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Firm Size, Heterogeneous Strategic Complementarities, and Real Rigidity[*]

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Abstract

Recent research finds that only large firms exhibit strategic complementarities in price setting. Using firm survey data, we show that cost pass-through decreases significantly with firm size. To examine the implications for inflation dynamics, we develop a DSGE model that features heterogeneous complementarities across firm size. While standard DSGE models with homogeneous firms generate real rigidity in relative prices, such rigidity is much weaker in our model. Large firms that exhibit complementarities align their prices with those of small firms that more fully pass through costs. Our findings challenge the notion of strategic complementarity as a source of real rigidity.

JEL Classification: E31, E52, L11

Keywords: Firm heterogeneity, Pass-through, Monetary non-neutrality

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1 Introduction

Recent research indicates that firm size matters for price-setting behavior. Amiti et al. (2019) present empirical evidence of substantial heterogeneity in strategic complementarity in price setting by firm size: "*Small firms exhibit no strategic complementarities in price setting, and fully pass through their marginal cost shocks into their domestic prices. ... In contrast, large firms exhibit strong strategic complementarities and incomplete pass-through of own marginal cost shocks*" (p. 2357).[1] Complementing their research, our paper presents new empirical evidence using firm survey data on price changes and cost changes. Our panel regression analysis shows that cost pass-through decreases significantly with firm size. The empirical evidence suggests that firm size could also matter for inflation dynamics.

In the literature on inflation dynamics, existing studies often use dynamic stochastic general equilibrium (DSGE) models of the sort developed in the seminal work of Christiano et al. (2005) and Smets and Wouters (2007) and assume that all firms identically exhibit strategic complementarities in price setting under monopolistic competition. The homogeneous complementarities generate real rigidity in relative prices, since price-adjusting firms respond more cautiously to changes in their marginal costs in order to keep their goods prices close to those of the other firms. Consequently, the complementarities allow DSGE models to reconcile micro evidence of moderate nominal price rigidity with macro evidence of substantial monetary non-neutrality.[2] Such models, however, abstract from firm size.

We develop a DSGE model that features heterogeneous strategic complementarities in price setting across firm size. Specifically, we introduce firm heterogeneity in productivity in an otherwise standard DSGE model, as the size of firms in terms of output and labor input is associated with their productivity. We then assume that low-productivity (or small) firms face a constant elasticity of demand, while higher-productivity (or larger) firms confront a positive superelasticity (i.e., elasticity of the elasticity) of demand that arises from a non-

[1] Berman et al. (2012) and Amiti et al. (2014) study the price-setting behavior of exporters and find that exporters' exchange-rate pass-through decreases with their market shares.

[2] This idea dates back at least to Ball and Romer (1990). Gopinath and Itskhoki (2011) review empirical evidence on real rigidity. For micro evidence on nominal price rigidity, see, e.g., Klenow and Kryvtsov (2008), Nakamura and Steinsson (2008), and Nakamura et al. (2018). A large literature documents monetary non-neutrality; see, e.g., Christiano et al. (2005) and Bu et al. (2021).

CES aggregator of individual differentiated goods of the sort proposed by Kimball (1995).[3] This leads larger firms but not small firms to exhibit strategic complementarities in line with the empirical evidence by Amiti et al. (2019). We then show that the log-linearized model is almost the same as its standard DSGE counterpart model with homogeneous firms, except for the slope (i.e., the real marginal cost elasticity of inflation) of the Phillips curve. In the presence of firm heterogeneity in the model, the slope reflects a steady-state revenue-weighted average of each firm's marginal cost elasticity of its optimized price.

An advantage of accounting for firm heterogeneity is that data can inform values of the productivity levels of larger firms (relative to that of small firms) and the superelasticity of demand for their goods. By calibrating the model to data from the Statistics of US Businesses (SUSB) of the US Census Bureau, we quantitatively examine the implications of heterogeneity in strategic complementarity in price setting by firm size for inflation dynamics. The data provide the number of firms and their employment, payrolls, and revenues for firm-size categories ranging from firms with fewer than five employees to those with 5,000 or more employees. Because many of the firm-size categories represent only a small share of aggregate revenues, we consolidate the number of categories into three groups. After normalizing the productivity level of the small-firm group, for which the elasticity of demand is assumed to be constant, we obtain, for the remaining two groups of larger firms, values of their relative productivity levels and the superelasticity of demand for their goods, by targeting the empirical revenue shares and labor shares of each firm-size group. The resulting values imply that larger-firm groups feature not only higher productivity but also stronger strategic complementarity in line with the empirical evidence. Moreover, a steady-state revenue-weighted average of the superelasticity of demand over the three groups of firms in our calibrated model implies an overall measure of curvature of demand that is consistent with micro evidence (Dossche et al., 2010; Beck and Lein, 2020).

Our main quantitative result is that heterogeneity in strategic complementarity in price setting by firm size substantially weakens real rigidity in relative prices in the DSGE model.

[3]Since Marshall (1890) argued that the elasticity of demand increases with price, a positive superelasticity of demand is often referred to as "Marshall's Second Law of Demand." Kimball (1995) introduced a non-CES aggregator as a source of real rigidity in relative prices. Smets and Wouters (2007) adopted it in their DSGE model, after which the aggregator has become mainstream in DSGE models. It is also used in other macroeconomic models with firm heterogeneity (e.g., Edmond et al., 2023) and in international economics (e.g., Gopinath and Itskhoki, 2010).

We show this result by comparing the slope of the Phillips curve in our calibrated model (with heterogeneous complementarities) to that in the standard DSGE counterpart model with homogeneous firms (and hence homogeneous complementarities). Although our calibrated model captures an overall measure of demand curvature that is both consistent with micro evidence as noted above and identical to that in the counterpart model, the slope of the Phillips curve is steeper in our calibrated model than in the counterpart model. We then examine monetary non-neutrality by comparing the impulse responses of output to an expansionary monetary policy shock in our calibrated model, in the counterpart model, and in the case where all firms face a constant elasticity of demand (so there is no complementarity). Output in both models increases more than in the case of no complementarity, and the increase in our calibrated model is about half of that in the counterpart model. Therefore, the concentration of strategic complementarities solely in larger firms weakens monetary non-neutrality substantially in our calibrated model.

Strategic complementarity and productivity have offsetting effects on the pass-through of larger firms' marginal costs in our calibrated model. While stronger complementarity lowers the pass-through, higher productivity raises it because a more productive firm's optimized price is lower, which reduces the price elasticity of demand for the firm's good. We show analytically that if productivity is homogeneous among firms, then the slope of the Phillips curve is steeper in our model than in the standard DSGE counterpart model with homogeneous firms, and thus, real rigidity is weaker. Then, additionally accounting for differences in productivity across firms further steepens the Phillips curve slope in our calibrated model. In this way, heterogeneity in strategic complementarity and in firm size each leads to weaker real rigidity.

The model's equilibrium conditions provide an explanation for our results. The model features a firm-size-specific condition for price setting. For each firm-size group, the condition relates the optimized relative price of firms in the group to its expected future value, the real marginal cost, and a steady-state revenue-weighted average of the expected future optimized relative prices of firms in the other size groups. As a consequence, larger firms that exhibit strategic complementarities in price setting bring their goods prices in line with those of small firms that more fully pass through changes in their marginal costs. This spillover effect from small firms to larger firms is absent in standard DSGE models with homogeneous firms.

Our results indicate that the real rigidity generated in standard DSGE models, which abstract from firm heterogeneity, is partly an artifact of homogeneity in strategic complementarity in price setting across firms. Once we account for the empirical heterogeneity in strategic complementarity by firm size, the real rigidity is greatly weakened, as noted above. Therefore, our findings challenge the notion of strategic complementarity as a source of real rigidity in DSGE models. Levin et al. (2008) demonstrate that the source of real rigidity in DSGE models can have implications for optimal monetary policy, which suggests that adopting an empirically plausible source is policy relevant.

The paper is related to different strands of the macroeconomic literature. Previous macroeconomic research on firm size is concerned with business fluctuations. Gertler and Gilchrist (1994) and Crouzet and Mehrotra (2020) document that small firms are more cyclically sensitive than large firms. While the former authors associate the greater cyclicality of small firms with financial frictions, the latter attribute it to a larger industry scope of large firms.[4] Research on the implications of firm heterogeneity for inflation dynamics focuses on sectoral heterogeneity in nominal price rigidity. Carvalho (2006) finds that homogeneous strategic complementarities in price setting lead firms with more flexible prices to behave similar to firms with stickier prices. Due to this spillover effect, the firms with stickier prices have a disproportionate influence on the aggregate price level, so heterogeneity in nominal price rigidity increases monetary non-neutrality.[5] Our model, in which all firms face the same nominal price rigidity, possesses a distinct spillover effect. Firms that exhibit strategic complementarities in price setting behave similar to firms that more fully pass through changes in their marginal costs, and therefore heterogeneity in strategic complementarity across firms weakens monetary non-neutrality. In our model, a positive superelasticity of demand leads larger firms to display both strategic complementarities and large markups. A recent strand of research endogenizes the link between market power and strategic price setting by departing from the assumption of monopolistic competition (e.g., Mongey, 2021; Wang and Werning, 2022; Ueda, 2023). Wang and Werning (2022) then point out that the implications of oligopolistic competition for monetary non-neutrality are well approx-

[4] Gilchrist et al. (2017) show that liquidity-constrained firms raised their goods prices during the global financial crisis, while unconstrained firms lowered their prices. Haque et al. (2025) examine the implications of multiple-product firms for equilibrium stability.

[5] See also Nakamura and Steinsson (2010), Pasten et al. (2020), and Carvalho et al. (2021).

imated by introducing a Kimball-type non-CES aggregator in models with monopolistic competition. Our model retains the tractability of monopolistic competition and employs a Kimball-type aggregator to highlight the spillover effect from small firms to larger firms that exhibit strategic complementarities. Our paper also contributes to research that challenges the use of strategic complementarity for generating monetary non-neutrality (e.g., Bils et al., 2012; Klenow and Willis, 2016).

The remainder of the paper proceeds as follows. Section 2 presents new empirical evidence supporting the notion that firm size matters for price setting. Section 3 develops a DSGE model that features heterogeneous strategic complementarities in price setting across firm size. Section 4 calibrates the model to US Census data and then quantitatively examines the implications of heterogeneity in strategic complementarity by firm size for inflation dynamics. Section 5 concludes.

2 Empirical Evidence

In this section, we empirically examine the role of firm size in price-setting behavior using firm survey data, and present new evidence that the pass-through from firms' costs to their prices decreases with firm size.[6]

The data are taken from the Business Inflation Expectations survey of the Federal Reserve Bank of Atlanta, a monthly survey of firms in the Sixth Federal Reserve District.[7] The survey has been asking firms about their prices and costs occasionally since December 2020. The high and volatile inflation observed during the sample period makes it an opportune time to study firms' cost pass-through. Our dataset contains all the firms with complete time series in the sample. The balanced panel contains $T = 7$ survey months and consists of $n_1 = 19$, $n_2 = 20$, and $n_3 = 14$ firms in the groups of small, medium, and large firms, respectively.[8]

[6] For evidence on the role of strategic complementarity in cost pass-through, see Gopinath and Itskhoki (2010), Auer and Schoenle (2016), Dogra et al. (2023), and Gödl-Hanisch and Menkoff (2025).

[7] The Sixth District includes Alabama, Florida, Georgia, and portions of Louisiana, Mississippi, and Tennessee. The industry composition of the panel roughly reflects that of the US economy.

[8] The seven survey months are December 2020, April 2021, July 2021, November 2021, March 2022, December 2022, and May 2023. Each firm remains within its firm-size group throughout the sample period. Although two more surveys were conducted in October 2023 and February 2024, our sample period ends in May 2023 because we have too few firms in the balanced panels during the sample periods extended up to October 2023 (i.e., $T = 8$) and February 2024 (i.e., $T = 9$).

We begin by discussing the three variables used in the panel estimation: price growth, cost growth, and firm size.

First, the survey question on price growth was phrased in one of two slightly different ways across survey waves.[9] Given the minor differentiations between the two formulations, we merged firms' answers to the question into one variable, the 12-month percentage change in a firm's price, which provides a larger time series dimension of the panel.

Second, firms in the survey indicate how their current unit costs compare with those a year earlier, by selecting one of five categories: "down," "unchanged," "up somewhat," "up significantly," and "up very significantly." We treat the cost growth indicator as an interval variable by assuming that each category covers a similar range of values for cost growth. This assumption should be innocuous because our goal is to test whether the average association between price growth and cost growth—the sum of all the coefficients if we were to include one for each possible value of the ordinal variable in the panel regression—differs across firm-size groups. Hence, whether one interval is wider than the others should be less relevant to the extent that it is wider for each firm size. The benefit of treating the ordinal variable as if it had linear effects is greater parsimony.

Third, a firm-size variable in the survey sorts firms into one of three groups: small firms (with 1–99 employees), medium firms (with 100–499 employees), or large firms (with 500 or more employees). While a more precise employee count is available, we choose the three groups of firm size so as to ensure that each group contains a sufficient number of firms.

Using the three survey variables, we estimate the following panel regression:

$$\Delta Price_{j,t} = \mu + \beta_1 \Delta Cost_{j,t} \mathbb{I}_{j,t}(1) + \beta_2 \Delta Cost_{j,t} \mathbb{I}_{j,t}(2) + \beta_3 \Delta Cost_{j,t} \mathbb{I}_{j,t}(3) + \alpha_j + \gamma_t + \varepsilon_{j,t}, \quad (1)$$

where μ is a constant term, $\Delta Price_{j,t} \in \mathbb{R}$ is the price growth of firm j in month t, $\Delta Cost_{j,t} \in \{1,2,3,4,5\}$ denotes its cost growth, and $\mathbb{I}_{j,t}(i)$ is a dummy variable that indicates the size $i = 1,2,3$ of firm j by taking the value one if the firm is small, medium, or large, respectively, and zero otherwise. The regression model includes firm fixed effects α_j, which

[9] One formulation of the question was: "*In percentage terms, over the past 12 months, by how much did your firm increase [decrease] the price of the product or service responsible for the largest share of your revenue?*" The other formulation was instead: "*By roughly what percentage has your firm changed the price of the product/product line or service responsible for the largest share of your revenue of the last 12 months?*"

can absorb structural differences in price growth between firms, including differences in the responsiveness of own prices to competitors' prices. Time fixed effects γ_t are also included to absorb aggregate drivers of price growth, such as changes in the average markup during the sample period that saw a rise and fall in inflation. The coefficients β_i capture the cost pass-through of firm-size group i. Although the ordinal regressor renders the magnitude of the estimated coefficients not economically meaningful, the estimates allow us to test whether the cost pass-through differs by firm size.

Table 1 presents the estimation results. Column (1) reports the main results obtained with the balanced panel, including the estimated coefficients β_i on $\Delta Cost_{j,t} \times \mathbb{I}_{j,t}(i)$ and their standard errors for small firms ($i = 1$), medium firms ($i = 2$), and large firms ($i = 3$). The estimators are significantly different from zero for small and medium firms but not for large firms, suggesting that large firms exhibit less pass-through from costs to prices than small and medium firms. Moreover, the estimates are decreasing in firm size.

Column (2) reports a robustness check on the number of firms in the firm-size groups. As mentioned above, the main balanced panel contains $n_1 = 19$, $n_2 = 20$, and $n_3 = 14$ firms in the small-, medium-, and large-firm groups, respectively. To increase these numbers, we limit the sample period up to December 2022 (i.e., $T = 6$), which results in larger numbers of firms: $n_1 = 33$, $n_2 = 31$, and $n_3 = 21$. The estimation results remain qualitatively the same as the aforementioned main results.

As another robustness check, we extend the balanced panel during $T = 7$ survey months by including firms with incomplete time series. In particular, we include all firms with data during at least two survey months assuming that data for the remaining survey months are randomly missing. Column (3) provides the estimation results obtained with the unbalanced panel. Although the estimated coefficient for large firms becomes significant at the 10 percent level, it remains smaller than those for small and medium firms. The latter two estimates remain significant at the 1 percent level and are of a similar magnitude. The estimation results are qualitatively the same as the main results, indicating that large firms exhibit less cost pass-through than small and medium firms.

We next examine whether the cost pass-through depends on firm size using a Wald test. Defining the coefficient vector $\beta = (\beta_1, \beta_2, \beta_3)'$, the asymptotic distribution $\sqrt{nT}(\hat{\beta} - \beta) \xrightarrow{d} N(0, V)$, where V is the variance matrix of β. The null hypothesis that the firm-size dummy

Table 1: Estimation results of panel regression.

Variables	(1) Main results	(2) Panel w/ $T = 6$	(3) Unbalanced panel
$\Delta Cost_{j,t} \times \mathbb{I}_{j,t}(1)$	6.945^{***}	7.933^{***}	5.184^{***}
	(1.958)	(2.192)	(1.596)
$\Delta Cost_{j,t} \times \mathbb{I}_{j,t}(2)$	3.659^{***}	3.696^{***}	5.054^{***}
	(0.917)	(0.923)	(1.325)
$\Delta Cost_{j,t} \times \mathbb{I}_{j,t}(3)$	-0.507	0.274	1.794^{*}
	(2.270)	(1.866)	(1.077)
Firm fixed effects	yes	yes	yes
Time fixed effects	yes	yes	yes
Sample size	371	510	1160
Wald test	6.183^{**}	7.093^{**}	7.172^{**}

Notes: ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively. Column (1) presents the estimation results obtained with the balanced panel during $T = 7$ survey months. Column (2) shows those obtained with the balanced panel during $T = 6$ survey months up to December 2022. Column (3) displays those obtained with the unbalanced panel during $T = 7$ survey months. The price growth variable is winsorized at the 1st and 99th percentiles. The within transformation of the panel regression model is estimated by OLS. Stock and Watson (2008) robust standard errors are reported in parentheses and critical values are based on the standard normal distribution.

variable is irrelevant to the cost pass-through, i.e., $\beta_1 = \beta_2 = \beta_3$, is represented as a two-dimensional vector $R\beta$, where

$$R = \begin{bmatrix} 1 & -1 & 0 \\ 1 & 0 & -1 \end{bmatrix}.$$

It follows that $\sqrt{nT}(R\hat{\beta} - R\beta) \xrightarrow{d} N(0, RVR')$. The Wald test statistic is then

$$\xi_W = nT \left(R\hat{\beta}\right)' \left(R\hat{V}R\right)^{-1} \left(R\hat{\beta}\right),$$

where $\hat{V}$ is a consistent estimator for V that is obtained by following Stock and Watson (2008).[10] Under the null, the test statistic has a chi-square distribution with two degrees of freedom. The null hypothesis of no role of firm size in cost pass-through is rejected for the main dataset and the robustness checks with the balanced panel and the unbalanced panel. Thus, the results shown in Table 1 indicate that large firms exhibit significantly less pass-through from costs to prices than small and medium firms.

[10]Specifically, $\hat{V} = \hat{Q}^{-1}_{\tilde{X}\tilde{X}} \hat{\Sigma} \hat{Q}^{-1}_{\tilde{X}\tilde{X}}$, where $\hat{Q}_{\tilde{X}\tilde{X}} = (nT)^{-1} \sum_{j=1}^{n} \sum_{t=1}^{T} \tilde{X}_{j,t} \tilde{X}'_{j,t}$, $\tilde{X}$ is the matrix of within-transformed regressors, and $\hat{\Sigma}$ is the bias-adjusted heteroskedasticity robust covariance matrix estimator described by eq. (6) in Stock and Watson (2008).

The evidence presented above complements existing evidence of heterogeneity in strategic complementarity in price setting by firm size.[11] Amiti et al. (2019) study the extent of strategic complementarity using micro data on prices, marginal costs, and competitors' prices of manufacturing firms in Belgium. The data feature variation in firms' own marginal costs as the firms source intermediate inputs from different suppliers in different countries. The authors empirically decompose firms' price changes into their own cost pass-through and a response to their competitors' price changes, which reveals strong evidence of strategic complementarity. Moreover, they find substantial evidence of heterogeneity in strategic complementarity, as noted in the Introduction. Small firms exhibit no strategic complementarities, whereas the price changes of large firms have a substantial, positive competitor-price elasticity. This evidence clearly indicates that firm size matters for price-setting behavior and raises the question of whether it also matters for inflation dynamics, which we turn to next.

3 Model

We develop a DSGE model augmented with firm heterogeneity in productivity and in strategic complementarity in price setting to examine whether firm size matters for inflation dynamics. A novel feature of the model is the presence of multiple groups of individual-goods producing firms that are distinguishable by their productivity levels and the superelasticities of demand for their goods. Then, a representative composite-good producer aggregates the outputs of the firms. The remaining part of the model is standard in the DSGE literature and consists of a representative household and a monetary authority.

3.1 Composite-good producers

A representative composite-good producer combines the outputs of a continuum of firms $j \in [0, 1]$, each of which belongs to one of the k groups $\Omega_i = \{j \in [0, 1] : z(j) = z_i, \epsilon(j) = \epsilon_i\}$,

[11] A plausible interpretation of our finding that large firms exhibit less cost pass-through than small and medium firms would be that the price-setting behavior of large firms is subject to greater real rigidity but not greater nominal price rigidity. This is because Goldberg and Hellerstein (2011) use PPI micro data to show that large firms change their goods prices more frequently (and by smaller amounts) than small firms. Consistent with this result, Bhattarai and Schoenle (2014) find that firms that produce more goods adjust their goods prices more frequently (and by smaller amounts).

$i = 1, \ldots, k$, where $z(j)$ denotes firm-j-specific productivity relative to that of firms in group Ω_1 with the normalization of $z_1 = 1$ and the parameter $\epsilon(j)$ governs the superelasticity of demand for firm j's good. The firm groups Ω_i, $i = 1, \ldots, k$ are disjoint and $\bigcup_{i=1}^{k} \Omega_i = [0, 1]$. The measure of firms in group Ω_i (i.e., type-i firms) is $n_i \in (0, 1]$, that is, $\int_{\Omega_i} dj = n_i$, so we have $\sum_{i=1}^{k} \int_{\Omega_i} dj = \sum_{i=1}^{k} n_i = 1$. The composite good Y_t is produced by combining individual differentiated goods $\{Y_t(j)\}$ with an aggregator of the sort proposed by Kimball (1995):

$$1 = \int_0^1 F_i\left(\frac{Y_t(j)}{Y_t}\right) dj = \sum_{i=1}^{k} \int_{\Omega_i} F_i\left(\frac{Y_t(j)}{Y_t}\right) dj. \tag{2}$$

Following Dotsey and King (2005) and Levin et al. (2008), the function $F_i(\cdot)$ is assumed to be of the form

$$F_i\left(\frac{Y_t(j)}{Y_t}\right) = \frac{\theta}{\gamma_i - 1}\left((1+\epsilon_i)\frac{Y_t(j)}{Y_t} - \epsilon_i\right)^{\frac{\gamma_i - 1}{\gamma_i}} + 1 - \frac{\theta}{\gamma_i - 1} \quad \forall j \in \Omega_i, \quad i = 1, \ldots, k,$$

where $\gamma_i \equiv \theta(1 + \epsilon_i)$. A value of $\epsilon_i < 0$ gives rise to a positive superelasticity of demand for goods produced by type-i firms and hence strategic complementarity in price setting. In the special case of $\epsilon_i = 0$ for all firm types i, the aggregator (2) is reduced to the CES one $Y_t = [\int_0^1 (Y_t(j))^{(\theta-1)/\theta} dj]^{\theta/(\theta-1)}$, where $\theta > 1$ represents the elasticity of substitution between individual differentiated goods.

The composite-good producer maximizes profit $\Pi_t = P_t Y_t - \int_0^1 P_t(j) Y_t(j)\, dj$ subject to the aggregator (2), given the composite goods' price P_t and individual goods' prices $\{P_t(j)\}$. Combining the first-order conditions for profit maximization and the aggregator (2) leads to

$$\frac{Y_t(j)}{Y_t} = \frac{1}{1+\epsilon_i}\left[\left(\frac{P_t(j)}{P_t\, d_t}\right)^{-\gamma_i} + \epsilon_i\right] \quad \forall j \in \Omega_i, \quad i = 1, \ldots, k, \tag{3}$$

$$d_{i,t} = \left[\frac{1}{n_i}\int_{\Omega_i}\left(\frac{P_t(j)}{P_t}\right)^{1-\gamma_i} dj\right]^{\frac{1}{1-\gamma_i}}, \quad i = 1, \ldots, k, \tag{4}$$

$$0 = \sum_{i=1}^{k} \frac{n_i}{\gamma_i - 1}\left[\left(\frac{d_{i,t}}{d_t}\right)^{1-\gamma_i} - 1\right], \tag{5}$$

$$1 = \sum_{i=1}^{k} \frac{n_i}{1+\epsilon_i}\left[\left(\frac{d_{i,t}}{d_t}\right)^{-\gamma_i} d_{i,t} + \epsilon_i\left(\frac{1}{n_i}\int_{\Omega_i}\frac{P_t(j)}{P_t}\, dj\right)\right]. \tag{6}$$

Eq. (3) is the demand curve for firm j's good, where d_t denotes the Lagrange multiplier on the aggregator (2). Eq. (4) describes an average relative price $d_{i,t}$ over goods of type-i firms. The aggregator (2) and the condition for zero profits (i.e., $\Pi_t = 0$) are reduced to (5) and (6), respectively. Eq. (5) shows that the Lagrange multiplier depends on the average relative prices $d_{i,t}$ and (6) states that the sum of each firm's revenue share is one.

3.2 Firms

Each firm $j \in [0, 1]$ produces an individual differentiated good $Y_t(j)$ using the Cobb-Douglas production technology $Y_t(j) = A_t\, z(j)\, (K_t(j))^{\alpha}\, (l_t(j))^{1-\alpha}$, where $\alpha \in (0, 1)$ is the capital elasticity of production, A_t represents economy-wide productivity and grows at a constant rate $A_t/A_{t-1} = g^{1-\alpha}$, and $K_t(j)$ and $l_t(j)$ are firm j's inputs of capital and labor.

Firm j minimizes cost $TC_t(j) = P_t r_{k,t}\, K_t(j) + P_t W_t\, l_t(j)$ subject to the Cobb-Douglas production technology, given the capital rental rate $P_t r_{k,t}$ and the wage rate $P_t W_t$. In the presence of economy-wide, perfectly competitive factor markets, combining the first-order conditions for cost minimization shows that all firms choose an identical capital–labor ratio, so that

$$\frac{K_{i,t}}{l_{i,t}} = \frac{\alpha}{1-\alpha}\frac{W_t}{r_{k,t}}, \quad i = 1, \ldots, k, \tag{7}$$

where $K_{i,t} \equiv \frac{1}{n_i}\int_{\Omega_i} K_t(j)\, dj$ and $l_{i,t} \equiv \frac{1}{n_i}\int_{\Omega_i} l_t(j)\, dj$. Aggregating the outputs of type-i firms leads to

$$Y_t \Delta_{i,t} = A_t z_i K_{i,t}^{\alpha}\, l_{i,t}^{1-\alpha}, \quad i = 1, \ldots, k, \tag{8}$$

where

$$\Delta_{i,t} \equiv \frac{s_{i,t} + \epsilon_i}{1 + \epsilon_i}, \quad i = 1, \ldots, k, \tag{9}$$

$$s_{i,t} \equiv \frac{1}{n_i}\int_{\Omega_i} \left(\frac{P_t(j)}{P_t}\right)^{-\gamma_i} dj, \quad i = 1, \ldots, k. \tag{10}$$

The aggregate output over firms of type i is their average output $Y_t \Delta_{i,t}$, where $\Delta_{i,t}$ is the average output over type-i firms relative to the composite goods' output Y_t and may differ from one due to the effects of productivity z_i on relative prices, strategic complementarity in price setting on demand, and price dispersion across firms of type i in the presence of staggered price setting. Moreover, each firm type i's real marginal cost of production varies inversely with its productivity level

$$mc_{i,t} = \frac{1}{A_t z_i} \left(\frac{r_{k,t}}{\alpha} \right)^{\alpha} \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha}, \quad i = 1, \ldots, k. \tag{11}$$

It follows that the ratio of two firm-types' marginal costs is inversely proportional to the ratio of their relative productivities:

$$\frac{mc_{i-1,t}}{mc_{i,t}} = \frac{z_i}{z_{i-1}}, \; i = 2, \ldots, k. \tag{12}$$

We turn next to firms' price setting. Firms set their goods prices on a staggered basis as in Calvo (1983). In each period, a fraction $\xi \in (0,1)$ of type-i firms (i.e., $j \in \Omega_i$) index their goods prices to the steady-state rate π of composite goods' price inflation $\pi_t \equiv P_t/P_{t-1}$, while the remaining fraction $1-\xi$ of the firms identically set the price $P_t(j)$ so as to maximize relevant profits

$$E_t \sum_{j=0}^{\infty} \xi^j \, \Lambda_{t,t+j} \left(P_t(j)\pi^j - P_{t+j} \, mc_{i,t+j} \right) \frac{Y_{t+j}}{1+\epsilon_i} \left[\left(\frac{P_t(j)\pi^j}{P_{t+j} \, d_{t+j}} \right)^{-\gamma_i} + \epsilon_i \right],$$

where E_t denotes the expectation operator conditional on information available in period t and $\Lambda_{t,t+j}$ is the (nominal) stochastic discount factor between period t and period $t+j$. Assuming the same fraction ξ for all firm types i allows us to highlight the implications of heterogeneity in strategic complementarity for inflation dynamics. The first-order conditions for profit maximization can be written as

$$\begin{aligned} 0 = E_t \sum_{j=0}^{\infty} (\beta\xi)^j \frac{Y_{t+j}}{C_{t+j}} \Bigg[\left(\frac{p^*_{i,t}}{d_{t+j}} \right)^{-\gamma_i} \prod_{\tau=1}^{j} \left(\frac{\pi_{t+\tau}}{\pi} \right)^{\gamma_i} \left(p^*_{i,t} \prod_{\tau=1}^{j} \left(\frac{\pi_{t+\tau}}{\pi} \right)^{-1} - \frac{\gamma_i}{\gamma_i - 1} mc_{i,t+j} \right) \\ - \frac{\epsilon_i}{\gamma_i - 1} p^*_{i,t} \prod_{\tau=1}^{j} \left(\frac{\pi_{t+\tau}}{\pi} \right)^{-1} \Bigg], \quad i = 1, \ldots, k, \end{aligned} \tag{13}$$

where we use the equilibrium condition $\Lambda_{t,t+j} = \beta^j (C_t/C_{t+j})/(P_t/P_{t+j})$, which will be shown later, $\beta \in (0,1)$ is the subjective discount factor, C_t denotes households' consumption of composite goods, $p^*_{i,t} \equiv P^*_{i,t}/P_t$, and $P^*_{i,t}$ is the price optimized by firms of type i in period t. Moreover, under staggered price setting, eqs. (4) and (9) can be reduced to, respectively,

$$d_{i,t}^{1-\gamma_i} = \xi \left(\frac{\pi_t}{\pi} \right)^{\gamma_i - 1} d_{i,t-1}^{1-\gamma_i} + (1-\xi) \left(p^*_{i,t} \right)^{1-\gamma_i}, \quad i = 1, \ldots, k, \tag{14}$$

$$d_t^{-\gamma_i} \, s_{i,t} = \xi \left(\frac{\pi_t}{\pi} \right)^{\gamma_i} d_{t-1}^{-\gamma_i} \, s_{i,t-1} + (1-\xi) \left(p^*_{i,t} \right)^{-\gamma_i}, \quad i = 1, \ldots, k. \tag{15}$$

3.3 Households and monetary authority

The representative household consumes composite goods C_t, purchases one-period riskless bonds B_t, supplies labor l_t, and makes a capital investment I_t so as to maximize the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \frac{l_t^{1+1/\chi}}{1+1/\chi} \right)$$

subject to the budget constraint

$$P_t C_t + P_t I_t + B_t = P_t W_t l_t + P_t r_{k,t} K_{t-1} + r_{t-1} B_{t-1} + J_t$$

and the capital accumulation equation

$$K_t = (1-\delta) K_{t-1} + \left(1 - S\left(\frac{I_t}{g I_{t-1}} \right) \right) I_t, \tag{16}$$

where $\chi > 0$ is the elasticity of labor supply, $\delta \in (0,1)$ is the depreciation rate of capital, r_t is the interest rate on the bonds and is assumed to coincide with the monetary policy rate, K_t is the capital stock, J_t denotes firm profits received, and $S(\cdot)$ is an adjustment cost function that is assumed to be of the quadratic form $S\left(I_t/(gI_{t-1})\right) = (\zeta/2)\left(I_t/(gI_{t-1}) - 1\right)^2$ with $\zeta \geq 0$.

Combining the first-order conditions for utility maximization with respect to consumption, bond holdings, labor supply, capital stock, and capital investment yields

$$1 = E_t \left[\frac{\beta C_t}{C_{t+1}} \frac{r_t}{\pi_{t+1}} \right], \tag{17}$$

$$W_t = l_t^{\frac{1}{\chi}} C_t, \tag{18}$$

$$1 = E_t \left[\frac{\beta C_t}{C_{t+1}} \frac{r_{k,t+1} + (1-\delta) q_{t+1}}{q_t} \right], \tag{19}$$

$$1 = q_t \left[1 - \frac{\zeta}{2} \left(\frac{I_t}{g I_{t-1}} - 1 \right)^2 - \zeta \left(\frac{I_t}{g I_{t-1}} - 1 \right) \frac{I_t}{g I_{t-1}} \right] + E_t \left[\frac{\beta C_t}{C_{t+1}} q_{t+1} \zeta \left(\frac{I_{t+1}}{g I_t} - 1 \right) \frac{I_{t+1}^2}{g I_t^2} \right], \tag{20}$$

where q_t denotes the real price of capital. Then, it follows that the stochastic discount factor $\Lambda_{t,t+j}$ meets the equilibrium condition $\Lambda_{t,t+j} = \beta^j \left(C_t/C_{t+j}\right) / \left(P_t/P_{t+j}\right)$.

The output of composite goods is equal to the sum of households' consumption and capital investment:

$$Y_t = C_t + I_t \,. \tag{21}$$

The labor market clearing condition is

$$l_t = \sum_{i=1}^{k} n_i \, l_{i,t} = \sum_{i=1}^{k} \int_{\Omega_i} l_t(j) \, dj \,, \tag{22}$$

while the capital-service market clearing condition is

$$K_{t-1} = \sum_{i=1}^{k} n_i \, K_{i,t} = \sum_{i=1}^{k} \int_{\Omega_i} K_t(j) \, dj \,. \tag{23}$$

The monetary authority conducts policy based on an interest-rate feedback rule of the sort proposed by Taylor (1993):

$$\log r_t = \log r + \phi_\pi \left(\log \pi_t - \log \pi\right) + \phi_y \left(\log y_t - \log y\right) + u_{r,t} \,, \tag{24}$$

where $y_t \equiv Y_t / A_t^{1/(1-\alpha)}$ is detrended aggregate output, y is its steady-state value, $u_{r,t}$ is a shock to the monetary policy rate that is governed by a stationary AR(1) process $u_{r,t} = \rho u_{r,t-1} + \varepsilon_{r,t}$ with $|\rho| < 1$ and $\varepsilon_{r,t} \sim$ i.i.d. $N(0, \sigma_r^2)$, and ϕ_π and ϕ_y are the policy responses to inflation and output, respectively. The monetary policy shock generates short-run responses in real economic activity due to the presence of nominal price rigidity in the model, i.e., $\xi > 0$.

3.4 Log-linearized equilibrium conditions

The equilibrium conditions of the model consist of eqs. (5)−(9), (11), and (13)−(24). After removing the balanced growth trend $\Upsilon_t \equiv A_t^{1/(1-\alpha)}$, we log-linearize the equilibrium conditions expressed in terms of stationary variables, such as $y_t = Y_t/\Upsilon_t$, $c_t = C_t/\Upsilon_t$, $w_t = W_t/\Upsilon_t$, $i_t = I_t/\Upsilon_t$, and $k_t = K_t/\Upsilon_t$.

The following $2k+1$ log-linearized equilibrium conditions capture firm heterogeneity in inflation dynamics:

$$\hat{p}^*_{i,t} = \beta\xi \, E_t \hat{p}^*_{i,t+1} + \beta\xi \, E_t \hat{\pi}_{t+1} + \frac{1-\beta\xi}{\Gamma_i} \, \hat{mc}_t, \quad i = 1, \ldots, k, \tag{25}$$

$$\hat{d}_{i,t} = (1-\xi) \; \hat{p}^*_{i,t} + \xi \left(\hat{d}_{i,t-1} - \hat{\pi}_t \right), \quad i = 1, \ldots, k, \tag{26}$$

$$0 = \sum_{i=1}^{k} \omega_i \, \hat{d}_{i,t} \,, \tag{27}$$

where

$$\Gamma_i \equiv 1 + (-\epsilon_i) \left(\frac{p_i^*}{d} \right)^{\gamma_i} \mu_i \tag{28}$$

measures real rigidity in price setting of type-i firms, $\mu_i = \gamma_i / [\gamma_i - 1 - \epsilon_i \, (p_i^*/d)^{\gamma_i}]$ is their steady-state average markup, and $\omega_i = n_i p_i^* \Delta_i$ is their steady-state share of aggregate revenues. Eq. (25) represents the price-setting behavior of type-i firms that optimize their goods prices in period t. In the real marginal cost term, the subscript i is dropped (i.e., $\hat{mc}_{i,t} = \hat{mc}_t$ for all i) in the presence of the economy-wide, perfectly competitive factor markets and constant differences in the productivity level among firm types. The marginal cost elasticity of type-i firms' optimized price $(1 - \beta\xi)/\Gamma_i$ depends not only on ϵ_i but also on z_i. A smaller, negative value of ϵ_i increases the value of Γ_i and thereby decreases the elasticity $(1 - \beta\xi)/\Gamma_i$, so stronger strategic complementarity in price setting leads to less pass-through of the marginal cost. The firm-type-specific productivity z_i then influences the elasticity through its effects on the steady-state variables p_i^* and d. Higher productivity mitigates the decrease in the marginal cost elasticity induced by stronger strategic complementarity, as shown later.

We can consolidate (25)–(27) into k price-setting conditions as follows. Eq. (26) describes type-i firms' average relative price $\hat{d}_{i,t}$ that consists of the $1 - \xi$ optimizing firms' relative price and the ξ remaining firms' average relative price, the latter of which erodes with higher inflation relative to steady-state inflation. Eq. (27) is the log-linearization of the composite-good producer's zero-profit condition (6) and requires that the steady-state revenue-weighted average of the average relative prices $\hat{d}_{i,t}$ over all firm types i is zero. Combining (26) and (27) yields

$$\hat{\pi}_t = \frac{1 - \xi}{\xi} \sum_{i=1}^{k} \omega_i \, \hat{p}_{i,t}^* \,, \tag{29}$$

so the average relative prices are canceled out and thus the inflation rate $\hat{\pi}_t$ reflects only the steady-state revenue-weighted average of the optimized relative prices of all firm types. Then, substituting (29) in (25) leads to

$$\hat{p}^*_{i,t} = \beta[\xi + (1-\xi)\omega_i]E_t\hat{p}^*_{i,t+1} + \beta(1-\xi)\sum_{j\neq i}\omega_j E_t\hat{p}^*_{j,t+1} + \frac{1-\beta\xi}{\Gamma_i}\,\hat{mc}_t, \quad i = 1,\ldots,k. \tag{30}$$

In the presence of firm heterogeneity, type-i firms' optimized relative price $\hat{p}^*_{i,t}$ reflects the expected future optimized relative prices $E_t\hat{p}^*_{j,t+1}$ of the other firm types $j \neq i$. As a consequence, there is a spillover effect from firms that more fully pass through changes in the marginal cost to firms that exhibit strategic complementarities in price setting, with larger revenue shares of the former firms increasing the magnitude of the effect. Moreover, from eqs. (25)–(27), it follows that the Phillips curve is of the standard form

$$\hat{\pi}_t = \beta E_t\hat{\pi}_{t+1} + \left(\sum_{i=1}^{k}\omega_i\kappa_i\right)\hat{mc}_t, \tag{31}$$

but with a slope $\kappa = \sum_i \omega_i\kappa_i$ that consists of the steady-state revenue-weighted average of each firm type's component $\kappa_i = (1-\xi)(1-\beta\xi)/(\xi\,\Gamma_i)$, a component that is proportional to the firm type's marginal cost elasticity of its optimized price $(1-\beta\xi)/\Gamma_i$. As with the marginal cost elasticities, the components κ_i of the Phillips curve slope are affected by ϵ_i and z_i. While a smaller, negative value of ϵ_i decreases the value of κ_i, higher productivity z_i mitigates the decrease in κ_i, as shown later.[12]

In sum, the log-linearized model consists of the Phillips curve (31) and the following 10 equations:

$$\hat{mc}_t = (1-\alpha)\hat{w}_t + \alpha\,\hat{r}_{k,t}\,, \tag{32}$$

$$\hat{k}_{t-1} - l_t = \hat{w}_t - \hat{r}_{k,t}\,, \tag{33}$$

$$\hat{y}_t = (1-\alpha)\hat{l}_t + \alpha\,\hat{k}_{t-1}, \tag{34}$$

$$\hat{c}_t = E_t\hat{c}_{t+1} - \hat{r}_t + E_t\hat{\pi}_{t+1}, \tag{35}$$

$$\hat{w}_t = \frac{1}{\chi}\,\hat{l}_t + \hat{c}_t\,, \tag{36}$$

$$\hat{k}_t = \frac{1-\delta}{g}\,\hat{k}_{t-1} + \left(1 - \frac{1-\delta}{g}\right)\hat{\imath}_t\,, \tag{37}$$

[12] A smaller, negative value of ϵ_i reduces the value of κ_i directly and indirectly through a larger steady-state markup μ_i. The latter effect is analogous to the finding of Wang and Werning (2022) that higher market concentration due to fewer firms in an oligopoly makes the Phillips curve flatter.

$$\hat{q}_t = \zeta\left(\hat{\iota}_t - \hat{\iota}_{t-1}\right) - \beta\zeta\left(E_t\hat{\iota}_{t+1} - \hat{\iota}_t\right), \tag{38}$$

$$\hat{r}_t - E_t\hat{\pi}_{t+1} = \left[1 - \beta\left(\frac{1-\delta}{g}\right)\right] E_t\hat{r}_{k,t+1} + \beta\left(\frac{1-\delta}{g}\right) E_t\hat{q}_{t+1} - \hat{q}_t\,, \tag{39}$$

$$\hat{y}_t = \frac{c}{y}\,\hat{c}_t + \frac{i}{y}\,\hat{\iota}_t\,, \tag{40}$$

$$\hat{r}_t = \phi_\pi\hat{\pi}_t + \phi_y\hat{y}_t + u_{r,t}\,. \tag{41}$$

The last 10 conditions (32)–(41) are the same as in the standard DSGE counterpart model with homogeneous firms, so the firm heterogeneity alters the slope of the Phillips curve.[13]

3.5 Firm size and demand curvature

Thus far firms differ by their productivity, as indexed by $i = 1, \ldots, k$. Empirically, there is a well-documented relationship between labor productivity and firm size (e.g., Leung et al., 2008). We now explore the relationship in the steady state of the model.

In the special case of a constant elasticity of demand for goods of each firm type i (i.e., $\epsilon_i = 0$ for all i), we have that $p_i^* = \theta/(\theta-1)\,mc_i$, and thus the real marginal cost ratios (12) imply that $p_i^* = p_1^*/z_i$. It follows that output per firm $y\Delta_i = (z_i/p_1^*)^\theta$ is increasing in z_i, where Δ_i is the steady-state value of type-i firms' average output relative to the composite-good producer's output. Likewise, given that all firms face the same real wage rate, more productive firms demand more labor. As a consequence, the labor input per firm is also increasing in z_i.

In the case of empirical interest, more productive firms exhibit stronger strategic complementarity. In the model, the price elasticity of demand for goods of type-i firms is derived as $\eta_i(Y_t(j)/Y_t) = \theta(1 + \epsilon_i - \epsilon_i(Y_t(j)/Y_t)^{-1})$. Then, given $\epsilon_i < 0$, the elasticity is smaller for a larger relative demand $Y_t(j)/Y_t$, which leads the desired markup $\eta_i(Y_t(j)/Y_t)/\left(\eta_i(Y_t(j)/Y_t) - 1\right)$ to be larger. The larger markup mitigates the relative price differential caused by the productivity difference between firms. In the next section we will confirm numerically that firms whose productivity is higher and whose strategic complementarity is stronger are larger firms in terms of steady-state output and labor input in the calibrated model. Thus, in the remainder of the paper we will refer to the firm group $i = 1, \ldots, k$ as indexing firm size.

[13] The firm heterogeneity also has a very small effect on the steady-state output shares of consumption and investment c/y and i/y in the log-linearized composite-good market clearing condition (40).

The degree of strategic complementarity can be summarized by the curvature of demand, which we define as the mean superelasticity of demand evaluated at a relative demand of one, i.e., $Y_t(j)/Y_t = 1$. The superelasticity of demand for goods of type-i firms (i.e., the elasticity of the elasticity $\eta_i(Y_t(j)/Y_t)$) is derived as $\sigma_i(Y_t(j)/Y_t) = -\theta\epsilon_i/(Y_t(j)/Y_t)$. Hence, a smaller, non-positive value of ϵ_i or a smaller firm size in terms of relative demand $Y_t(j)/Y_t$ leads to a larger superelasticity of demand for the goods. Evaluating the superelasticity at a relative demand of one prevents changes in firm size over time or size differences between firms from directly affecting the curvature of demand and is consistent with the approaches used in previous studies (e.g., Dossche et al., 2010; Klenow and Willis, 2016; Beck and Lein, 2020). Aggregating each firm's superelasticity evaluated at a relative demand of one using its steady-state revenue share as its weight yields a mean curvature of demand:

$$\sigma = \sum_{i=1}^{k} \omega_i \left(-\theta\epsilon_i\right). \tag{42}$$

In the next section, we will compare the cases of heterogeneous versus homogeneous strategic complementarities in price setting across firm size in which the mean curvature of demand has the same value.

4 Quantitative Investigation

In this section, we explain the method to calibrate parameters of the model and demonstrate the main result: accounting for firm size weakens the link between strategic complementarity in price setting and real rigidity in relative prices.

4.1 Calibration of model parameters

For the model parameters that are not related to firm size, we adopt values that are commonly used in the macroeconomic literature. Table 2 presents the quarterly calibration of the model parameters. We set the subjective discount factor at $\beta = 0.995$, the elasticity of labor supply at $\chi = 1$, the depreciation rate of capital at $\delta = 0.025$, and the capital elasticity of production at $\alpha = 0.33$. The rate of balanced growth is chosen at $g = 1.005$, that is, 2 percent annually. The parameter governing investment adjustment costs is set at $\zeta = 2.5$, the estimate of Christiano et al. (2005). The parameter governing the elasticity of substitution between individual goods is chosen at $\theta = 10$ to target a desired markup of about 11 percent for firms that face a constant elasticity of demand; firms that exhibit strategic complementarities will have a larger desired markup. The probability of each firm not optimizing its good's price is set at $\xi = 0.6$. The monetary policy responses to inflation and output are chosen respectively at $\phi_\pi = 1.5$ and $\phi_y = 0.5/4$, as in Taylor (1993), and the persistence of monetary policy shocks is set at $\rho = 0.8$.

Table 2: Quarterly calibration of model parameters.

Parameter	Description	Value
β	Subjective discount factor	0.995
χ	Elasticity of labor supply	1
δ	Depreciation rate of capital	0.025
α	Capital elasticity of production	0.33
g	Gross rate of balanced growth	1.005
ζ	Parameter governing investment adjustment costs	2.5
θ	Parameter governing elasticity of substitution between goods	10
ξ	Probability of not optimizing price	0.6
ϕ_π	Monetary policy response to inflation	1.5
ϕ_y	Monetary policy response to output	0.5/4
ρ	Persistence of monetary policy shocks	0.8

The firm heterogeneity introduces $3k$ new parameters: n_i, z_i, and ϵ_i for $i = 1, \ldots, k$. To select values for these parameters, we calibrate the model to data from the SUSB of the US Census Bureau. Although the SUSB provides summary statistics for 23 firm-size categories, many of them represent only a small share of aggregate revenues. This indicates that the model can capture the role of firm size by choosing a smaller number of groups k than the 23 available categories. Hence we combine them into $k = 3$ clusters or groups. The first group consists of firms with fewer than 500 employees, which is a common definition of a small business. The second and third groups consist of firms with 500–4,999 employees and with 5,000 or more employees, respectively.[14]

First, the measure n_i of firms of each size $i = 1, \ldots, k$ is set equal to the fraction of establishments in each firm-size group. In the model, every firm produces one good as in

[14]The results presented in this section remain qualitatively unchanged if we use k-means clustering to combine the 23 categories into three clusters or groups. This method expands the first group to firms with fewer than 1,000 employees and reduces the second group to firms with 1,000–4,999 employees. Grouping firms based on the number of their production units or establishments, another metric of firm size, also leaves the results qualitatively unchanged.

standard DSGE models. While this is a good approximation for small firms, actual large firms typically produce multiple goods (Broda and Weinstein, 2010; Bernard et al., 2010). We can account for this empirical fact by calibrating n_i to the number of goods in each firm-size group.[15] Because the SUSB data do not provide information on the number of goods per firm, we approximate that number with the number of establishments per firm assuming every establishment produces one good. Although empirical evidence about the mapping between a firm's establishments and its goods is lacking, this assumption is in line with models of industrial organization (e.g., Cao et al., 2022).

Second, values of ϵ_i for all $i = 1, \ldots, k$ are obtained jointly with values of the steady-state variables d and p_i^* for $i = 1, \cdots, k$. We assume $\epsilon_1 = 0$ based on the micro evidence in Amiti et al. (2019) that small firms exhibit no strategic complementarities. To calibrate the remaining parameters ϵ_i for $i = 2, \ldots, k$ and determine the relative prices, we rely on the SUSB data on payrolls and revenues.[16] Specifically, we target the empirical labor share S_i and revenue share R_i by firm size i. Firms' labor demand conditions imply the steady-state labor share $S_i = wl_i/(p_i^* y \Delta_i) = (1-\alpha)/\mu_i$. Thus, we have $k-1$ conditions

$$S_i \mu_i - S_{i-1}\mu_{i-1} = 0, \quad i = 2, \ldots, k. \tag{43}$$

The steady-state composite-good producer's zero profit condition (6) involves the revenue share ω_i for $i = 1, \ldots, k$. We can target revenues of $k-1$ firm-size groups because the condition requires that the revenue shares across firm size groups sum to one. Thus, we match the revenue shares $\omega_2, \ldots, \omega_k$ with their empirical counterparts using the $k-1$ conditions

$$\omega_i - R_i = n_i p_i^* \frac{\left(\frac{p_i^*}{d}\right)^{-\gamma_i} + \epsilon_i}{1+\epsilon_i} - R_i = 0, \quad i = 2, \ldots, k. \tag{44}$$

Solving the $2k-2$ conditions (43) and (44) and the 2 steady-state conditions

[15] The model of the paper is observationally equivalent to a model that distinguishes the number of firms and the number of goods. In the latter model, there are m_i firms in each group $i = 1, \ldots, k$ and they produce a total of n_i goods using a production technology distinguished by the productivity level z_i. The steady state and the equilibrium conditions of such a model remain unchanged from those of our model. The details of the model with multi-product firms are provided in Appendix A.

[16] The data on revenues are provided every five years. We use the latest available data in 2022, but our results are virtually unchanged using the pre-COVID-19 data in 2017.

$$0 = \sum_{i=1}^{k} \frac{n_i}{\gamma_i - 1} \left[\left(\frac{p_i^*}{d} \right)^{1-\gamma_i} - 1 \right], \tag{45}$$

$$1 = \sum_{i=1}^{k} \omega_i, \tag{46}$$

yields $k-1$ values ϵ_i for $i = 2, \ldots, k$ and $k+1$ values d and p_i^* for $i = 1, \ldots, k$.

Third, the relative productivity level of small firms is normalized to $z_1 = 1$ and the parameters z_i for $i = 2, \ldots, k$ are obtained from the ratio of marginal costs (12) in the steady state, which can be written as

$$z_i = \frac{\mu_i \, p_1^*}{\mu_1 \, p_i^*}, \quad i = 2, \ldots, k. \tag{47}$$

Table 3 presents the values of the firm-size-specific parameters and steady-state variables. Recall that these values can affect inflation dynamics through the slope κ of the Phillips curve (31). The first row of the table shows that the small-firm group $i = 1$ makes up the vast majority of all establishments in the SUSB ($n_1 = 0.8330$), whereas the measure of the other firm-size groups $i > 1$ is small. However, revenue shares in the SUSB are more evenly distributed across firm size, as displayed in the second row. The large-firm group $i = 3$ actually has the largest revenue share. The third row presents the relative productivity level of each firm group. The productivity level increases with firm size, such that the productivity of firms in the large-firm group is almost double that in the small-firm group, as indicated by the value of z_3.[17]

The fourth row of Table 3 displays the superelasticity of demand $-\theta\epsilon_i$ by firm size. Two points are worth noting. First, the superelasticity rises with firm size. The stronger superelasticity for larger-firm groups coincides with the micro evidence that the price-setting behavior of small firms is consistent with a constant elasticity of demand, while that of larger firms exhibits strategic complementarities, as discussed in Section 2. While the model is agnostic about the source of heterogeneity in the superelasticity by firm size, a possible

[17] While the calibrated model considers only three productivity levels, it accounts for more than half of the observed dispersion in productivity across establishments. Cunningham et al. (2023) present micro evidence on dispersion in establishment-level productivity. They report that the standard deviation of the log total factor productivity of establishments across detailed US manufacturing industries is 0.46. This standard deviation is 0.27 in our model using the parameter values in Table 3.

Table 3: Values of firm-size-specific model parameters and steady-state variables.

	Parameter or variable	Description	Value for firm group i 1	2	3
(1)	n_i	Share of establishments (percent)	83.30	5.69	11.01
(2)	ω_i	Revenue share (percent)	34.96	19.50	45.54
(3)	z_i	Relative productivity level	1	1.41	1.82
(4)	$-\theta\epsilon_i$	Superelasticity of demand	0	4.87	7.65
(5)	p_i^*	Steady-state optimized relative price	1.16	0.88	0.78
(6)	μ_i	Steady-state average markup	1.11	1.19	1.36

Source: US Census Bureau and authors' calculations.
Notes: The table presents the values of the firm-size-specific model parameters n_i, ω_i, z_i, and ϵ_i (multiplied by $-\theta$) and steady-state variables p_i^* and μ_i for all firm groups i. The values of n_i and ω_i are taken from the SUSB of the US Census Bureau. The values of ϵ_i and p_i^* are obtained as part of a solution to eqs. (43)–(45), by setting $\epsilon_1 = 0$ and using the data on the firm-size measure n_i, the revenue shares R_i, and the labor shares $S_{i,t}$ as well as the calibration of model parameters reported in Table 2. The values of z_i and μ_i are then calculated.

interpretation is that customers are less loyal to the goods produced by larger firms, leading their demand elasticity to increase for higher prices. Holmes and Stevens (2014) suggest that small firms create specialty goods and large firms produce standardized goods. Thus, less customer loyalty to standard goods than to custom goods could rationalize the heterogeneity in strategic complementarity by firm size presented in our calibrated model. Second, given the firm-size-specific values reported in the table, the curvature of demand defined as (42) is calculated as $\sigma = 4.43$, a value roughly in line with the micro evidence in Dossche et al. (2010) and Beck and Lein (2020), who indicate that values in the range of 2–4 are empirically plausible.

The steady-state optimized relative prices and average markups are shown in the last two rows of Table 3. The optimized price p_i^* decreases with firm size.[18] In addition, the steady-state average markups μ_i increase with firm size, consistent both with a declining labor share by firm size S_i in the SUSB data and with the micro evidence on markups in De Loecker et al. (2020) and Autor et al. (2020). Finally, firm size, measured as relative output $(\Delta_1, \Delta_2, \Delta_3) = (0.36, 3.91, 5.33)$ or labor input $(l_1, l_2, l_3) \propto (0.12, 0.90, 0.95)$, increases with

[18] A lower optimized relative price for larger firms implies that revenue productivity is less dispersed than physical productivity, consistent with the establishment-level evidence in Foster et al. (2008). The steady-state real marginal cost of producing composite goods is calculated as $d = 1.05$, thus raising the demand for all individual differentiated goods evenly.

productivity in the model.[19]

4.2 Case of homogeneous productivity

We begin the analysis of heterogeneous strategic complementarities by abstracting from differences in productivity across firms in our model. The results obtained in this case will clarify the distinct roles of heterogeneity in firm size and in strategic complementarity in the next subsection, where we analyze the calibrated model with both features. If productivity is homogeneous among firms (i.e., $z_i = 1$ for all i), then for any arbitrary values of $\{\epsilon_i\}$, $p_i^* = d = 1$ for all i is a solution to eqs. (46)–(47).[20] Thus, there is no effect of firm size on the slope of the Phillips curve (31).

The extent to which strategic complementarity induces real rigidity can be measured by its effect on the slope of the Phillips curve, particularly on the slope factor Γ_i described in (28). All else equal, a larger value of Γ_i causes more real rigidity and thus the model displays greater monetary non-neutrality. By comparing the Phillips curve slope (factor) in the model with heterogeneous complementarities (in the absence of heterogeneity in firm size) to that in the standard DSGE counterpart model with homogeneous firms and hence homogeneous complementarities, where the parameter that governs the superelasticity of demand for each good is set at $\bar{\epsilon} = \sum_{i=1}^{k} \omega_i \epsilon_i$ so that the two models share the same demand curvature σ, we have the following result.

Proposition 1 *Suppose that productivity is homogeneous across firms, i.e., $z_i = 1$ for all $i = 1, \ldots, k$, that the Phillips curve slope factor Γ_i is positive for each $i = 1, \ldots, k$, and that the curvature of demand in the standard DSGE counterpart model with homogeneous firms is the same as that in the model with heterogeneous strategic complementarities, i.e., $\sigma = -\theta \sum_{i=1}^{k} \omega_i \epsilon_i$. Then, the slope $\kappa = \sum_{i=1}^{k} \omega_i \kappa_i$ of the Phillips curve (31) in the latter model is steeper than that in the former model.*
Proof: See Appendix B.

Proposition 1 states that heterogeneous strategic complementarities in price setting across firm groups weaken real rigidity in relative prices. To illustrate this result, we use the values

[19] These values can be obtained from Table 3 using $\Delta_i = \omega_i/(n_i p_i^*)$ and $l_i \propto p_i^* \Delta_i / \mu_i$ for $i = 1, \cdots, k$.

[20] The solution implies that $\Delta_i = 1$ for all i and that eqs. (43) and (44) are not satisfied with the empirical number of establishments, labor share, and revenue share by firm-size group. Thus, the model needs heterogeneity in firm productivity to determine values of the parameters $\{\epsilon_i\}$ that govern strategic complementarities, as in the next subsection.

of $\{\omega_i\}$ and $\{\epsilon_i\}$ reported in Table 3. Then, the slope of the Phillips curve (31) is calculated as $\kappa = \sum_i \omega_i \kappa_i = 0.194$. In the standard DSGE counterpart model with homogeneous firms, where the value of $\epsilon_i = \bar{\epsilon}$ for each i is chosen to achieve the same demand curvature $\sigma = 4.43$ as in the model with heterogeneous complementarities, the Phillips curve slope is computed as a smaller value of $\bar{\kappa} = (1-\xi)(1-\beta\xi)/\{\xi[1-\bar{\epsilon}\theta/(\theta-1)]\} = 0.180$. Moreover, in the absence of strategic complementarities, the Phillips curve slope is given by $(1-\xi)(1-\beta\xi)/\xi$, so we have a larger value of 0.269. Therefore, strategic complementarities reduce the slope of the Phillips curve less if they are concentrated in only some firm groups than if they are spread uniformly across firms, and thus real rigidity is weaker. We will find an even smaller effect of heterogeneous strategic complementarities once we account for firm size in the next subsection.

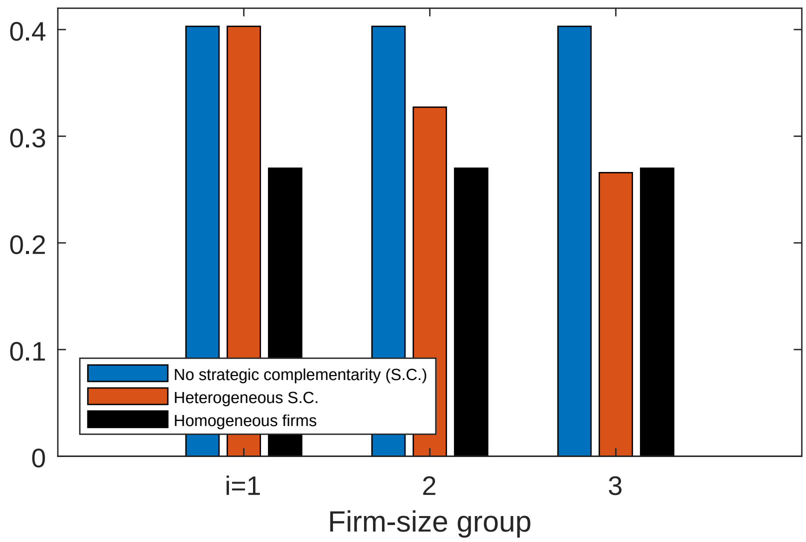
4.3 Main result

In this subsection, we use the calibrated model and show our main result that heterogeneity in strategic complementarities in price setting by firm size substantially weakens real rigidity in relative prices and monetary non-neutrality in the model, compared to the standard DSGE counterpart model with homogeneous firms (and hence homogeneous complementarities).

The calibration of model parameters presented in Tables 2 and 3 makes our model consistent both with the aggregate SUSB data and with the empirical evidence on cost pass-through by firm size reported in Table 1. Figure 1 displays the marginal cost elasticity of the optimized price for each firm-size group i. The middle bars illustrate the elasticity $(1-\beta\xi)/\Gamma_i$ observed in eq. (25) in our calibrated model. As a reference, the left bars show the corresponding elasticity $1-\beta\xi$ in the case of no strategic complementarity, i.e., $\epsilon_i = 0$ for all i (so $\Gamma_i = 1$ for all i), while the right bars present the one $(1-\beta\xi)/[1-\bar{\epsilon}\theta/(\theta-1)]$ in the standard DSGE counterpart model with homogeneous firms. If firms are homogeneous, strategic complementarities reduce the marginal cost elasticity evenly among all firm-size groups, compared to the case of no strategic complementarity. In contrast, when strategic complementarities are heterogeneous across firm-size groups, the larger-firm groups have lower marginal cost elasticities because of their stronger complementarities.

The slope of the Phillips curve is again steeper if strategic complementarities are concentrated in only larger-firm groups. In our calibrated model, the slope of the Phillips curve (31)

Figure 1: Marginal cost elasticities.

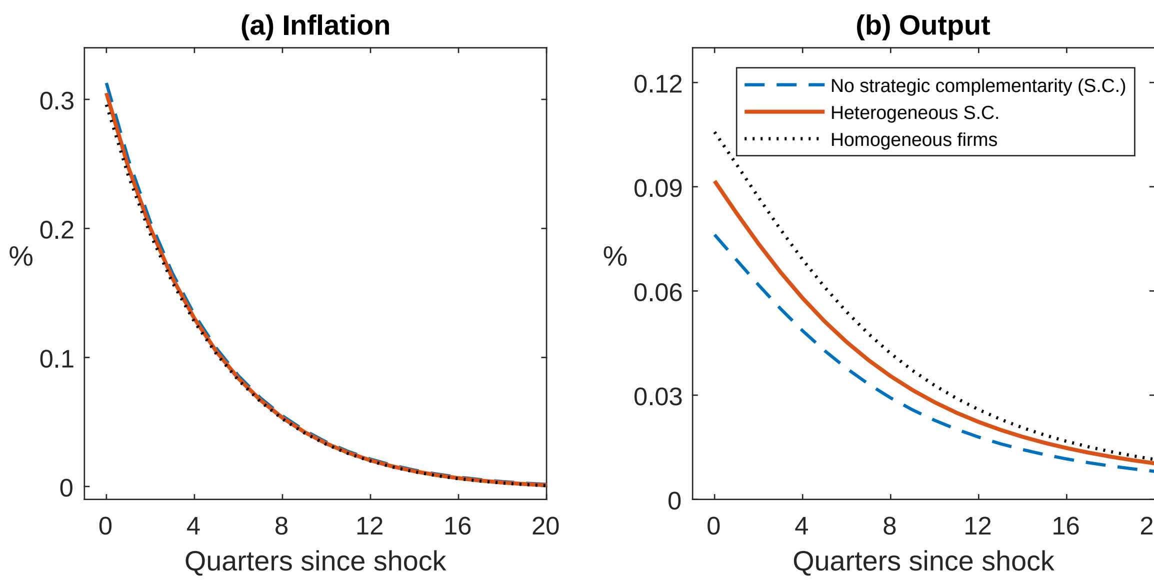


Notes: The figure displays the marginal cost elasticity of the optimized price $(1-\beta\xi)/\Gamma_i$ for each firm-size group $i = 1, 2, 3$. The bars labeled "Heterogeneous S.C." are obtained in our model under the calibration of parameters reported in Tables 2 and 3, while those labeled "No strategic complementarity (S.C.)" represent the case of a constant elasticity of demand for each good (i.e., $\epsilon_i = 0$ for all i) in the calibration and those labeled "Homogeneous firms" are obtained in the standard DSGE counterpart model with homogeneous firms in which the value of $\epsilon_i = \bar{\epsilon}$ for each i is chosen to achieve the same demand curvature $\sigma = 4.43$ as in our calibrated model.

is calculated as $\kappa = 0.217$, which exceeds the value of $\bar{\kappa} = 0.180$ obtained in the standard DSGE counterpart model with homogeneous firms. The value of $\kappa = 0.217$ is also larger than that of $\kappa = 0.194$ obtained in the absence of firm heterogeneity in productivity analyzed in the previous subsection. This is because higher productivity of larger-firm groups reduces their steady-state optimized prices and hence the price elasticities of demand for their goods, which mitigates the increase in real rigidity induced by the groups' greater superelasticity. The latter effect, captured by $(p_i^*/d)^{\gamma_i} < 1$ in (28), is only partly offset by greater steady-state markups $\mu_i > 1$ of larger-firm groups that result from their lower price elasticities of demand.

The steeper slope κ and hence weaker real rigidity arising from heterogeneous strategic complementarities across firm size reduces monetary non-neutrality in the calibrated model. Monetary non-neutrality can be gauged by the impulse responses to a monetary policy shock. Figure 2 plots the responses of inflation (panel a) and output (panel b) to a 1 percent expansionary shock to the annualized monetary policy rate in our model (with heterogeneous strategic complementarities) under the calibration of parameters reported in Tables 2 and 3 (solid lines), and compares the responses with those obtained in the case of no strategic complementarity, that is, a constant elasticity of demand for each good (i.e., $\epsilon_i = 0$ for all i) in the calibration (dashed lines) and those obtained in the standard DSGE counterpart model with homogeneous firms (dotted lines). Both inflation and output increase on impact as the shock raises consumption and the real marginal cost, before returning to their steady-state values. In each panel, the impulse response in our calibrated model lies about midway between those in the case of no complementarity and in the counterpart model with homogeneous firms. The response of output indicates that heterogeneous strategic complementarities dampen the increase in monetary non-neutrality by about half.

Figure 2: Impulse responses to a monetary policy shock.



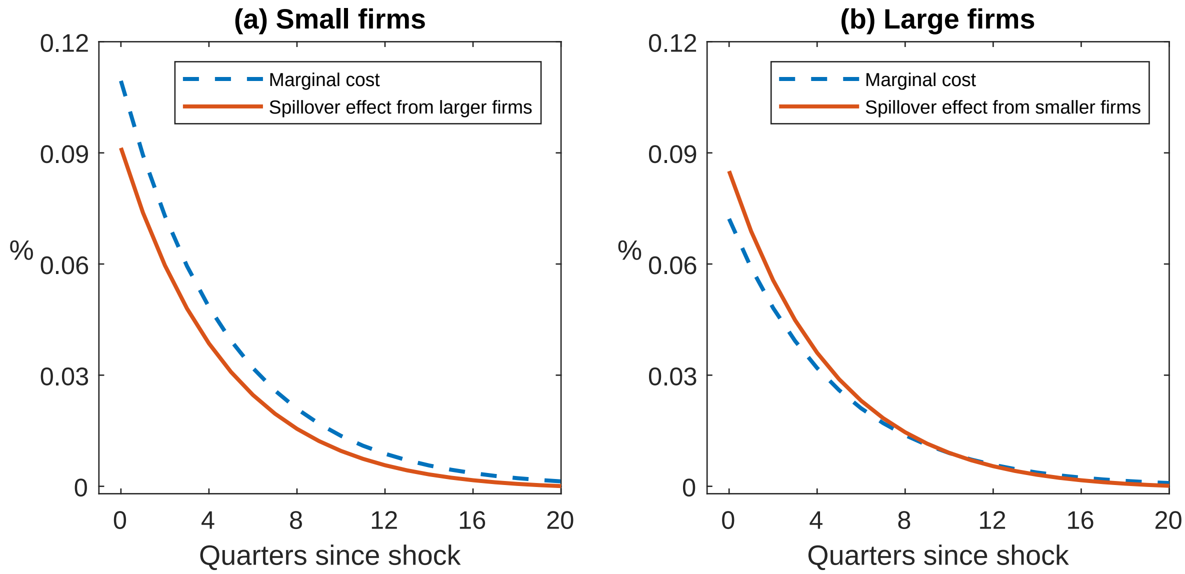
Notes: Panels (a) and (b) plot impulse responses of inflation and output, respectively, to a 1 percent expansionary shock to the annualized monetary policy rate. The solid lines labeled "Heterogeneous S.C." are obtained in our model under the calibration of parameters reported in Tables 2 and 3, while the dashed lines labeled "No strategic complementarity (S.C.)" represent the case of a constant elasticity of demand for each good (i.e., $\epsilon_i = 0$ for all i) in the calibration and the dotted lines labeled "Homogeneous firms" are obtained in the standard DSGE counterpart model with homogeneous firms in which the value of $\epsilon_i = \bar{\epsilon}$ for each i is chosen to achieve the same curvature $\sigma = 4.43$ as in our calibrated model.

For a more quantitative assessment of monetary non-neutrality, we compare the cumulative impulse responses. The ratio of the cumulative response of inflation in our calibrated model to that in the case of no strategic complementarity is 0.963, while the corresponding ratio of the cumulative response of output is 1.222. In contrast, the ratio of the cumulative response of inflation in the standard DSGE counterpart model with homogeneous firms to that in the case of no complementarity is 0.934, whereas the corresponding ratio of the cumulative response of output is 1.414. This confirms that heterogeneous complementarities reduce the amplification of the output response by almost half and thus dampen the increase in monetary non-neutrality substantially.

An economic explanation for the weakened real rigidity and dampened increase in monetary non-neutrality in our calibrated model is as follows. Because firms in the small-size group adjust their goods prices facing a constant elasticity of demand, they more fully pass through changes in the marginal cost to their prices. Firms in the larger-size groups, however, exhibit strategic complementarities in price setting. Then, an expansionary monetary policy shock raises the real marginal cost and hence the optimized relative price of the small-firm group, which in turn increases the optimized relative prices of the larger-firm groups through their strategic complementarities. In this way, the fraction $1 - \xi$ of firms in each size group adjusts their goods prices substantially after the policy shock, thus weakening real rigidity. This explanation is supported by Figure 3, which displays the external drivers of the impulse responses of the optimized relative prices $\hat{p}^*_{i,t}$ of the small-firm group ($i = 1$) and the large-firm group ($i = 3$) to an expansionary monetary policy shock. The two external drivers are the effect of the real marginal cost and the spillover effect from the other firm-size groups' optimized relative prices, which are the third and second terms on the right-hand side of eq. (30), respectively. Each panel of the figure plots these two drivers' contributions to the impulse response of the optimized relative price of the small- or large-firm group. Among the two drivers, the effect of the marginal cost is the primary one for the small-firm group, as shown by the dashed line in panel (a) of the figure. In contrast, the spillover effect from the other firm-size groups is the primary driver for the large-firm group, as demonstrated by the solid line of panel (b).[21]

[21] The impulse response of the optimized relative price is not shown, but it increases less for the large-firm group than for the small-firm group, consistent with the evidence of Goldberg and Hellerstein (2011) that large firms change their prices on average by a smaller amount than small firms and of Bhattarai and Schoenle (2014) that firms selling more goods—a proxy for firm size—change their prices on average by a smaller amount.

Figure 3: Contributions to the impulse responses of optimized relative prices of goods.



Notes: Panels (a) and (b) plot contributions to the impulse responses of the optimized relative prices $\hat{p}^*_{i,t}$ of the small-firm group ($i = 1$) and the large-firm group ($i = 3$), respectively, to a 1 percent expansionary shock to the annualized monetary policy rate. The contributions come from the two external drivers of the optimized relative price described in (30): the effect of the real marginal cost $(1-\beta\xi)/\Gamma_i\,\hat{mc}_t$ and the spillover effect from the other firm-size groups' optimized relative prices $\beta(1-\xi)\sum_{j\neq i}\omega_i E_t\,\hat{p}^*_{j,t+1}$.

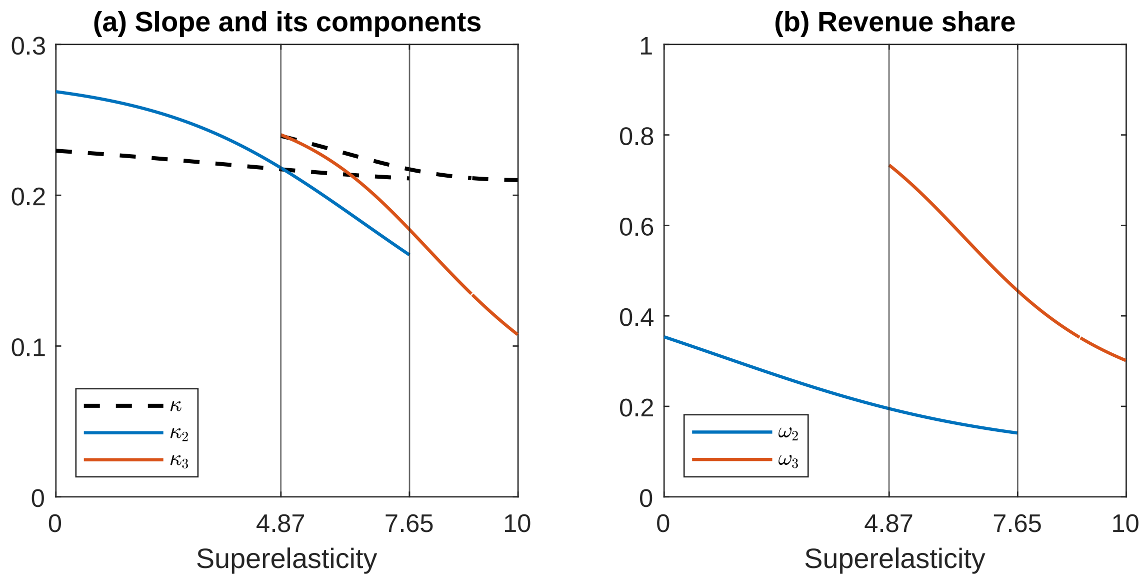
4.4 Robustness analysis

We have found that heterogeneity in strategic complementarity in price setting by firm size substantially weakens real rigidity in relative prices and monetary non-neutrality in the model. In this subsection, we confirm the robustness of the finding to alternative values of model parameters. We begin by varying the degree of strategic complementarity and then consider the role of other structural parameters of the model.

A rise in the superelasticity of demand for goods of each group of middle and large firms ($i = 2, 3$) leads to a muted increase in real rigidity. Figure 4 plots the Phillips curve slope $\kappa = \sum_i \omega_i \kappa_i$ as the dashed lines in panel (a), its components $\kappa_i = (1-\xi)(1-\beta\xi)/(\xi\,\Gamma_i)$ for middle- and large-firm groups $i = 2, 3$ as the solid lines in panel (a), and the components' weights ω_i, or equivalently, the groups' steady-state revenue shares in panel (b), as the superelasticity of demand for goods of each group of middle and large firms in turn increases while those of the other firm-size groups are held fixed at their calibrated values reported in Table 3. In panel (a) of the figure, the solid lines demonstrate that the slope component

κ_i of each group of middle and large firms $i = 2, 3$ decreases for a larger superelasticity of demand for goods of the group. The dashed line then traces the Phillips curve slope κ and shows that the slope remains relatively flat. The effect of each component κ_i depends on its weight in the slope κ. As shown in panel (b), the weight or steady-state revenue share of the middle-firm group $i = 2$ is smaller than that of the large-firm group $i = 3$ and thus the slope is less sensitive to the superelasticity of demand for goods of the middle-firm group than that of the large-firm group.

Figure 4: Phillips curve slope, its components, and revenue shares for various degrees of strategic complementarities of middle- and large-firm groups.



Notes: Panel (a) plots the Phillips curve slope $\kappa = \sum_i \omega_i \kappa_i$ (dashed line) and its components $\kappa_i = (1-\xi)(1-\beta\xi)/(\xi\,\Gamma_i)$ for middle- and large-firm groups $i = 2, 3$ (solid lines), while panel (b) displays the components' weights, or equivalently, the groups' steady-state revenue shares ω_2 and ω_3. The slope component κ_i and its weight ω_i are calculated by increasing the superelasticity of demand for goods of each group of middle and large firms $i = 2, 3$ while keeping those of the other firm-size groups fixed at their calibrated values presented in Table 3. The values of other model parameters are reported in Tables 2 and 3 and the values of the steady-state variables d and p_i^*, for $i = 1, \ldots k$, are determined by (45)–(47).

Another reason why the slope κ remains relatively flat is that a greater superelasticity lowers the steady-state revenue share of each group of middle and large firms ($i = 2, 3$) in panel (b), thus reducing the effect of the smaller slope component κ_i on the slope κ. This is because for each group of middle and large firms, a greater superelasticity implies a higher steady-state average markup and thus raises the steady-state optimized relative price, which induces decelerating demand and lower revenue in the steady state by increasing the steady-state price elasticity of demand. Thus, stronger strategic complementarities in the price-setting behavior of middle- and large-firm groups are evident both in their smaller marginal cost elasticities and in a larger spillover effect in the price-setting condition (30) because the revenue shares shift toward the other firm-size groups, in particular the small-firm group ($i = 1$), which exhibits no strategic complementarities.

Table 4: Cumulative impulse responses and their ratios.

	Inflation		Output	
Case	CIR	Ratio	CIR	Ratio
(a) *Baseline calibration of model parameters* ($\sigma = 4.43$)				
No strategic complementarity (S.C.)	1.537	1	0.757	1
Heterogeneous S.C.	1.480	0.963	0.925	1.222
Homogeneous firms	1.435	0.934	1.071	1.414
(b) *More nominal price rigidity*: $\xi = 0.75$ ($\sigma = 4.43$)				
No S.C.	1.156	1	1.944	1
Heterogeneous S.C.	1.040	0.899	2.291	1.178
Homogeneous firms	0.961	0.831	2.561	1.318
(c) *Less elastic labor supply*: $\chi = 1/2$ ($\sigma = 4.43$)				
No S.C.	1.461	1	0.966	1
Heterogeneous S.C.	1.391	0.952	1.171	1.212
Homogeneous firms	1.335	0.914	1.345	1.392
(d) *Smaller elasticity of substitution between goods*: $\theta = 7$ ($\sigma = 2.50$)				
No S.C.	1.534	1	0.762	1
Heterogeneous S.C.	1.494	0.974	0.878	1.153
Homogeneous firms	1.446	0.943	1.032	1.353
(e) *Modest superelasticity for small-firm group*: $-\theta\epsilon_1 = 2$ ($\sigma = 4.66$)				
No S.C.	1.537	1	0.757	1
Heterogeneous S.C.	1.454	0.947	1.006	1.329
Homogeneous firms	1.430	0.931	1.086	1.435
(f) *Larger number of firm groups*: $k = 5$ ($\sigma = 4.21$)				
No S.C.	1.537	1	0.757	1
Heterogeneous S.C.	1.483	0.965	0.917	1.212
Homogeneous firms	1.440	0.937	1.056	1.395

Notes: The table presents the cumulative impulse responses (CIR) of inflation and output to a 1 percent expansionary shock to the annualized monetary policy rate obtained in our model with the values of ϵ_i reported in Table 3 ("Heterogeneous S.C."), those obtained in the standard DSGE counterpart model with homogeneous firms in which $\epsilon_i = \bar{\epsilon}$ for all i ("Homogeneous firms"), and their ratios with the corresponding CIR in the case of "No strategic complementarity (S.C.)," i.e., $\epsilon_i = 0$ for all i. The other model parameter values are reported in Tables 2 and 3, except for the alternative parameter values used in panels (b)–(e).

As for other structural parameters of the model, Table 4 reports the cumulative impulse responses (CIR) in our model (with heterogeneous strategic complementarities) and in the standard DSGE counterpart model with homogeneous firms in which the same demand curvature σ is achieved as in our model, and the ratios of the CIR with the corresponding ones in the case of no strategic complementarity. Panel (a) summarizes the numbers obtained under the baseline calibration of model parameters reported in Table 2 and the firm-size-specific parameter values presented in Table 3. As observed before, the amplification of the CIR of output to a monetary policy shock obtained in the counterpart model with homogeneous firms is dampened substantially once strategic complementarities are concentrated in only larger-firm groups. Panels (b), (c), and (d) consider more nominal price rigidity ($\xi = 0.75$), a less elastic labor supply ($\chi = 1/2$), and a smaller elasticity of substitution between goods ($\theta = 7$), respectively. Although the alternative parameter values influence the CIR quantitatively, their influence goes in the same direction both in our model with heterogeneous complementarities and in the case of no complementarity, so that the ratios of the CIR are less sensitive. Panel (e) relaxes the assumption of a constant elasticity of demand in the small-firm group ($i = 1$) by selecting a modest positive value of the superelasticity of $-\theta\epsilon_1 = 2$. Because this makes the marginal cost elasticities across firm-size groups more similar, the increase in monetary non-neutrality is somewhat more substantial, but still weaker, in the model with heterogeneous complementarities than in the counterpart model with homogeneous firms. Finally, panel (f) increases the number of firm groups to $k = 5$ using k-means clustering and detects almost no change from the results obtained under the baseline calibration reported in panel (a).

5 Concluding Remarks

This paper has presented new empirical evidence based on firm survey data that compared to small firms, larger firms show significantly less cost pass-through. The evidence complements the empirical result of recent research that only large firms exhibit strategic complementarities in price setting. To examine the implications of heterogeneity in strategic complementarity by firm size for inflation dynamics, the paper develops a DSGE model with the twin features that firm heterogeneity in productivity generates heterogeneity in firm size and that strategic complementarity in price setting arising from a non-CES aggregator of differentiated goods is heterogeneous across firm size. The model is calibrated to the SUSB data of the US Census Bureau, and the calibration implies that larger firms with higher productivity exhibit stronger strategic complementarities in line with the empirical result of recent research. The calibrated model generates substantially less real rigidity in relative prices and a substantially smaller increase in monetary non-neutrality than the standard DSGE counterpart model with homogeneous firms and hence homogeneous strategic complementarities achieves. Real rigidity is weakened because small firms more fully pass through changes in the marginal cost, which leads larger firms that exhibit strategic complementarities to bring their goods prices in line with those of small firms.

Monetary policymakers gain insights from results based on DSGE models that often assume homogeneous strategic complementarities in price setting across firms to ensure real rigidity in relative prices and hence plausible monetary non-neutrality along with moderate nominal price rigidity. The paper has shown that the link between strategic complementarity and real rigidity is a fragile one that depends on the unrealistic simplifying assumption that firm size is irrelevant for price-setting behavior. A promising agenda for future research using DSGE models is therefore to consider other sources of real rigidity. A shift in emphasis from so-called micro real rigidities, including strategic complementarity in price setting, toward macro real rigidities, such as real wage rigidity and the input-output structure of the economy, could put DSGE models on a more robust footing.

Appendix

A Multi-product firms

This appendix outlines a version of the model in which firms possibly produce multiple goods.

There are k groups of firms $\Omega_i = \{f \in [0,1] : z(f) = z_i, \epsilon(f) = \epsilon_i\}$, $i = 1, \dots, k$. The firm groups Ω_i, $i = 1, \dots, k$ are disjoint, $\bigcup_{i=1}^k \Omega_i = [0,1]$, and the measure of firms in group Ω_i is $\int_{\Omega_i} df = m_i$, so we have $\sum_{i=1}^k \int_{\Omega_i} df = \sum_{i=1}^k m_i = 1$. Each firm $f \in [0,1]$ may produce multiple goods. Let the set of firm f's goods be denoted by $\Phi_f = \{j \in [0,1] : \text{goods produced by firm } f\}$. The sets Φ_f for $f \in \Omega_i$ are disjoint, the sets $\bigcup_{f \in \Omega_i} \Phi_f$, $i = 1, \dots, k$ are also disjoint, $\bigcup_{i=1}^k \bigcup_{f \in \Omega_i} \Phi_f = [0,1]$, and the measure of goods produced by all firms in group i is $\int_{\Omega_i} \int_{\Phi_f} dj\, df = n_i$, so we have $\sum_{i=1}^k \int_{\Omega_i} \int_{\Phi_f} dj\, df = \sum_{i=1}^k n_i = 1$. Note that in the model with multi-product firms presented here, n_i denotes the number of goods produced by firms in group i and differs from the number m_i of firms in the group.

In the model, all goods are indexed by the pair (j, f). Thus, the aggregator (2) of the composite-good producer becomes

$$1 = \int_0^1 F_i\left(\frac{Y_t(j,f)}{Y_t}\right) dj = \sum_{i=1}^k \int_{\Omega_i} \int_{\Phi_f} F_i\left(\frac{Y_t(j,f)}{Y_t}\right) dj\, df.$$

The average relative price (4) and the condition for zero profits (6) also become, respectively,

$$d_{i,t} = \left[\frac{1}{n_i} \int_{\Omega_i} \int_{\Phi_f} \left(\frac{P_t(j,f)}{P_t}\right)^{1-\gamma_i} dj\, df\right]^{\frac{1}{1-\gamma_i}}, \quad i = 1, \dots, k,$$
$$1 = \sum_{i=1}^k \frac{n_i}{1+\epsilon_i} \left[\left(\frac{d_{i,t}}{d_t}\right)^{-\gamma_i} d_{i,t} + \epsilon_i \left(\frac{1}{n_i} \int_{\Omega_i} \int_{\Phi_f} \frac{P_t(j,f)}{P_t}\, dj\, df\right)\right].$$

The aggregate production function of each firm group $i = 1, \dots, k$ continues to be described by (8) but with

$$s_{i,t} \equiv \frac{1}{n_i} \int_{\Omega_i} \int_{\Phi_f} \left(\frac{P_t(j,f)}{P_t}\right)^{-\gamma_i} dj\, df.$$

These equilibrium conditions are apparently different from those of our model. Because Calvo-style staggered price setting takes place across the goods produced by firms in group i (i.e., n_i), rather than across the firms themselves (i.e., m_i), the two models are observationally equivalent.

B Proof of Proposition 1

Suppose that $z_i = 1$ for all $i = 1, \ldots, k$. Then, we can verify that for any arbitrary values of $\{\epsilon_i\}_{i=1}^k$, $p_i^* = d = 1$ for all $i = 1, \ldots, k$ is a solution to eqs. (46)–(47) in the model with heterogeneous strategic complementarities. Thus, from (28), it follows that for each i, we have $\Gamma_i = 1 - \epsilon_i \theta/(\theta - 1)$ and hence

$$\kappa_i = \frac{(1-\xi)(1-\beta\xi)}{\xi\,\Gamma_i} = \frac{(1-\xi)(1-\beta\xi)}{\xi[1-\epsilon_i\theta/(\theta-1)]}$$

in the Phillips curve slope $\kappa = \sum_{i=1}^k \omega_i \kappa_i$. Moreover, in the standard DSGE counterpart model with homogeneous firms, the slope of the Phillips curve is given by

$$\bar{\kappa} = \frac{(1-\xi)(1-\beta\xi)}{\xi[1-\bar{\epsilon}\theta/(\theta-1)]},$$

where $\bar{\epsilon} = \sum_{i=1}^k \omega_i \epsilon_i$.

Define the function

$$f(x) = \frac{(1-\xi)(1-\beta\xi)}{\xi[1+x\theta/(\theta-1)]}.$$

Then, we have $\kappa_i = f(-\epsilon_i)$ for all $i = 1, \ldots, k$ and $\bar{\kappa} = f(-\bar{\epsilon})$. Since $\theta > 1$, we can show that for $x > -(\theta-1)/\theta$ (so that $f(x) > 0$), f is a convex function, i.e., $f'(x) < 0$ and $f''(x) > 0$. From the convexity of $f(x)$, it follows that for any arbitrary values $\{\epsilon_i\}_{i=1}^k$ such that $\kappa_i > 0$ for all $i = 1, \ldots, k$, we have

$$\kappa = \sum_{i=1}^k \omega_i \kappa_i = \sum_{i=1}^k \omega_i f(-\epsilon_i) > f\left(-\sum_{i=1}^k \omega_i \epsilon_i\right) = f(-\bar{\epsilon}) = \bar{\kappa}.$$

Therefore, the slope of the Phillips curve is steeper in the model with heterogeneous strategic complementarities than in the standard DSGE counterpart model with homogeneous firms. ∎

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