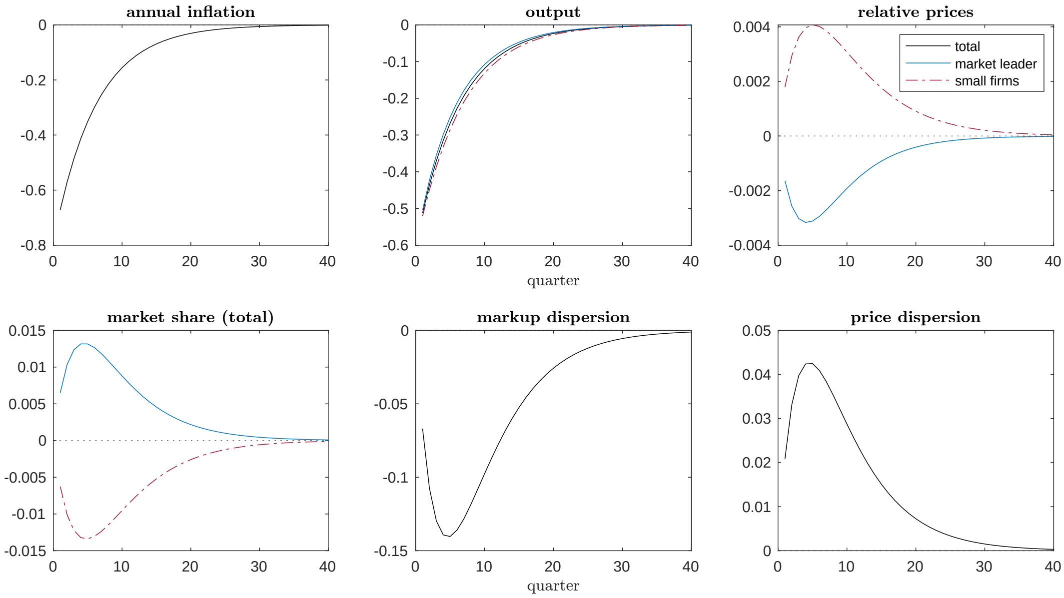
Figure 19: Concentration, Adjustment Costs, and the Phillips Curve ($\gamma_L = 0.7$ and $\gamma_S = 1.4$)



The underlying exercise and its interpretation are the same as figure 3, 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 $\gamma_S = 1.3$. The change in the Phillips curve from the expansion of large firms is ambiguous if their prices are more flexible.

A monetary policy shock is applied as before in figure 20, 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 and higher price dispersion. The outcomes are the opposite of the result in figure 6, but much smaller in magnitude since differences in the pass-through and adjustment costs largely offset.

Figure 20: Baseline Impulse Response to Monetary Tightening ($\varepsilon_0 = 0.25$)



Here large firms have a lower price adjustment cost ($\gamma_L = 0.6$ 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.8. 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 standard model is implemented using Dynare, modifying the replication package for Galí (2015) chapter 3.[60] The calibration matches the main outcomes from the baseline model. The settings in table 8 give the same equilibrium markup (0.14) and slope for the Phillips curve (0.36). All other parameter settings are identical to table 1.

Table 8: 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 $\boldsymbol{P}_t^* = \{\widetilde{P}_0, \widetilde{P}_1^*, \widetilde{P}_2^*, ..., \widetilde{P}_t^*\}$, their respective weights are given

[60]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).

by $\boldsymbol{\omega}_t = \{\omega_0, \omega_1, \omega_2, ..., \omega_t\}$ where

$$\omega_0 = \theta^t \quad \text{and} \quad \omega_k = (1-\theta)\theta^{t-k} \quad \text{for} \quad 0 < k \leq t \tag{164}$$

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

$$\boldsymbol{p}_t^* = \boldsymbol{P}_t^* - \widetilde{P}_t \tag{165}$$

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

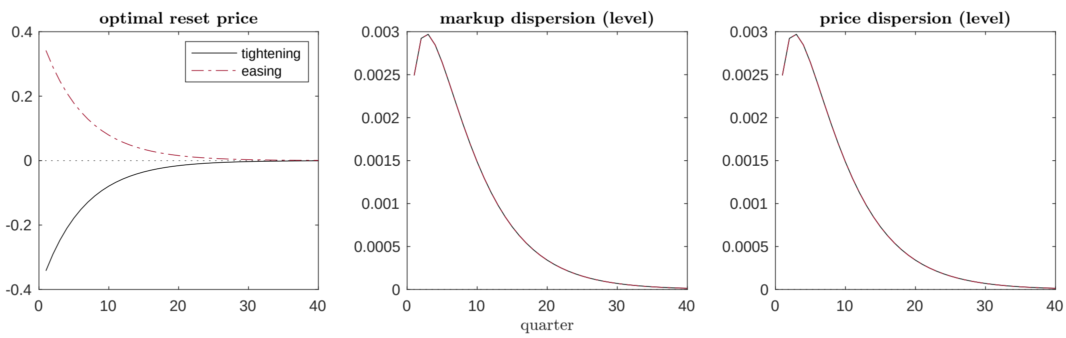
$$\boldsymbol{\mu}_t^* = \boldsymbol{P}_t^* - \widetilde{\boldsymbol{\mathcal{C}}}_t \tag{166}$$

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

$$\widetilde{P}_t = \theta\widetilde{P}_{t-1} + (1-\theta)\widetilde{P}_t^* \quad \Longrightarrow \quad \tilde{\pi}_t = \frac{1-\theta}{\theta}(\widetilde{P}_t^* - \widetilde{P}_t) \quad \text{since} \quad \tilde{\pi}_t = \widetilde{P}_t - \widetilde{P}_{t-1} \tag{167}$$

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

Figure 21: Impulse Response to a Monetary Shock (Standard NK Model)



The figure shows the response of prices and markups in a model with Calvo pricing. The left-hand panel shows the price firms choose when they get the opportunity to reset. The center and right-hand panels show the impact on price and markup dispersion, taking the weighted standard deviation. For a 1 percent increase/decrease in the nominal interest rate, there is an increase in the dispersion of log markups and log prices since they are identical in the steady state.

The results for the monetary shock are presented in figure 21. 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 6. 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 in 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 21). 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 shock should generate price compression. This is not the case. In addition, Calvo pricing 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 standard model returns almost 11x the appropriate level.[61] Table 9 presents the corresponding estimates.

Table 9: OLS Regression of Price Dispersion on Inflation Following a Productivity Shock

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

[61]The coefficient (0.050) omits industry as a control. It falls to 0.026 when controlling for industry. Still, the 'correct' level of price dispersion is up for debate. Ideally, this would be measured using closely substitutable varieties. The comparison in Sheremirov (2020) captures dispersion across retailers.

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