Imperfect Information, Heterogeneous Demand Shocks, and Inflation Dynamics[*]

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Abstract

We use survey data for the universe of Japanese firms to establish the positive co-movement of expectation about aggregate demand and that of sector-specific demand indicative of significant information frictions. We show that a parsimonious model with imperfect information on the *current* aggregate and sector-specific components of demand aligns with the observed positive co-movement. The model further predicts that an increase in the relative volatility of sector-specific demand –compared to aggregate demand– dampens the sensitivity of inflation to fluctuations in real activity. We empirically test this theoretical prediction using Japanese data and show that variations in the volatility of sector-specific shocks account for shifts in the responsiveness of inflation to economic activity in Japan over the past three decades.

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1 Introduction

A large class of macroeconomic models builds on the premise that firms set prices to maximize profits by optimally responding to demand, and several studies show that shocks to demand are heterogeneous and reflect aggregate and sector-specific disturbances.[1] The classic study by Ball and Mankiw (1995) shows that the optimal price changes if the movement in demand originates from the aggregate shock, but it remains unchanged if the movement originates from the sector-specific shock. In reality, however, information is imperfect and firms cannot perfectly distinguish the source of the changes in demand. Thus, firms optimally adjust prices based on the expectations about whether the source of the demand change stems from aggregate or sector-specific disturbances.

Despite the centrality of expectations to price changes, the empirical evidence on expectations about the distinct aggregate and sector-specific components of demand is scarce. Moreover, despite standard models with perfect information outline a tight link between the source of the shock and the firm's optimal pricing decision, there are no studies that connect imperfect information on the different components of demand to the sensitivity of inflation to economic activity.

Our analysis fills these gaps by providing novel empirical evidence on the formation of expectations on the different components of demand from unique sector-level survey data for the universe of Japanese firms, and developing a simple model of imperfect information that links those expectations to the sensitivity of inflation to economic activity. We show that imperfect information on the components of demand plays a critical role in explaining the observed positive comovement in the expectations on the different components of demand and to account for the changes in the sensitivity of inflation to changes in economic activity in Japan over the past three decades.

Our analysis establishes four new results. First, we document novel evidence on the positive co-movements between expectations on aggregate and sector-specific components of demand using two distinctive sector-level surveys, respectively, for the universe of Japanese firms across around 30 sectors. This evidence is important since it shows that expectations about the aggregate and sector-specific components of demand are not independent, as implied by models based on perfect information.

Second, we demonstrate that imperfect information on the *current* shocks to demand is

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[1] See di Giovanni et al. (2014) and references therein.

critical to generate the observed positive co-movement in firms' expectations. Motivated by the empirical results, we extend the seminal island framework in Lucas (1972) with nominal price rigidities, assuming that firms cannot separately observe the different aggregate and sector-specific components that jointly move the observed demand and cannot adjust prices flexibly. We prove analytically that imperfect information generates a positive co-movement in the expectations about the different components of demand that is consistent with survey data.

Third, we use our model to study the sensitivity of inflation to changes in aggregate demand. Nominal price rigidities link inflation to the expectations of demand that in our model comprise the expectations on the different aggregate and sector-specific components. We show that the degree of sectoral heterogeneity in demand shocks – encapsulated by the ratio of volatility of sector-specific demand shocks with respect to the volatility of aggregate demand shocks – is critical for the sensitivity of inflation to demand. Under perfect information, if the change in total sectoral demand originates from the aggregate component of demand, the price adjustment is large as a result of strategic complementarity in price-setting that leads all firms to adjust prices in response to the aggregate shock. If instead the change in total sectoral demand originates from the sector-specific component of demand, the price adjustment in the sector is contained since firms would either lose customers (if the price rises) or forego earnings for a lower markup (if the price falls), while firms in other sectors maintain the same price. Imperfect information prevents firms from accurately disentangling the different contributions of aggregate and sector-specific components to total sectoral demand. Therefore, firms optimally attribute part of a change in total sectoral demand to movements in the sector-specific component of demand and thus underreact to shocks compared to an environment with perfect information. A testable prediction of our theoretical framework is that the response of prices to aggregate demand is inversely related to the volatility of sector-specific shocks.

Fourth, we test the prediction from the model on the inverse relationship between the volatility of sector-specific shocks and the response of inflation to aggregate demand on Japanese data. We estimate the volatility of the sector-specific component of demand relative to the volatility of the aggregate component of demand by using principal component analysis on sector-level data for Japanese firms across 29 sectors for the period 1975-2022. In line with the theory, we show that the increase in the ratio of the volatility in sector-specific shocks compared to the volatility in aggregate shocks played a significant role in the reduction of the sensitivity of inflation to aggregate demand. The same pattern is also confirmed for the sectoral inflation.

Our analysis is linked to four strands of literature. First, we relate to the literature on the formation of expectations under imperfect information. The study closest to us is Andrade et al. (2022) who examine the empirical plausibility of information frictions in the Lucas-island model by studying the relation between firms' expectations about aggregate variables and estimated industry-specific shocks. The literature includes studies that develop imperfect information in models with flexible prices (Woodford, 2003; Hellwig and Venkateswaran, 2009; Crucini et al., 2015; Afrouzi, 2018; and Kato et al., 2021a) and nominal price rigidities (Fukunaga, 2007; Nimark, 2008; Angeletos and La'O, 2009; Melosi, 2017; and L'Huillier, 2020). We also relate to studies that allow for coexistence of aggregate and idiosyncratic shocks in the presence of costly information acquisition (Veldkamp and Wolfers, 2007; and Acharya, 2017). Coibion et al. (2021) and Coibion et al. (2020) provide broad evidence on the relevance of firms' expectations to firms' decisions. Compared to the aforementioned studies, we provide novel evidence on firms' expectations about aggregate and sector-specific components of demand and assess the role of expectations for the sensitivity of inflation to aggregate demand.

Second, our analysis relates to the literature that investigates the effect of imperfect information on the Phillips curve. Mankiw and Reis (2002) and Dupor et al. (2010) develop sticky-information models to investigate the effect of informational frictions on the empirical performance of the Phillips curve. Coibion and Gorodnichenko (2015) establish that information frictions are critical in generating an empirically-consistent formation of expectations that explain the missing disinflation between 2009 and 2011. Coibion et al. (2018) show that information frictions are important to formulate an empirically congruent Phillips curve. Afrouzi (2018) and Afrouzi and Yang (2021) investigate the effect of rational inattention on the Phillips curve, showing that the endogenous attention allocation of firms to economic variables is critical for the sensitivity of inflation to the aggregate conditions.

Third, we are related to studies that investigate changes in the sensitivity of inflation to economic slack, as generated by the anchoring effect of inflation targets (Roberts, 2004; L'Huillier and Zame, 2020; and Gáti, 2023), the increase in competition in the goods market (Sbordone, 2008; and Zanetti, 2009), downward wage rigidities (Akerlof et al., 1996), and labor market frictions (Thomas and Zanetti, 2009; Zanetti, 2011; Chahrour et al., 2016 Cacciatore and Fiori, 2016; and Mitra, 2025).[2] Unlike these studies, however, our focus is on the relationship between imperfect information and the sensitivity of inflation to changes in aggregate demand.

Finally, our analysis relates to studies that investigate the formation of expectations under imperfect information using firm-level survey data. Several studies focus on inflation expectations (Andrade et al., 2022 use a survey of French manufacturing firms, Coibion et al., 2020 and Bartiloro et al., 2017 use a survey of Italian firms, Kumar et al., 2015 use a survey of firms in New Zealand, L'Huillier et al., 2023 use the Survey of Professional Forecasters). We are the first to use a survey on Japanese firms to study the formation of expectations about the aggregate and sector-specific components of demand.

The remainder of the paper is organized as follows. Section 2 provides evidence on the co-movement in expectations about aggregate and sector-specific demand from survey data. It develops a simple model with imperfect information that explains the positive co-movement in the expectations of the separate components of demand. Section 3 augments the model to incorporate general equilibrium and derive equilibrium pricing with and without nominal rigidities. Section 4 studies the sensitivity of inflation dynamics to demand, and it shows that the data corroborates the theoretical predictions. Section 5 concludes.

2 Evidence from Survey Data

In this section, we analyze the relationship between firms' expectations of aggregate and sector-specific components of sectoral demand using survey data from Japan. Our findings reveal a positive co-movement between firms' expectations of sector-specific and aggregate demand, underscoring the significant role of imperfect information in shaping these expectations, as we show in a parsimonious model of imperfect information.

2.1 Empirical Assessment

The empirical analysis consists of two distinct approaches. First, we estimate the relationship between firms' expectations of their current sector-specific demand and current aggregate demand. Second, we study the relationship between firms' expectations of the *future growth*

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[2] Several studies show a decline in the sensitivity of inflation to real activity. See survey by Mavroeidis et al. (2014) for a recent review of the literature on U.S. data. Kaihatsu et al. (2017) and Bundick and Smith (2020) provide evidence on the reduced sensitivity of inflation to real activity in Japanese data.

rate of sector-specific demand and aggregate demand. Both analyses lead to the same conclusion: firms' expectations regarding sector-specific and aggregate demand components exhibit a positive and significant co-movement.

We first describe the data used in the regression analyses, followed by a presentation of our empirical results.

Survey Data. We use two different datasets, the Business Outlook Survey and Annual Survey of Corporate Behavior. The Business Outlook Survey covers around 14,400 Japanese firms.[3] The survey is administered by the Cabinet Office and the Ministry of Finance starting in 2004. The survey is conducted quarterly and covers corporations with capital of 10 million yen or more (about 10 thousand firms) in 37 industries and three firm sizes (large, medium and small firms).[4]

The survey inquires about the direction of the current and future (one-quarter ahead) business conditions of the firms ("Business conditions") and the broader macroeconomic conditions ("Domestic economic conditions"). Specifically, firms are requested to provide an assessment on the changes to demand relative to the previous quarter, choosing from categories: "Rise," "Unchanged," "Fall," and "Unknown." The answers are aggregated in the Business Survey Index (BSI), providing the ratio of firms that choose "Rise" minus the ratio of firms that choose "Fall."

The design of the survey allows us to use the BSIs for firms of different sizes as proxies for firms' sector-level average expectations regarding the growth of their sectoral demand and aggregate demand in the subsequent regressions.[5] Given that BSIs represent the average expectations of multiple firms in each sector, we assume that firm-specific noise each within a sector is washed out through aggregation.

We also use the Annual Survey of Corporate Behavior (ASCB) covering approximately 1,500 publicly listed Japanese firms.[6] The survey is administered by the Cabinet Office of Japan across 33 industries over the period 2003-2021. Firms complete a quantitative questionnaire that records the separate expectations about the one year ahead growth rate

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[3] Appendix E provides a description and summary statistics for the Business Outlook Survey.

[4] Large firms are the firms with capital of one billion yen or over, medium-sized firms are those with capital of 100 million to one billion yen, and small firms are those with capital of 10 million to 100 million yen.

[5] Since the published BSIs are those aggregated at industry-by-firm-size level rather than industry level, we treat these series as sectoral data for the regression analysis.

[6] Appendix F provides a description and summary statistics for the ASCB.

of the demand in their sectors and aggregate demand, thus providing an account of the firms' expectations about the different aggregate and sector-specific components of total sectoral demand.[7] The sector-level averages of the surveyed firms' responses are publicly available, and we use these series in our regression analysis below. Again, firm-specific noise is assumed to be eliminated in the average expectations of multiple firms through aggregation.

(i) Expectations on current sector-specific and aggregate demands. We study the relationship between the expectations on the *current* sector-specific and aggregate demands. Specifically, we estimate the following equation using panel data for all industries $i \in \mathcal{I}$, where $\mathcal{I}$ denotes the set of industries in the sample.

$$y_{i,t} = \alpha_i + \alpha_t + \alpha x_{i,t} + \epsilon_{i,t}, \tag{1}$$

where $y_{i,t}$ represents the average expectations of firms in sector i in period t regarding the changes in current aggregate demand, proxied by the sector-level BSIs related to current macroeconomic conditions, taken from the Business Outlook Survey.[8] α_i and α_t denote the fixed effect at sector-level and the time effect, respectively. $x_{i,t}$ represents the average expectations of firms in sector i in period t regarding the changes in current sectoral demand, proxied by the sector-level BSIs related to their own current economic conditions from the Business Outlook Survey. $\epsilon_{i,t}$ is the error term. While the changes in sectoral demand ($x_{i,t}$) may be driven by aggregated demand, the time effect (α_t) controls the common fluctuations across sectors. Consequently, the estimate of α reflects the correlation between changes in firms' expectations about changes in current sector-specific demand and those about changes in current aggregate demand. A positive correlation would suggest that firms' expectations about current aggregate demand are influenced by sector-specific demand.

Table 1 shows the estimation results. The first column shows the estimates $\hat{\alpha}$ for the entire sample, while the other columns display the estimates when focusing on samples from firms of different sizes. The table reveals that all estimates of $\hat{\alpha}$ are positive and statistically significant at the one percent level. This suggests that firms' expectations about changes

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[7] The question asked in the survey is: "Please enter a figure up to one decimal place in each of the boxes below as your rough forecast of Japan's nominal economic growth rates and the nominal growth rates of demand in your industry for FY20XX". The questionnaire of the survey is available at: https://www.esri.cao.go.jp/en/stat/ank/ank-e.html.

[8] While the survey publishes BSIs aggregated only at industry-by-firm-size level rather than at industry level, we treat these represent BSIs for different sectors. For example, we treat "Large&Construction" and "Small&Construction" as different sectors.

Table 1: Firms' expectations about current aggregate and sector-specific demand

Dataset: Tankan Survey; 2004/2Q-2023/1Q

Dependent Variable: Assessment of general economic conditions in the current quarter (industry average)

	(1) All samples	*(2) Large firms*	*(3) Mid-sized firms*	*(4) Small firms*
Assessment of own economic conditions in the current quarter (industry average)	0.54*** (0.02)	0.48*** (0.04)	0.50*** (0.03)	0.64*** (0.03)
Fixed effect	Yes	Yes	Yes	Yes
Period effect	Yes	Yes	Yes	Yes
Observations	7,864	2,672	2,672	2,520
Cross Section	109	37	37	35
Adjusted-R^2	0.85	0.84	0.83	0.84

Note: Estimated by ordinary-least-squares. The standard errors are cross-section (sector) cluster robust standard errors.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

in aggregate demand are positively correlated with firms' expectations about changes in sector-specific demand, regardless of the firm size.

(ii) Expectations on future sector-specific and aggregate demands. We next study the relationship between the expectations on the *future* sector-specific and aggregate demands. We first examine the relationship using the data from Business Outlook Survey and then complement the results with data from the Annual Survey of Corporate Behavior. Specifically, we estimate the following equation using panel data for all industries.

$$y_{i,t} = \beta_i + \beta_t + \beta x_{i,t} + \epsilon_{i,t}, \tag{2}$$

where $y_{i,t}$ represents the firms' sector-level average expectations regarding changes in future aggregate demand, and $x_{i,t}$ represents the firms' sector-level average expectations regarding the growth rate of future sectoral demand. β_i and β_t denote the sector-specific and period fixed effects, respectively. The common fluctuations in $x_{i,t}$ are accounted by the time effect (β_t), and thus the estimates of β capture the correlation between firms' expectations of future sector-specific demand growth and their expectations of future aggregate demand growth. In the analysis using the Business Outlook Survey, $y_{i,t}$ is proxied by the sector-level BSIs related to future (one-quarter ahead) macroeconomic conditions, while $x_{i,t}$ is proxied by the sector-level BSIs related to their own future economic conditions. For the analysis with the ASCB, $y_{i,t}$ is proxied by the firms' expectations of future (one-year ahead) nominal output growth, whereas $x_{i,t}$ is proxied by the firms' expectations of future (one-year ahead) nominal sectoral demand.

Table 2 presents the estimation results for $\hat{\beta}$ using the Business Outlook Survey, showing that the correlation between firms' expectations of future aggregate demand and their expectations of sector-specific components of sectoral demand is positive and statistically significant at the one percent level.

Table 2: Firms' expectations on future aggregate and sector-specific demands

Dataset: Tankan Survey; 2004/2Q-2023/1Q

Dependent Variable: Assessment of general economic conditions in the next quarter (industry average)

	(1) All samples	*(2) Large firms*	*(3) Mid-sized firms*	*(4) Small firms*
Assessment of own economic conditions in the current quarter (industry average)	0.50*** (0.02)	0.42*** (0.05)	0.47*** (0.02)	0.57*** (0.02)
Fixed effect	Yes	Yes	Yes	Yes
Period effect	Yes	Yes	Yes	Yes
Observations	7,864	2,672	2,672	2,520
Cross Section	109	37	37	35
Adjusted-R^2	0.76	0.69	0.72	0.78

Note: Estimated by ordinary-least-squares. The standard errors are cross-section (sector) cluster robust standard errors.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

To ensure results are robust, we perform the same analysis using the data of ASCB. Table 3 shows the estimation results for $\hat{\beta}$ using the ASCB, confirming a statistically significant positive correlation between firms' expectations of future aggregate demand and their expectations of the sector-specific components of sectoral demand at the one-percent level.

Table 3: Firms' expectations on future aggregate and sector-specific demands

Dataset: Annual Survey of Corporate Behavior; 2003-2021

Dependent Variable: Expectations about nominal output growth$_t$ (one-year ahead)

Expectations about nominal sectoral demand growth$_t$ (one-year ahead)	0.06*** (0.02)
Fixed effect	Yes
Period effect	Yes
Observations	574
Cross Section	33
Adjusted-R^2	0.86

*Note: Estimated by ordinary-least-squares. The standard errors are cross-section (sector) cluster robust standard errors. *** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

To summarize, our results from both types of analyses consistently demonstrate that the positive co-movement between firms' expectations of aggregate and sector-specific components of demand is a significant characteristic of firms' expectations.

2.2 Expectations under Imperfect Information

To link the significance of the positive co-movement of the firms' expectations about the components of aggregate and sector-specific demand observed in survey data with imperfect information, we develop a parsimonious model of imperfect information on the different components of demand. We will extend the model to a general equilibrium framework to study the implications for the sensitivity of inflation to demand in Section 3.

We assume the economy is populated by a representative household and a continuum of monopolistic competitive firms that produce differentiated goods indexed by $j \in [0,1]$ in a continuum of sectors indexed by $i \in [0,1]$. Each firm j in sector i observes total sectoral demand ($x_t(i)$) that changes in response to aggregate demand and sector-specific demand, according to $x_t(i) = q_t + v_t(i)$, without observing the separate realizations for the aggregate (q_t) and sector-specific components ($v_t(i)$).[9] Aggregate demand follows the stochastic process:

$$q_t = q_{t-1} + u_t, \tag{3}$$

where u_t is an AR(1) process:

$$u_t = \rho_u u_{t-1} + e_t, \tag{4}$$

with $0 \leq \rho_u < 1$, and $e_t \sim \mathcal{N}(0, \sigma_t^2)$. The sector-specific demand follows the AR(1) process:

$$v_t(i) = \rho_v v_{t-1}(i) + \epsilon_t(i), \tag{5}$$

where $-1 < \rho_v < 1$, and $\epsilon_t(i) \sim \mathcal{N}(0, \tau_t^2)$.

To simplify notation, we label $\widetilde{x}_t(i) = \Delta x_t(i)$, $\widetilde{v}_t(i) = \Delta v_t(i)$, and $u_t = \Delta q_t$ by using equation (3). Combining equations (4)-(5), we write the change in total sectoral demand, $\widetilde{x}_t(i)$, as the sum of the change in aggregate demand, u_t, and the change in sector-specific demand, $\widetilde{v}_t(i)$:

$$\widetilde{x}_t(i) = u_t + \widetilde{v}_t(i). \tag{6}$$

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[9] We will derive and revisit this relation in a general equilibrium framework in Section 3. A recent study by Chahrour and Ulbricht (2019) shows that imperfect information on disaggregate shocks of the type we have in our simple model generates realistic business cycle statistics.

In each period t, firms set prices without observing the current aggregate and sector-specific components of total sectoral demand and therefore are unable to infer the current aggregate price.[10] Thus, each firm uses information from the common signal of total sectoral demand (i.e., $x_t(i) = q_t + v_t(i)$) and the past realizations of aggregate and sector-specific components of demand to make inference on the current components of aggregate (q_t) and sector-specific demand ($v_t(i)$), such that $q_t \sim \mathcal{N}\left(q_{t-1} + \rho_u u_{t-1}, \sigma_t^2\right)$ and $v_t(i) \sim \mathcal{N}\left(\rho_v v_{t-1}(i), \tau_t^2\right)$.[11] Hence, in each period t, the information set for the firms in sector i is:

$$\mathcal{H}_t(i) \equiv \left\{ \{x_s(i)\}_{s=0}^{t}, \{q_s, u_s, v_s(i), e_s, \epsilon_s(i)\}_{s=0}^{t-1} \right\}, \tag{7}$$

and hereafter we denote the expectations under imperfect information as: $\mathbb{E}_t \equiv \mathbb{E}\left[\bullet | \mathcal{H}_t(i)\right]$.

In what follows, we show that imperfect information on the *current* components of demand explains the observed positive correlation between firms' expectations on aggregate and sector-specific components of total sectoral demand.

Mapping the model to the data. In the context of this model, Table 1 in Section 2 establishes the positive correlation between $\mathbb{E}_t\left[u_t\right]$ and $\widetilde{v}_t(i)$, and Table 3 indicates the positive correlation between $\mathbb{E}_t\left[\sum_{h=1}^{4} u_{t+h}\right]$ and $\mathbb{E}_t\left[\sum_{h=1}^{4} \widetilde{v}_{t+h}(i)\right]$. Under perfect information, they never hold as firms can separate aggregate demand from sector-specific demand that are orthogonal. However, in the following propositions, we show that the information structures above can explain our empirical observations.

First, the following proposition shows the structures of the firms' expectations under the information structures.

Proposition 1 *If total demand comprises unobservable aggregate and sector-specific components (i.e., $\widetilde{x}_t(i) = u_t + \widetilde{v}_t(i)$), the expectations at time t about the changes in aggregate and sector-specific demands are equal to:*

$$\mathbb{E}_t\left[u_t\right] = \rho_u u_{t-1} + \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2}\left[e_t + \epsilon_t(i)\right] \tag{8}$$

and

$$\mathbb{E}_t\left[\widetilde{v}_t(i)\right] = (\rho_v - 1) v_{t-1}(i) + \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\left[e_t + \epsilon_t(i)\right], \tag{9}$$

respectively.

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[10] The assumption that q_t is unobservable in period t implies that the labor market clears after firms set prices. Therefore, firms base their profit-maximizing decisions on the expected nominal wage in period t, as in Angeletos and La'O (2009).

[11] See Guerron-Quintana et al. (2018) for an overview on solutions for filtering problems in economics.

Proof: See Appendix D.1. □

Equations (8) and (9) show that the firm's expectations on the changes in aggregate and sector-specific demand depend on the changes in sectoral demand, which comprises shocks to aggregate and sector-specific shocks ($e_t + \epsilon_t(i)$) that the firm cannot separately observe. The response of each expectation to movement in total sectoral demand depends on the ratio τ_t/σ_t, which represents the volatility of sector-specific shocks relative to aggregate shocks. As the volatility of the shock to sector-specific demand is larger than the volatility of the shock to aggregate demand (i.e., $\tau_t/\sigma_t > 1$) – reflecting the fact that changes in total sectoral demand are predominantly driven by the sector-specific component of demand – the response of firms' expectations about the sector-specific component of demand to the change in total sector demand increases while the response of firms' expectations on the aggregate component of demand to total sectoral demand decreases.

The next propositions characterize the sign of the co-movement between the expectations of *current* aggregate and sector-specific demand, observed in Table 1

Proposition 2 *If total demand comprises unobservable aggregate and sector-specific components, the co-movement in the current expectations about aggregate and sector-specific demand is equal to:*

$$\mathbb{C}(\mathbb{E}_t[u_t], \mathbb{E}_t[\tilde{v}_t(i)]) = \frac{\sigma_t^2 \tau_t^2}{\sigma_t^2 + \tau_t^2} > 0, \tag{10}$$

where $\mathbb{C}(\cdot)$ is the unconditional covariance operator.

Proof: See Appendix D.2. □

Proposition 2 shows that the presence of imperfect information generates a positive co-movement between the expectations of *current* aggregate and sector-specific components of total sectoral demand. Given the non-zero persistence of aggregate and sector-specific shocks (equations 4 and 5), this generates a positive co-movement between the expectations about the components of 4-period (one-year) ahead demand, empirically observed in Table 3, as shown in the next proposition.

Proposition 3 *If total demand comprises unobservable aggregate and sector-specific components, the positive co-movement in the current expectations generates the positive co-movement in the 4-period ahead expectations:*

$$\mathbb{C}(\mathbb{E}_t[u_t], \mathbb{E}_t[\tilde{v}_t(i)]) > 0 \Rightarrow \mathbb{C}\left(\mathbb{E}_t\left[\sum_{h=1}^{4} u_{t+h}\right], \mathbb{E}_t\left[\sum_{h=1}^{4} \widetilde{v}_{t+h}(i)\right]\right) > 0.$$

Proof: See Appendix D.3. □

Proposition 3 provides the theoretical underpinning that imperfect information generates the positive correlation between the expectations on future aggregate and sector-specific components of demand. To sum up, the analysis shows that imperfect information on the distinct components of current sectoral demand is critical to replicate the positive co-movement in the expectations of aggregate and sector-specific components of demand observed in the data.

3 General Equilibrium

To study the implications of imperfect information on firms' price setting and the resulting link between inflation and economic activity, this section embeds the expectations based on imperfect information regarding distinct components of sectoral demand in a general equilibrium framework.

3.1 Model

The model is based on Woodford (2003) and Angeletos and La'O (2009). We maintain the information structure as in Lucas (1972) developed in the previous section and enrich the model with nominal price rigidities. The economy is populated by a representative household and a continuum of monopolistic competitive firms that produce differentiated goods, indexed by $j \in [0,1]$ in a continuum of sectors, indexed by $i \in [0,1]$. The representative household consumes the whole income with no saving in equilibrium. Monopolistic competitive firms face a total sectoral demand that comprises aggregate and sector-specific shocks, as described in equations (3), (4), and (5). Firms observe current total sectoral demand and the past realizations of aggregate and sector-specific shocks to demand, but they are unable to separately observe the realizations of aggregate and sector-specific components of total sectoral demand in real time. Namely, firms form expectations at time t, using the information set $\mathcal{H}_t(i)$ in equation (7).

The rest of the section develops the problems of households and firms and derives the equilibrium.

Households. The following utility function describes the preferences of the representative household over consumption, C_t, and labor, N_t:

$$\sum_{t=0}^{\infty} \beta^t \left(\log C_t - N_t\right),$$

where $\beta \in (0,1)$ is the discount rate. The household's aggregate consumption, C_t, and consumption of goods in sector i, $C_t(i)$, are defined by the CES consumption aggregators:

$$C_t \equiv \left[\int_0^1 \left(C_t(i)\Theta_t(i)\right)^{\frac{\eta-1}{\eta}} di\right]^{\frac{\eta}{\eta-1}}, \text{and } C_t(i) \equiv \left[\int_0^1 \left(C_t(i,j)\right)^{\frac{\widetilde{\eta}-1}{\widetilde{\eta}}} dj\right]^{\frac{\widetilde{\eta}}{\widetilde{\eta}-1}},$$

where $\eta > 1$ is the elasticity of substitution across sectors, $\widetilde{\eta} > 1$ is the elasticity of substitution across goods within the same sector, $C_t(i,j)$ is consumption of good j in sector i, and $\Theta_t(i)$ is the sector-specific preference shocks (defined below).

Firms. Each firm j in sector i (referred to as "firm (i,j)") faces the following demand:

$$C_t(i,j) = \Theta_t^{\eta-1}(i) \left(\frac{P_t(i,j)}{P_t(i)}\right)^{-\widetilde{\eta}} \left(\frac{P_t(i)}{P_t}\right)^{-\eta} C_t, \tag{11}$$

where $P_t(i) \equiv \left[\int_0^1 P_t^{1-\widetilde{\eta}}(i,j)dj\right]^{\frac{1}{1-\widetilde{\eta}}}$ is the price index for sector i, $P_t \equiv \left[\int_0^1 P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)di\right]^{\frac{1}{1-\eta}}$ is the aggregate price index, and the sector-specific preference shock, $\Theta_t(i)$, acts as an exogenous demand shifter for firm (i,j).[12]

Each firm (i,j) manufactures a single good $Y(i,j)$, according to the production technology:

$$Y_t(i,j) = AL_t^{\epsilon}(i,j), \tag{12}$$

where A is aggregate productivity and $\epsilon \in (0,1)$ determines the degree of diminishing marginal returns in production.

Market Clearing. In a symmetric equilibrium, market clearing implies $Y_t(i,j) = C_t(i,j)$ for each firm (i,j) and thus $Y_t = C_t$ in the economy. Aggregate nominal demand, Q_t, is given by the following cash-in-advance constraint:

$$Q_t = P_t C_t.$$

In the rest of the analysis, we use lower-case variables to indicate logarithm of the corresponding upper-case variables (i.e., $x_t \equiv \log X_t$).

---

[12] See Appendix A for the derivation of the demand function for each firm (i,j) and price indexes.

Optimal Price-Setting Rule and Total Sectoral Demand. In what follows, we derive the optimal price-setting rule as a function of total sectoral demand.

During each period t, the firm (i,j) sets the optimal price as a mark-up over the marginal cost:

$$p_t(i,j) = \mu + mc_t(i,j), \tag{13}$$

where $\mu \equiv \widetilde{\eta}/(\widetilde{\eta}-1) > 0$ is the mark-up and $mc_t(i,j)$ is the nominal marginal cost faced by firm (i,j). The nominal marginal cost is the difference between the nominal wage, w_t, and the marginal product of labor:

$$mc_t(i,j) = w_t + (1-\epsilon)\, l_t(i,j) - a - log(\epsilon). \tag{14}$$

Using the production technology in equation (12), we express labor input as: $l_t(i,j) = [y_t(i,j) - a]/\epsilon$, and we use it in equation (14) to rewrite the nominal marginal cost as:

$$mc_t(i,j) = w_t + \frac{1-\epsilon}{\epsilon} y_t(i,j) - \frac{1}{\epsilon} a - log(\epsilon).$$

The optimal labor supply condition for the representative household is:

$$w_t - p_t = c_t, \tag{15}$$

and the linearized consumer demand in equation (11) is:

$$c_t(i,j) = -\widetilde{\eta}\,(p_t(i,j) - p_t(i)) - \eta\,(p_t(i) - p_t) + c_t + (\eta - 1)\,\theta_t(i), \tag{16}$$

where the sector-specific preference shock, $\theta_t(i)$, follows the AR(1) process:

$$\theta_t(i) = \rho_v \theta_{t-1}(i) + \widetilde{\epsilon}_t(i), \tag{17}$$

and $\widetilde{\epsilon}_t(i) \sim \mathcal{N}(0, (1-\epsilon)^{-2}\,(\eta-1)^{-2}\,\tau_t^2)$.[13]

We derive the optimal price-setting rule for firm (i,j) by using equations (15), (16), the equilibrium conditions, $y_t(i,j) = c_t(i,j)$, $y_t = c_t$, and the cash-in-advance constraint, $y_t = q_t - p_t$, which yields:[14]

$$p_t(i,j) = r_1 p_t(i) + r_2 p_t + (1 - r_1 - r_2)\, x_t(i) + \xi, \tag{18}$$

---

[13] Note that the information set is augmented with $p_s, \theta_s(i)$, and $\widetilde{\epsilon}_t(i)$. Namely, the following is the observed variables at time t: $\mathcal{H}_t(i) \equiv \left\{\{x_s(i)\}_{s=0}^{t}, \{p_s, q_s, u_s, v_s(i), \theta_s(i), e_s, \epsilon_s(i), \widetilde{\epsilon}_s(i)\}_{s=0}^{t-1}\right\}$. All propositions in the previous section continue to hold.

[14] Appendix C shows the derivation of the price setting rule.

where

$$
\begin{aligned}
x_t(i) &= q_t + v_t(i), && (19)\\
v_t(i) &= (1-\epsilon)(\eta-1)\,\theta_t(i), && (20)\\
\xi &= \frac{\epsilon}{\epsilon+\widetilde{\eta}\,(1-\epsilon)}(\mu-\frac{1}{\epsilon}a-log(\epsilon)), && (21)\\
r_1 &= \frac{(\widetilde{\eta}-\eta)(1-\epsilon)}{\epsilon+\widetilde{\eta}\,(1-\epsilon)}, && (22)\\
r_2 &= \frac{(\eta-1)(1-\epsilon)}{\epsilon+\widetilde{\eta}\,(1-\epsilon)}, && (23)
\end{aligned}
$$

and $p_t = \int_0^1 p_t(i)di$.[15] Equation (18) shows that the optimal pricing rule for firm (i,j) is a weighted average of the sectoral prices $(p_t(i))$, aggregate prices (p_t), and total sectoral demand $(x_t(i))$, which adds aggregate and sector-specific demand (i.e., $x_t(i) = q_t + v_t(i)$). The weights on each term of equation (18) are determined by the parameters r_1 and r_2, which reflect the degree of strategic complementarity among firms in the same sector and across sectors, respectively. Equation (19) shows that total sectoral demand $(x_t(i))$ is the sum of aggregate (q_t) and sector-specific components $(v_t(i))$. Equation (20) shows that the sector-specific demand depends on the sector-specific preference shock $\theta_t(i)$. The constant parameter ξ, defined by equation (21), is a linear transformation of the level of aggregate productivity, a. By normalizing aggregate productivity such that $\xi = 0$, the price level for firm (i,j) is uniquely determined by sector-specific and aggregate prices and total sectoral demand.[16]

Since firms in the same sector face the same marginal costs and have access to the same information, $p_t(i) = p_t(i,j) = p_t(i,j')$ for $j \neq j'$ in equilibrium, and equation (18) reduces to:

$$p_t(i) = rp_t + (1-r)\,x_t(i), \tag{24}$$

where

$$r \equiv \frac{r_2}{1-r_1} = \frac{(\eta-1)(1-\epsilon)}{\epsilon+\eta\,(1-\epsilon)}.$$

Equation (24) shows that the optimal pricing rule for firm (i,j) is a weighted average of aggregate prices (p_t) and total sectoral demand $(x_t(i))$. The weights for average prices and total sectoral demand are determined by the parameter r, which reflects the degree of strategic complementarity between firms in different sectors, consistent with equation (18).[17]

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[15] Appendix B shows the derivation of the index of aggregate prices.

[16] Note that setting $\xi = 0$ is irrelevant for inflation since ξ affects the price level only.

[17] Equation (24) shows that if production technology converges to constant returns (i.e., $\epsilon \to 1$), average

3.2 Nominal Price Rigidities

To account for the potential presence of nominal price rigidities in the price-setting behavior of the firm, we enrich the model with nominal price rigidities that prevent firms from optimally adjusting prices in each period.

We embed nominal price rigidities, as in Calvo (1983), by assuming that a firm maintains the same price with exogenous probability $\theta \in (0,1)$ and otherwise changes the price optimally based on the expectations of demand. The optimal reset price for firms in sector i, denoted by $p_t^*(i)$, depends on expectations formed at time t on present and future prices, as described by the pricing rule:

$$\begin{aligned} p_t^*(i) &= (1-\beta\theta)\sum_{j=0}^{\infty}(\beta\theta)^j \mathbb{E}_t[p_{t+j}(i)] \\ &= (1-\beta\theta)\sum_{j=0}^{\infty}(\beta\theta)^j \left[r\mathbb{E}_t[p_{t+j}] \; + (1-r)\mathbb{E}_t[x_{t+j}(i)]\right], \end{aligned} \tag{25}$$

where the second equation is derived by substituting the optimal pricing rule in equation (24). Unlike standard full-information rational expectations models, the expectations in equation (25) are formed under imperfect information, and they are determined in accordance to Proposition 1. Equation (25) shows that each firm in sector i sets prices as a weighted average of the firm's expectations about current and expected future prices, and the expectations are formed based on the information available at time t. Since expectations about total sectoral demand ($\mathbb{E}_t[x_{t+j}(i)]$) depend on the different aggregate and sector-specific components of demand, the co-movement of these components is critical to set the price.

The Equilibrium Average Price. Equation (25) provides the equilibrium average price once we derive the expectations for prices and total sectoral demand. The model is sufficiently simple to provide an analytical solution for the equilibrium average price, characterized in the next proposition.

Proposition 4 *The equilibrium average price and sectoral price are given by:*

$$p_t = [\theta + (1-\theta)a_1]\, p_{t-1} + (1-\theta)\, a_2 q_t + (1-\theta)\, a_3 q_{t-1} + (1-\theta)\, a_4 u_{t-1}, \tag{26}$$

---

prices become less important in the determination of the price for firm i (i.e., $r \to 0$) since the marginal cost converges to the aggregate nominal wage across firms (i.e., $mc_t(i) \to w_t$) and heterogeneity in the firms' prices decreases. The magnitude of the sector-specific shock decreases (i.e., $v_t(i) \to 0$) as the production technology converges to constant returns (i.e., $\epsilon \to 1$). As a result, in the limiting case of a linear production technology (i.e., $\epsilon = 1$), the optimal pricing rule is $p_t(i) = q_t + \xi$.

$$p_t(i) = p_t + (1-\theta)\, a_2 v_t(i) + a_5 v_{t-1}(i) \tag{27}$$

where $(a_1, a_2, a_3, a_4, a_5)$ *are non-linear functions of the ratio in the volatility of sector-specific to aggregate shocks* (τ_t/σ_t)*. In an extreme case of flexible prices* $(\theta = 0)$*,* $a_1 = 0$ *holds and the equilibrium average price and sectoral price are given by:*

$$p_t = a_2 q_t + a_3 q_{t-1} + a_4 u_{t-1}, \tag{28}$$

$$p_t(i) = p_t + a_2 v_t(i) + a_5 v_{t-1}(i) \tag{29}$$

Proof: See Appendix D.4. □

Equations (26) and (27) show that the equilibrium aggregate and sectoral price depend on the equilibrium price in the period $t-1$ (p_{t-1}) and the sequence of present and past demands $(q_t, v_t(i), q_{t-1}, v_{t-1}(i))$. Similarly, equations (28) and (29) show that the equilibrium aggregate and sectoral price depend on the sequence of present and past demands $(q_t, v_t(i), q_{t-1}, v_{t-1}(i))$, while not depending on the equilibrium price in the period $t-1$ (p_{t-1}). Important to our subsequent analysis, the proposition shows that the relative volatility of sector-specific shocks compared to aggregate shocks, encapsulated by the ratio τ_t/σ_t, plays a critical role for the sensitivity of the aggregate price to present and past aggregate demands, as we study in the next section.

4 Demand Shocks and Inflation Dynamics

Using the definition of the average price in equation (26) and the sectoral price in equation (27), we derive the analytical solution for the aggregate and sectoral inflation rate, defined as the change in the average and sectoral price from period $t-1$ to period t $(\pi_t \equiv p_t - p_{t-1}$ and $\pi_t(i) \equiv p_t(i) - p_{t-1}(i))$, as characterized by the next proposition.

Proposition 5 *Under imperfect information on aggregate and sector-specific demand shocks, average price inflation* (π_t) *and sectoral price inflation* $(\pi_t(i))$ *are equal to:*

$$\begin{aligned} \pi_t &= [\theta + (1-\theta)a_1]\, \pi_{t-1} + (1-\theta)\, a_2 u_t + (1-\theta)\,(a_3 + a_4)\, u_{t-1} - (1-\theta)\, a_4 u_{t-2} \\ &= \alpha_1 \pi_{t-1} + \alpha_2 u_t + \alpha_3 u_{t-1} + \alpha_4 u_{t-2}, \end{aligned} \tag{30}$$

$$\pi_t(i) = \pi_t + (1-\theta)\, a_2 \widetilde{v}_t(i) + a_5 \widetilde{v}_{t-1}(i) = \pi_t + \alpha_2 \widetilde{v}_t(i) + \alpha_5 \widetilde{v}_{t-1}(i), \tag{31}$$

where $\alpha_1 \equiv \theta + (1-\theta)a_1$*,* $\alpha_2 \equiv (1-\theta)a_2$*,* $\alpha_3 \equiv (1-\theta)(a_3+a_4)$*,* $\alpha_4 \equiv -(1-\theta)a_4$*, and* $\alpha_5 \equiv (1-\theta)a_5$*. In an extreme case of flexible prices (*$\theta = 0$*),* $a_1 = 0$ *holds and the equilibrium average price and sectoral price inflation are given by:*

$$\pi_t = a_2 u_t + (a_3 + a_4)\, u_{t-1} - a_4 u_{t-2} = \alpha_2 u_t + \alpha_3 u_{t-1} + \alpha_4 u_{t-2}, \tag{32}$$

$$\pi_t(i) = \pi_t + a_2 \widetilde{v}_t(i) + a_5 \widetilde{v}_{t-1}(i) = \pi_t + \alpha_2 \widetilde{v}_t(i) + \alpha_5 \widetilde{v}_{t-1}(i). \tag{33}$$

Proof: Taking the first difference of the equations (26) and (27) yields equations (30) and (31), respectively. Similarly taking the first difference of the equations (28) and (29) yields equations (32) and (33), respectively.□

Equations (30) and (31) provide the analytical solution for aggregate and sectoral inflation under imperfect information, respectively. Equation (30) shows that current inflation (π_t) depends on past inflation (π_{t-1}) and current and past changes in aggregate demand (u_t, u_{t-1}, and u_{t-2}, respectively), stemming from the assumption that demand in the past period $t-1$ is fully revealed in the current period t.[18] Similarly, equation (31) shows that current sectoral inflation ($\pi_t(i)$) depends on past average inflation (π_{t-1}) and current changes in total sectoral demand and past changes in aggregate and sector-specific demand ($\widetilde{x}_t(i)$, u_{t-1}, and $\widetilde{v}_{t-1}(i)$, respectively). The effect of τ_t/σ_t on the coefficients $(\alpha_2, \alpha_3, \alpha_4, \alpha_5)$ is non-linear, and it interacts with the degree of nominal price rigidities θ.[19] Equations (32) and (33) in Proposition 5 show that if prices are flexible ($\theta = 0$), the parameter α_1 is equal to zero, showing that nominal price rigidities are the main driver of inflation persistence in this reduced form inflation dynamics. Since the effect of τ_t/σ_t on coefficients for equations (30) and (31), $\alpha_1, \alpha_2, \alpha_3, \alpha_4$, and α_5, is highly non-linear and interplays with the degree of nominal price rigidities, we rely on numerical simulations to study the sensitivity of inflation to demand in the next subsection. Note that in an extreme case of flexible price inflation, the relationship between τ_t/σ_t and coefficients for equations (32) and (33), $\alpha_2, \alpha_3, \alpha_4$, and α_5, can be analytically derived as follows.

---

[18] The dynamics for inflation is related to Angeletos and La'O (2009), but it differs across two important dimensions. First, the coefficients $(\alpha_2, \alpha_3, \alpha_4, \alpha_5)$ depend on the volatility of sector-specific shocks (τ^2), and second, inflation depends on the changes in demand two periods before u_{t-2} since aggregate shocks are persistent.

[19] See Appendix D.4 for the characterization of parameters a_1, a_2, a_3, a_4.and a_5.

Proposition 6 *α_2 and α_4 are decreasing in τ_t/σ_t, while α_3 is increasing. The relationship between α_5 and τ_t/σ_t depends on the sign of ρ_v as the positive relationship holds if $\rho_v > 0$ and vice versa.*

Proof: See Appendix D.5.□

Proposition 6 indicates that average and sectoral inflation in equations (32) and (33) respond more weakly to changes in aggregate demand (u_t) and sector-specific demand ($\widetilde{v}_t(i)$), respectively, when τ_t/σ_t is higher.

Finally, we derive the Phillips curve under the simplified assumption $\rho_u = \rho_v = 0$.

Corollary 1 *Suppose $\rho_u = \rho_v = 0$. The Phillips curve is given as follows:*

$$\pi_t = \frac{\alpha_2}{1-\alpha_2} y_t + \frac{\alpha_3}{1-\alpha_2} y_{t-1}, \tag{34}$$

Proof: See Appendix D.6.□

Corollary 1 shows the equation for aggregate inflation, which has no lagged inflation term (i.e. inflation persistence), as in the standard New Keynesian Phillips curve.[20] The lagged output gap emerges because firms face imperfect information about current economic variables, and thus the expectations depend on past economic variables.

4.1 Numerical Simulations

The model shows that imperfect information makes the response of average and sectoral inflation to demand a non-linear function of the ratio of volatility of the sector-specific to aggregate shock (τ_t/σ_t) and the degree of nominal rigidities (θ), which jointly determine the response of inflation to demand, as encapsulated by the coefficients α_1, α_2, α_3, α_4, and α_5 in equations (30) and (31). In this section, we use numerical simulations to study the sensitivity of inflation to demand.

Sensitivity of Inflation to Changes in Demand. We simulate the model using a standard calibration. We set $\beta = 0.99$, $\eta = 8$, $\epsilon = 2/3$, and $r = [(\eta-1)(1-\epsilon)]/[\epsilon+\eta(1-\epsilon)] = 0.7$.

To investigate the role of shock heterogeneity, we allow the ratio $\tau_t/\sigma_t \in [0, 5]$ to cover a wide range of values, while the baseline calibration is $\tau_t/\sigma_t = 3.5$. We will estimate this

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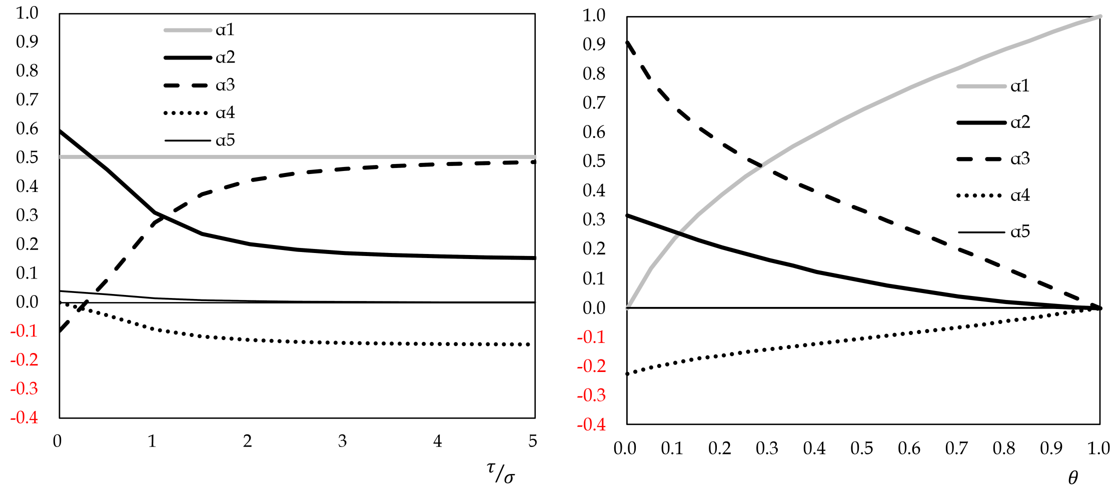
[20] Inflation expectations do not appear in the equation for inflation since they are determined by the linear combination of current and past economic variables in the information structure of the model.

ratio in the next section. Similarly, we allow the degree of nominal price rigidity $\theta \in [0,1]$ to cover the whole range of admissible values. Additionally, we set the parameters for the persistence of aggregate and sector-specific shocks equal to $\rho_u = 0.33$ and $\rho_v = -0.09$ to replicate the estimates of first-order auto-correlation in Table A10 for both the aggregate and the median of sector-specific components of demand.

Figure 1: Sensitivity of coefficients

(a) The degree of shock heterogeneity (τ/σ)

(b) The degree of nominal price rigidity (θ)



Notes: Parameters are $\theta = 0.3$ $r = 0.7$, $\beta = 0.99$, $\rho_u = 0.33$, $\rho_v = -0.09$ *for (a), and* $\tau/\sigma = 3.5$, $r = 0.7$, $\beta = 0.99$, $\rho_u = 0.33$, $\rho_v = -0.09$ *for (b).*

Figure 1 in panel (a) shows the coefficients α_1, α_2, α_3, α_4, and α_5 for different values of the relative volatility of sector-specific shocks (i.e., τ_t/σ_t). The coefficient α_1 on past inflation is insensitive to τ_t/σ_t, evincing that the relative volatility of sector-specific shocks plays no role in the relation between current inflation and past inflation, which instead is determined by the degree of nominal price rigidities, as we discuss below. The coefficient α_2 on current aggregate and sector-specific demand is instead highly sensitive to the relative volatility of sector-specific shocks, and inflation becomes less responsive to changes in current demand (i.e., α_2 decreases) when τ_t/σ_t increases. Strategic complementarity in the optimal price-setting, encapsulated by $r > 0$ in equation (24), induces the firm to hold the adjustment of prices if it attributes that the change in total sectoral demand is generated by the sector-specific component. Therefore, *ceteris paribus*, an increase in the volatility of the sector-specific component of demand decreases the response of prices to changes in total sectoral demand. The coefficient α_3 (past lag of aggregate demand) increase while the coefficient α_4 (past two lags of aggregate demand) and α_5 (past lag of sector-specific demand) decrease in response to the increase in τ_t/σ_t. The response of inflation is on average more sensitive to movements in past lags of demand. Overall, the numerical simulations show that the parameter α_2, which internalizes the effect of changes in τ_t/σ_t, plays a critical role in the sensitivity of inflation to demand. Note that these properties of the coefficients are fully consistent with those under flexible prices, as shown in Proposition 6.

Figure 1 in panel (b) shows the sensitivity of coefficients α_1, α_2, α_3, α_4, and α_5 to changes in the degree of nominal price rigidity (θ) in the inflation equation (30). The increase in nominal price rigidities generates a rise in the coefficient α_1 since a low frequency of price adjustment increases the importance of past inflation in the determination of current inflation. The increase in the degree of nominal price rigidity generates a decrease in the absolute value of the coefficients α_2, α_3, α_4 and α_5 since the sensitivity of individual prices to movements in current demand is lowered by the increase in nominal price rigidity (θ). As the degree of nominal price rigidity increases, these parameters converge to zero. This makes a stark contrast from the case of higher shock heterogeneity where the influence of past shocks increases by directly changing the coefficients on the past shocks (α_3) while keeping the coefficient on the lagged inflation (α_1) unchanged.[21]

4.2 Empirical Analysis on the Aggregate Inflation Dynamics

This section investigates the empirical relevance of imperfect information, encapsulated by the change of the ratio of the volatility of the sector-specific component to the aggregate component of demand (τ_t/σ_t) for the sensitivity of aggregate inflation (π_t) to total demand. To this end, we first estimate the ratio of the volatility in Japan using principal component analysis. We then test the empirical relevance of the increases in the relative volatility of sector-specific shocks for the reduced sensitivity of aggregate inflation to changes in aggregate demand.

Estimation of τ_t/σ_t. To estimate the ratio τ_t/σ_t, we derive the variances for the changes in the aggregate and sector-specific components of demand (σ_t^2 and τ_t^2, respectively). We proxy changes in aggregate demand by the principal component of the movements in sales growth across sectors, following the approach in Boivin et al. (2009). We use quarterly data on sector-level sales of Japanese firms from the Financial Statements Statistics of Corporations

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[21] Appendix K.1 shows the impulse response function of the inflation to aggregate demand.

by Industry, compiled by the Ministry of Finance of Japan. The data cover the period 1975:Q3-2022:Q4 for 29 major sectors in the economy.[22]

We proxy the changes in the aggregate component of demand with sales, u_t, by the first principal component of $\widetilde{x}_t(i)$ across sectors, $i \in \{1, 2, ..., 29\}$, by calculating it as $u_t = (\sum_{i=1}^{29}\Lambda_i)_{i=1}^{-1}\sum_{i=1}^{29}\Lambda_i\widetilde{x}_t(i)$, where Λ_i is the loading factor of $\widetilde{x}_t(i)$ and the term $\left(\sum_{i=1}^{29}\Lambda_i\right)^{-1}$ normalizes $\sum_{i=1}^{29}\widetilde{x}_t(i)$.[23] We proxy sector-specific demand, $\widetilde{v}_t(i)$, by subtracting the estimated principal component from changes in total sectoral demand:[24] $\widetilde{x}_t(i) - u_t = \widetilde{x}_t(i) - (\sum_{i=1}^{29}\Lambda_i)^{-1}\sum_{i=1}^{29}\Lambda_i\widetilde{x}_t(i)$.[25]

We proxy the variance of aggregate fluctuations, σ_t^2, with the average of the square of residuals of equation (4) for alternative moving windows of size $2k+1$:

$$
{\sigma_t}^2 = \frac{1}{2k+1}\sum_{s=-k}^{k}\widehat{e}_{t-s}^2. \tag{35}
$$

To ensure the results are robust across the different time windows, we compute the variance of each shock in equations (35) and (36), using four alternative time windows: two quarters ($k = 1$), four quarters ($k = 2$), and eight quarters ($k = 4$).

Similarly, we proxy the variance of the sector-specific fluctuations, ${\tau_t}^2$, with the average of the square of the averages of the residuals of (5) across sectors for alternative moving windows of size $2k+1$:

$$
{\tau_t}^2 = \frac{1}{2k+1}\sum_{s=-k}^{k}\left(\frac{1}{29}\sum_{i=1}^{29}\frac{\left(\widehat{\epsilon}_{t-s}(i) - \widehat{\epsilon}_{t-s-1}(i)\right)^2}{2}\right), \tag{36}
$$

where $k = 1, 2, 4$.

Finally, we measure shock heterogeneity as the ratio of the square root of the estimate of the variance of sector-specific shocks (τ_t) to that of aggregate shocks (σ_t).

---

[22] Appendix G provides a description of the data.

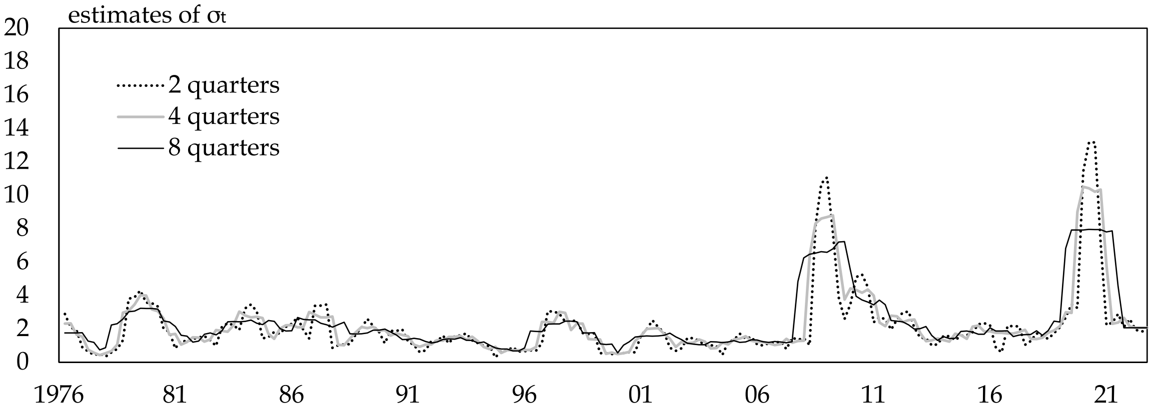
[23] The proportion of the variance of the first component is around 19%, which is considerably larger than the variance of the second component (7%), suggesting that the second principal component plays a limited role in aggregate shocks. Note that since the principal component is $\sum_{i=1}^{29}\Lambda_i\widetilde{x}_t(i)$ and changes in sectoral demand are $\widetilde{x}_t(i)$, the scale of the principal component $\sum_{i=1}^{29}\Lambda_i$ may differ from the scale of changes in sectoral demand. Estimation results reveal that $\sum_{i=1}^{29}\Lambda_i \approx 4.7$, which we use to normalize the principal component.

[24] To ensure results are robust to alternative normalization, we implement alternative specifications. First, we define $u_t = \sum_{i=1}^{29}\Lambda_i\widetilde{x}_t(i)$ and $\widetilde{x}_t(i) - u_t$, and second, we define $u_t = \left(\sum_{i=1}^{29}\Lambda_i\right)^{-1}\sum_{i=1}^{29}\Lambda_i\widetilde{x}_t(i)$ and $\widetilde{x}_t(i) - u_t$. Results remain unchanged across different normalization assumptions.

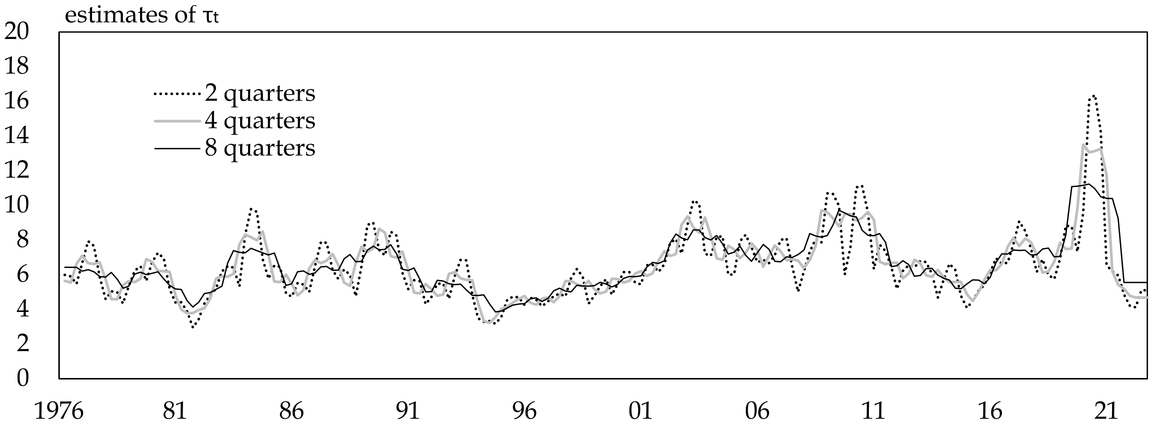
[25] Appendix H discusses the methodology we use to extract the sequence of shocks on aggregate and sector-specific components of total sectoral demand, and it provides summary statistics on the volatility of aggregate and sectoral-specific demand shocks. Appendix I shows that the changes in the series for aggregate demand extracted from the industry-level data are representative of aggregate movements in demand. Our series closely co-move with the average of industry-level data and with the measure of the output gap from the Bank of Japan that several studies use as a proxy for changes in aggregate demand.

Figure 2: Estimated shock heterogeneity (τ_t/σ_t)

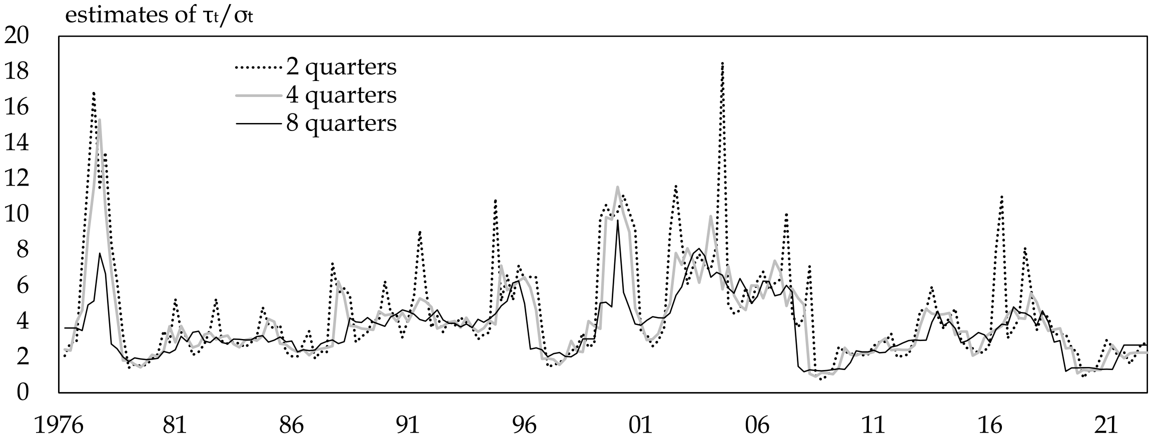
(a) Standard deviation of aggregate shocks



(b) Standard deviation of sector-specific shocks



(c) Shock heterogeneity



Source: Ministry of Finance "Financial statements statistics of corporations by industry".

Figure 2 shows the estimated series for the ratio of the standard deviation of sector-specific shocks to that of aggregate shocks (τ_t/σ_t) for the alternative time windows. Entries show that the ratio τ_t/σ_t substantially varies throughout the sample period. The shorter the time window, the larger the volatility, but the overall dynamics of the changes are similar across the alternative estimates. Overall, the analysis establishes substantial changes in the τ_t/σ_t ratio during the sample period.[26]

Sensitivity of Inflation to Changes in Aggregate Demand. Using the estimated volatility ratio (τ_t/σ_t), we study the empirical relevance of the demand shock heterogeneity to inflation under imperfect information. Specifically, we investigate how an increase (or decrease) in the ratio affect the reduced (increased) sensitivity of inflation to changes in aggregate demand.

We set up the empirical model using the insights from the price equation (30) that accounts for the effect of information frictions in the relation between inflation and aggregate demand. We regress current inflation (π_t) on past inflation (π_{t-1}),[27] changes in current aggregate demand (u_t), an interaction term between past inflation and the volatility ratio between sector-specific and aggregate shocks ($\pi_{t-1} \times \tau_t/\sigma_t$), and an interaction term between changes in current aggregate demand and the volatility ratio. The interaction terms $\pi_{t-1} \times \tau_t/\sigma_t$ and $u_t \times \tau_t/\sigma_t$ capture the differential effect of the volatility ratio τ_t/σ_t for the effect of past inflation and aggregate demand on current inflation, respectively. In line with the theoretical model, we include aggregate demand with two lags and control for the degree of nominal price rigidities, motivated by the fact the comparative statics in the model described in section 4.1 show that the higher degree of nominal price rigidity increases the persistence of inflation and reduces the sensitivity of current inflation to changes in current aggregate demand. Specifically, we use an indicator variable equal to 1 for the period 2000-2022 ($\mathbf{1}_{\{2000-2022\}}$) when nominal price rigidities slightly decreased (see evidence in Sudo et al., 2014 and Kurachi et al., 2016), and we enrich the estimation of the price equation with two additional interaction terms. The first term interacts the indicator variable for nominal price rigidities with past inflation ($\pi_{t-1} \times \mathbf{1}_{\{2000-2022\}}$) to capture the interplay between the degree

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[26] Movements in τ_t/σ_t are primarily driven by changes in the volatility of sector-specific demand shocks (τ_t) while the volatility of aggregate demand shock (σ_t) remains broadly stable across the sample period, except during the period of the global financial crisis (2007:4Q to 2010:1Q).

[27] We use quarterly changes in consumer price index as a proxy for aggregate inflation. The CPI is from the Japanese Statistics Bureau and available here https://www.stat.go.jp/english/data/cpi/index.html

of nominal price rigidity and the effect of past inflation on current inflation. The second term interacts the indicator variable for nominal price rigidities with current aggregate demand ($u_t \times \mathbf{1}_{\{2000-2022\}}$) to capture the interplay between nominal price rigidities and current aggregate demand. The empirical specification of the price inflation is summarized by the following equation:

$$\begin{aligned} \pi_t =& c_1 + \underbrace{\left(c_2 + c_3 \mathbf{1}_{\{2000-2022\}} + c_4 \left(\tau_t/\sigma_t\right)\right)}_{\alpha_1} \pi_{t-1} + \underbrace{\left(c_5 + c_6 \mathbf{1}_{\{2000-2022\}} + c_7 \left(\tau_t/\sigma_t\right)\right)}_{\alpha_2} u_t \\ & + c_8 u_{t-1} + c_9 u_{t-2} + \varepsilon_t^c, \end{aligned} \tag{37}$$

where the coefficients $c_1, \ldots, c_9$ are regression coefficients, and ε_t^c is the error term.

Table 4: Estimation of inflation dynamics

Dataset: Financial statement statistics of corporations by industry, consumer price index; 29 sectors; 1976/2Q-2022/4Q

Dependent Variable: Inflation rate (π_t, core consumer price index, seasonally adjusted, QoQ)

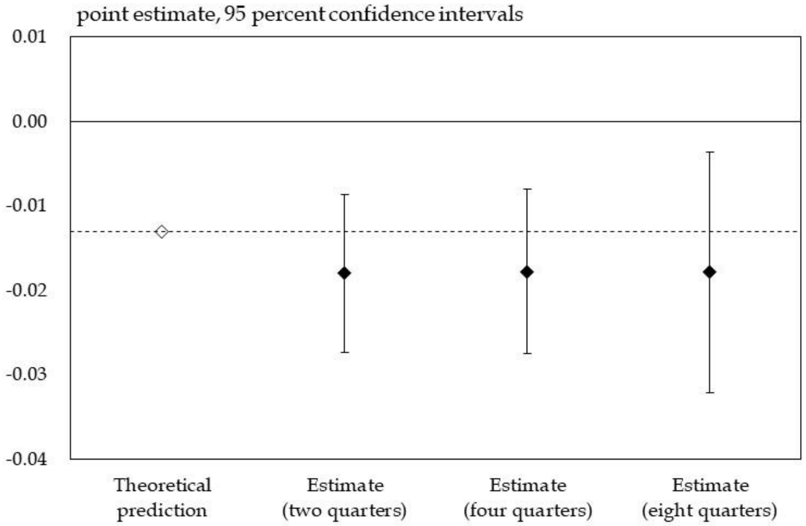
	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Constant	0.07 **	0.06 **	0.04
	(0.03)	(0.03)	(0.03)
Lag of inflation (π_{t-1})	0.66 ***	0.66 ***	0.63 ***
	(0.11)	(0.13)	(0.15)
Lag of inflation ×time dummy (2000-2022)	-0.27	-0.27	-0.26
($\pi_{t-1} \times 1_{\{2000-2022\}}$)	(0.21)	(0.21)	(0.21)
Lag of inflation	0.01	0.02	0.03
×shock heterogeneity ($\pi_{t-1} \times {}^{\tau_t}/_{\sigma_t}$)	(0.01)	(0.02)	(0.03)
Changes in aggregate demand (u_t)	0.09 ***	0.09 ***	0.09 ***
	(0.03)	(0.03)	(0.03)
Changes in aggregate demand ×time	-0.03	-0.03	-0.03
dummy (2000-2022) ($u_t \times 1_{\{2000-2022\}}$)	(0.03)	(0.03)	(0.03)
Changes in aggregate demand	**-0.02 *****	**-0.02 *****	**-0.02 ****
×shock heterogeneity ($\boldsymbol{u_t \times {}^{\tau_t}/_{\sigma_t}}$)	(0.005)	(0.005)	(0.01)
Observations	188	188	188
Adjusted-R²	0.75	0.74	0.74

Note: Estimated by ordinary-least-squares. The standard errors are HAC estimators. First and second lags of changes in aggregate demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity. The series for the core consumer price index is "all items, less fresh food and energy (impact of consumption taxes are adjusted)".

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table 4 shows the estimates for equation (37), using the τ_t/σ_t ratio based on time-windows of two quarters (column 1), four quarters (column 2), and eight quarters (column 3), respectively. All entries show that current inflation is positively correlated with past inflation and current demand, consistent with the theoretical prediction in equation (26). The estimation also shows that the coefficient for the interaction term of past inflation with the indicator variable ($\pi_{t-1} \times \mathbf{1}_{\{2000-2022\}}$) is negative while non-significant and that for the interaction term of past inflation with shock heterogeneity is almost zero, indicating that the positive correlation between current inflation and past inflation might have decreased with a modest decline in nominal price rigidities, again in line with the predictions of our model. The estimates for the interaction term of changes in demand with the indicator variable ($u_t \times \mathbf{1}_{\{2000-2022\}}$) are insignificant for all proxies of the τ_t/σ_t ratio. Important for our analysis, the interaction term between aggregate demand and the degree of shock heterogeneity ($u_t \times \tau_t/\sigma_t$) is negative and significant, implying that a rise in the τ_t/σ_t ratio reduces the positive correlation between inflation and aggregate demand, in accordance with the results of our analysis.

Figure 3: Shock heterogeneity and sensitivity of inflation to changes in aggregate demand



Notes: Theoretical prediction is calculated as the slope of α_2 *at* $\tau/\sigma = 3.5$ *in Figure 1 (a).*
Parameters for theoretical prediction are $\theta = 0.3,\ r = 0.7,\ \beta = 0.99, \rho_u = 0.33,\ \rho_v = -0.09$.

Figure 3 compares the estimates for the coefficient c_7 on the interaction term ($u_t \times \tau_t/\sigma_t$) for the alternative time windows of two, four, and eight quarters for the computation of the variance (dark diamond) against the coefficient α_2 on the interaction term $u_t \times \tau_t/\sigma_t$ in equation (30), which represents the theoretical interaction between shock heterogeneity and aggregate demand (white diamond).[28] The bands around the central estimate in dark diamond represent 90 percent confidence intervals of the empirical estimates. The figure illustrates that the estimates derived from the data closely align with those generated by the theoretical model. This suggests that our theoretical framework is empirically consistent

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[28] The results are calculated as the changes in α_2 in accordance with changes in τ_t/σ_t from 2.5 to 4.5, divided by the changes in τ_t/σ_t (i.e. 4.5-2.5=2) under the same calibration of Figure 1.

Table 5: Estimation of inflation dynamics

Dataset: Financial statement statistics of corporations by industry, consumer price index; 29 sectors; 1976/2Q-2022/4Q

Dependent Variable: Inflation rate (π_t, core consumer price index, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Constant	0.08 ***	0.07 ***	0.05 **
	(0.02)	(0.02)	(0.02)
Lag of inflation (π_{t-1})	0.68 ***	0.68 ***	0.62 ***
	(0.11)	(0.11)	(0.15)
Lag of inflation ×shock heterogeneity ($\pi_{t-1} \times {}^{\tau_t}/_{\sigma_t}$)	0.01	0.02	0.04
	(0.01)	(0.01)	(0.03)
Changes in aggregate demand (u_t)	0.07 ***	0.07 ***	0.07 ***
	(0.02)	(0.02)	(0.02)
Changes in aggregate demand ×shock heterogeneity ($\mathbf{u_t \times {}^{\tau_t}/_{\sigma_t}}$)	**-0.02 *****	**-0.02 *****	**-0.02 ***
	(0.01)	(0.01)	(0.01)
Observations	188	188	188
Adjusted-R²	0.72	0.72	0.72

Note: Estimated by ordinary-least-squares. The standard errors are HAC estimators. First and second lags of changes in aggregate demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity. The series for the core consumer price index is "all items, less fresh food and energy (impact of consumption taxes are adjusted)".

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

with the observed data.

Moreover, to ensure that the significance of the negative relation between τ_t/σ_t and inflation is not driven by the inclusion of the 2000-2022 dummy variable, Table 5 presents results for the benchmark regression, omitting the indicator variable $\mathbf{1}_{\{2000-2022\}}$ by omitting the interaction term between past inflation and the indicator variable (i.e., $\pi_{t-1} \times \mathbf{1}_{\{2000-2022\}}$) and the interaction term between changes in demand and the indicator variable ($u_t \times \mathbf{1}_{\{2000-2022\}}$) from equation (37). The regression coefficient on the term $u_t \times (\tau_t/\sigma_t)$ (bold entry) remains significant and negative, as in the benchmark regression.

Finally, to account for the possibility that firms set their prices flexibly, following equation (32), Table 6 presents the results for the benchmark regression (37) excluding the lagged inflation term π_{t-1}. The regression coefficient on the interaction term $u_t \times (\tau_t/\sigma_t)$ (highlighted in bold) remains negative in all entries and statistically significant in (i) and (ii), consistent with the findings from the benchmark regression.

Our results suggest that the imperfect information on sectoral demand, together with the changes in shock heterogeneity, has significantly contributed to the time-variation in the

Table 6: Estimation of inflation dynamics

Dataset: Financial statement statistics of corporations by industry, consumer price index; 29 sectors; 1976/1Q-2022/4Q

Dependent Variable: Inflation rate (π_t, core consumer price index, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Constant	0.25 ***	0.23 ***	0.22 ***
	(0.05)	(0.05)	(0.05)
Changes in aggregate demand (u_t)	0.08 ***	0.08 ***	0.07 ***
	(0.02)	(0.02)	(0.02)
Changes in aggregate demand	**-0.02 ****	**-0.02 ****	**-0.01**
×*shock heterogeneity* ($\boldsymbol{u_t \times {}^{\tau_t}/_{\sigma_t}}$)	(0.01)	(0.01)	(0.01)
Observations	188	188	188
Adjusted-R²	0.28	0.28	0.27

Note: Estimated by ordinary-least-squares. The standard errors are HAC estimators. First and second lags of changes in aggregate demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity. The series for the core consumer price index is "all items, less fresh food and energy (impact of consumption taxes are adjusted)".

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

sensitivity of inflation to the aggregate demand shock in Japan.[29][30] Appendix N shows that all results in this section remain broadly unchanged when we exclude the samples since the Covid-19 pandemic. Appendix O further examines the validity of our theoretical framework using data on *sectoral* inflation.

5 Conclusion

Our study shows that imperfect information and shock heterogeneity play an important role on the expectations of firms and the sensitivity of inflation to real activity. Because firms are not necessarily able to observe the aggregate and sector-specific components of their sectoral demand separately, their price setting behavior may be influenced by shock heterogeneity. We use unique sector-level survey data for the universe of Japanese firms to establish a positive co-movement between sector-specific components of demand and the expectations of aggregate demand components. We then show that imperfect information allows a simple model with firms facing demand driven by sector-specific and aggregate shocks to reproduce the observed positive co-movement in expectations. Our model shows that an increase in the volatility of the sector-specific component of demand reduces the sensitivity of inflation to real activity. We test and corroborate this theoretical prediction using sector-level sales

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[29] Since shock heterogeneity modestly increased in the late 1990s, our result is relevant for the flattening of the Phillips curve in Japan during the same period (see recent studies by Kaihatsu et al., 2017 and Bundick and Smith, 2020).

[30] Appendix K.2 shows the estimated impulse response of inflation to aggregate demand.

data for Japanese firms across 29 sectors.

Our study opens important avenues for future research. A fundamental question left unanswered is the source of the reduction in the volatility of sector-specific shocks. Is the decline in the volatility of sector-specific demand resulting from improved production efficiency or, alternatively, is it a by-product of smoother input-output linkages among firms? Both sources lead to a decrease in the variation of relative prices that is consistent with the recent decline in the volatility of sector-specific demand, but with a distinct impact on the propagation of shocks and different normative implications. Should monetary policy strategically communicate the economic outlook to exploit the effects of different demand components on firms' pricing decisions to achieve price stability? We plan to pursue some of these questions in future work.

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A Derivation of Demand Functions and Price Indexes

A.1 Demand Functions

The representative household first determines the allocation of consumption across sectors and then determines that to goods in each sector taking the expenditure level to each sector as given.

Define the expenditure level by $Z_t \equiv \int_0^1 P_t(i)C_t(i)di$, the Lagrangian is:

$$L = \left[\int_0^1 (C_t(i)\Theta_t(i))^{\frac{\eta-1}{\eta}}\, di\right]^{\frac{\eta}{\eta-1}} - \lambda_t \left(\int_0^1 P_t(i)C_t(i)di - Z_t\right), \tag{A.1}$$

and the first-order conditions are:

$$C_t(i)^{-\frac{1}{\eta}} C_t^{\frac{1}{\eta}} (\Theta_t(i))^{\frac{\eta-1}{\eta}} = \lambda_t P_t(i). \tag{A.2}$$

Thus, for any two sectors, the following equation holds:

$$C_t(i) = C_t(j)\left(\frac{P_t(i)}{P_t(j)}\right)^{-\eta}\left(\frac{\Theta_t(i)}{\Theta_t(j)}\right)^{\eta-1}. \tag{A.3}$$

By substituting equations (A.2) and (A.3) into the definition of consumption expenditures ($Z_t \equiv \int_0^1 P_t(i)C_t(i)di$), it yields:

$$\int_0^1 P_t(i)\left[C_t(j)\left(\frac{P_t(i)}{P_t(j)}\right)^{-\eta}\left(\frac{\Theta_t(i)}{\Theta_t(j)}\right)^{\eta-1}\right] di = Z_t$$

$$\Leftrightarrow \quad C_t(j) = P_t^{-\eta}(j)\Theta_t^{\eta-1}(j)Z_t\frac{1}{\int_0^1 P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)di}. \tag{A.4}$$

By substituting the equation:

$$\int_0^1 P_t(i)C_t(i)di = Z_t = P_tC_t,$$

into equation (A.4), it yields:

$$C_t(i) = \Theta_t^{\eta-1}(i)\left(\frac{P_t(i)}{P_t}\right)^{-\eta} C_t\frac{P_t^{1-\eta}}{\int_0^1 P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)di}. \tag{A.5}$$

Using the definition of the price level, $P_t \equiv \left[\int_0^1 P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)di\right]^{\frac{1}{1-\eta}}$, we can re-write equation (A.5) as:

$$C_t(i) = \Theta_t^{\eta-1}(i)\left(\frac{P_t(i)}{P_t}\right)^{-\eta} C_t. \tag{A.6}$$

Applying the same calculation for $C_t(i) = \left[\int_0^1 (C_t(i,j))^{\frac{\widetilde{\eta}-1}{\widetilde{\eta}}} dj\right]^{\frac{\widetilde{\eta}}{\widetilde{\eta}-1}}$, it yields:

$$C_t(i,j) = \left(\frac{P_t(i,j)}{P_t(i)}\right)^{-\widetilde{\eta}} C_t(i). \tag{A.7}$$

By combining equations (A.6) and (A.7), we obtain the demand for good (i,j) as follows:

$$C_t(i,j) = \Theta_t^{\eta-1}(i)\left(\frac{P_t(i,j)}{P_t(i)}\right)^{-\widetilde{\eta}}\left(\frac{P_t(i)}{P_t}\right)^{-\eta} C_t.$$

A.2 Price Indexes

We show the derivation of aggregate price index $P_t \equiv \left[\int_0^1 P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)di\right]^{\frac{1}{1-\eta}}$, and we omit the derivation of sectoral price index $P_t(i) \equiv \left[\int_0^1 P_t^{1-\widetilde{\eta}}(i,j)dj\right]^{\frac{1}{1-\widetilde{\eta}}}$ since it can be similarly derived.

Recall that λ_t^{-1} indicates the shadow price of one unit of utility. The first-order condition in equation (A.2) can be re-written as:

$$\begin{aligned}
& C_t(i)^{-\frac{1}{\eta}} C_t^{\frac{1}{\eta}} (\Theta_t(i))^{\frac{\eta-1}{\eta}} = \lambda_t P_t(i) \\
\Leftrightarrow\ & C_t(i)^{\frac{\eta-1}{\eta}} C_t^{\frac{1}{\eta}} (\Theta_t(i))^{\frac{\eta-1}{\eta}} = \lambda_t C_t(i) P_t(i) \\
\Leftrightarrow\ & \int_0^1 \left(C_t(i)^{\frac{\eta-1}{\eta}} (\Theta_t(i))^{\frac{\eta-1}{\eta}}\right) di C_t^{\frac{1}{\eta}} = \lambda_t \int_0^1 C_t(i)P_t(i)di \\
\Leftrightarrow\ & C_t\lambda_t^{-1} = Z.
\end{aligned}$$

From the first-order condition (A.2) we derive the aggregate price index:

$$\begin{aligned}
& C_t(i)^{-\frac{1}{\eta}} C_t^{\frac{1}{\eta}} (\Theta_t(i))^{\frac{\eta-1}{\eta}} = \lambda_t P_t(i) \\
\Leftrightarrow\ & (C_t(i)\Theta_t(i))^{-\frac{1}{\eta}} C_t^{\frac{1}{\eta}} \Theta_t(i) = \lambda_t P_t(i) \\
\Leftrightarrow\ & (C_t(i)\Theta_t(i))^{\frac{1}{\eta}} = C_t^{\frac{1}{\eta}} \Theta_t(i) \lambda_t^{-1} P_t^{-1}(i) \\
\Leftrightarrow\ & (C_t(i)\Theta_t(i))^{\frac{\eta-1}{\eta}} = C_t^{\frac{\eta-1}{\eta}} \Theta_t^{\eta-1}(i) \lambda_t^{1-\eta} P_t^{1-\eta}(i) \\
\Leftrightarrow\ & \int_0^1 (C_t(i)\Theta_t(i))^{\frac{\eta-1}{\eta}} di = C_t^{\frac{\eta-1}{\eta}} \lambda_t^{1-\eta} \int_0^1 \left(P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)\right) di \\
\Leftrightarrow\ & 1 = \lambda_t^{1-\eta} \int_0^1 \left(P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)\right) di \\
\Leftrightarrow\ & \lambda_t^{-1} = \left[\int_0^1 \left(P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)\right) di\right]^{\frac{1}{1-\eta}}.
\end{aligned}$$

B Derivation of the Index of Aggregate Prices

Recall that: $P_t \equiv \left[\int_0^1 P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)di\right]^{\frac{1}{1-\eta}}$ can be expressed as, $P_t = \left[\int_0^1 \left(\frac{P_t(i)}{\Theta_t(i)}\right)^{1-\eta} di\right]^{\frac{1}{1-\eta}} = \left[\int_0^1 \left(\widetilde{P}_t(i)\right)^{1-\eta} di\right]^{\frac{1}{1-\eta}}$, where $\widetilde{P}_t(i) \equiv \frac{P_t(i)}{\Theta_t(i)}$. We then define $p_t \equiv \int_0^1 \widetilde{p}_t(i)di$, such that:

$$p_t \equiv \int_0^1 \widetilde{p}_t(i)di = \int_0^1 p_t(i)di - \int_0^1 \theta_t(i)di = \int_0^1 p_t(i)di,$$

since $\theta_t(i) \sim \mathcal{N}(0, (1-\epsilon)^{-2}(\eta-1)^{-2}\tau_t^2)$ and $\int_0^1 \theta_t(i)di = 0$.

C Derivation of the Price Setting Rule

Using the following equations:

$$p_t(i,j) = \mu + mc_t(i,j),$$

$$c_t(i,j) = -\widetilde{\eta}\left(p_t(i,j) - p_t(i)\right) - \eta\left(p_t(i) - p_t\right) + c_t + (\eta - 1)\,\theta_t(i),$$

and

$$mc_t(i,j) = w_t + \frac{1-\epsilon}{\epsilon} y_t(i,j) - \frac{1}{\epsilon} a - log(\epsilon),$$

the price of firm j in sector i, $p_t(i,j)$, is equal to:

$$\begin{aligned}
p_t(i,j) &= \mu + mc_t(i,j) = \mu + y_t + p_t - \frac{1}{\epsilon}a - log(\epsilon) \\
&\quad + \frac{1-\epsilon}{\epsilon}\left[-\widetilde{\eta}\left(p_t(i,j) - p_t(i)\right) - \eta\left(p_t(i) - p_t\right) + c_t + (\eta - 1)\,\theta_t(i)\right] \\
&= -\frac{1-\epsilon}{\epsilon}\widetilde{\eta} p_t(i,j) + \frac{1-\epsilon}{\epsilon}\left(\widetilde{\eta} - \eta\right) p_t(i) + \left(1 + \frac{1-\epsilon}{\epsilon}\eta\right) p_t \\
&\quad + (\mu - \frac{1}{\epsilon}a - log(\epsilon)) + \left(1 + \frac{1-\epsilon}{\epsilon}\right) y_t + \frac{1-\epsilon}{\epsilon}\left(\eta - 1\right)\theta_t(i) \\
&= -\frac{1-\epsilon}{\epsilon}\widetilde{\eta} p_t(i,j) + \frac{1-\epsilon}{\epsilon}\left(\widetilde{\eta} - \eta\right) p_t(i) + (\mu - \frac{1}{\epsilon}a - log(\epsilon)) \\
&\quad + \left(1 + \frac{1-\epsilon}{\epsilon}\right) q_t + \frac{1-\epsilon}{\epsilon}\left(\eta - 1\right) p_t + \frac{1-\epsilon}{\epsilon}\left(\eta - 1\right)\theta_t(i) \\
&= \frac{\frac{1-\epsilon}{\epsilon}\left(\widetilde{\eta} - \eta\right)}{1 + \frac{1-\epsilon}{\epsilon}\widetilde{\eta}} p_t(i) + \frac{1}{1 + \frac{1-\epsilon}{\epsilon}\widetilde{\eta}}(\mu - \frac{1}{\epsilon}a - log(\epsilon)) \\
&\quad + \frac{1 + \frac{1-\epsilon}{\epsilon}}{1 + \frac{1-\epsilon}{\epsilon}\widetilde{\eta}} q_t + \frac{\frac{1-\epsilon}{\epsilon}\left(\eta - 1\right)}{1 + \frac{1-\epsilon}{\epsilon}\widetilde{\eta}} p_t + \frac{\frac{1-\epsilon}{\epsilon}\left(\eta - 1\right)}{1 + \frac{1-\epsilon}{\epsilon}\widetilde{\eta}}\theta_t(i) \\
&= \frac{\left(\widetilde{\eta} - \eta\right)\left(1 - \epsilon\right)}{\epsilon + \widetilde{\eta}\left(1 - \epsilon\right)} p_t(i) + \frac{\epsilon}{\epsilon + \widetilde{\eta}\left(1 - \epsilon\right)}(\mu - \frac{1}{\epsilon}a - log(\epsilon)) \\
&\quad + \frac{1}{\epsilon + \widetilde{\eta}\left(1 - \epsilon\right)} q_t + \frac{\left(1 - \epsilon\right)\left(\eta - 1\right)}{\epsilon + \widetilde{\eta}\left(1 - \epsilon\right)} p_t + \frac{\left(1 - \epsilon\right)\left(\eta - 1\right)}{\epsilon + \widetilde{\eta}\left(1 - \epsilon\right)}\theta_t(i).
\end{aligned}$$

D Proofs of Propositions

D.1 Proof of Proposition 1

The terms $\mathbb{E}_t\left[u_t\right]$ and $\mathbb{E}_t\left[v_t(i)\right]$ are equal to:

$$\begin{aligned}
\mathbb{E}_t\left[u_t\right] &= \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\left(q_{t-1} + \rho_u u_{t-1}\right) + \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2}\left[x_t(i) - \rho_v v_{t-1}(i)\right] - q_{t-1} \\
&= \rho_u u_{t-1} + \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2}\left[x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i)\right] \\
&= \rho_u u_{t-1} + \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2}\left[e_t + \epsilon_t(i)\right] \\
\mathbb{E}_t\left[v_t(i)\right] &= \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2}\rho_v v_{t-1}(i) + \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\left[x_t(i) - q_{t-1} - \rho_u u_{t-1}\right] \\
&= \rho_v v_{t-1}(i) + \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\left[x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i)\right] \\
&= \rho_v v_{t-1}(i) + \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\left[e_t + \epsilon_t(i)\right]
\end{aligned}$$

Thus, $\mathbb{E}_t\left[\tilde{v}_t\right]$ is given by,

$$\begin{aligned}
\mathbb{E}_t\left[\tilde{v}_t(i)\right] &= \rho_v v_{t-1}(i) + \frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\left[e_t+\epsilon_t(i)\right] - v_{t-1}(i) \\
&= (\rho_v - 1)v_{t-1}(i) + \frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\left[e_t+\epsilon_t(i)\right].\square
\end{aligned}$$

D.2 Proof of Proposition 2

From equations (8) and (9), we have the following.

$$\mathbb{C}(\mathbb{E}_t\left[u_t\right], \mathbb{E}_t\left[\tilde{v}_t\right]) = \frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\mathbb{V}[e_t+\epsilon_t(i)] = \frac{\sigma_t^2\tau_t^2}{\sigma_t^2+\tau_t^2} > 0.\square$$

D.3 Proof of Proposition 3

Denote k-period ahead expectations by $\mathbb{E}_t\left[\sum_{h=1}^k u_{t+h}\right]$ and $\mathbb{E}_t\left[\sum_{h=1}^k \widetilde{v}_{t+h}(i)\right]$. The terms $\mathbb{E}_t\left[\sum_{h=1}^k u_{t+h}\right]$ and $\mathbb{E}_t\left[\sum_{h=1}^k \widetilde{v}_{t+h}(i)\right]$ are then equal to:

$$\mathbb{E}_t\left[\sum_{h=1}^k u_{t+h}\right] = \frac{1-{\rho_u}^{k+1}}{1-\rho_u}\mathbb{E}_t\left[u_t\right],$$

$$\mathbb{E}_t\left[\sum_{h=1}^k \widetilde{v}_{t+h}(i)\right] = \frac{1-{\rho_v}^{k+1}}{1-\rho_v}\mathbb{E}_t\left[\tilde{v}_t\right],$$

respectively. It follows that:

$$\mathbb{C}\left(\mathbb{E}_t\left[\sum_{h=1}^k u_{t+h}\right], \mathbb{E}_t\left[\sum_{h=1}^k \widetilde{v}_{t+h}(i)\right]\right) = \frac{1-{\rho_u}^{k+1}}{1-\rho_u}\frac{1-{\rho_v}^{k+1}}{1-\rho_v}\mathbb{C}\left(\mathbb{E}_t\left[u_t\right], \mathbb{E}_t\left[\tilde{v}_t\right]\right) > 0.$$

Plugging $k=4$ into this equation proves the proposition.□

D.4 Proof of Proposition 4

First, we guess that $p_t^*(i)$ takes the following form:

$$p_t^*(i) = a_1 p_{t-1} + a_2 x_t(i) + a_3 q_{t-1} + a_4 u_{t-1} + a_5 v_{t-1}(i).$$

Given the guess, and since only a randomly selected fraction $1-\theta$ of firms adjusts prices in any given period, we infer that the sectoral and aggregate price level must satisfy:

$$\begin{aligned}
p_t(i) &= \theta p_{t-1}(i) + (1-\theta)\int_0^1 p_t^*(i)di \\
&= \left[\theta + (1-\theta)\, a_1\right] p_{t-1} + (1-\theta)\, a_2 x_t(i) + (1-\theta)\, a_3 q_{t-1} + (1-\theta)\, a_4 u_{t-1} + a_5 v_{t-1}(i).
\end{aligned}$$

$$\begin{aligned} p_t &= \int_0^1 p_t(i)di \\ &= \left[\theta + (1-\theta)\, a_1\right] p_{t-1} + (1-\theta)\, a_2 q_t + (1-\theta)\, a_3 q_{t-1} + (1-\theta)\, a_4 u_{t-1}. \end{aligned}$$

Therefore, $p_t^*(i)$ is obtained as:

$$\begin{aligned} p_t^*(i) &= (1-\beta\theta)\left[(1-r)x_t(i) + r\mathbb{E}_t\left[p_t\right]\right] \;\; + \beta\theta\mathbb{E}_t[p_{t+1}^*(i)] \\ &= (1-\beta\theta)(1-r)x_t(i) + (1-\beta\theta)r\mathbb{E}_t\left[p_t\right] + \beta\theta\mathbb{E}_t[p_{t+1}^*(i)] \\ &= (1-\beta\theta)(1-r)x_t(i) + (1-\beta\theta)r\mathbb{E}_t\left[p_t\right] \\ &\quad + \beta\theta\mathbb{E}_t\left[a_1 p_t + a_2 x_{t+1}(i) + a_3 q_t + a_4 u_t + a_5 v_t(i)\right] \\ &= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\mathbb{E}_t\left[p_t\right] \\ &\quad + \beta\theta a_2\mathbb{E}_t\left[x_{t+1}(i)\right] + \beta\theta a_3\mathbb{E}_t\left[q_t\right] + \beta\theta a_4\mathbb{E}_t\left[u_t\right] + \beta\theta a_5\mathbb{E}_t\left[v_t(i)\right] \\ &= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\mathbb{E}_t\left[p_t\right] \\ &\quad + \beta\theta a_2\mathbb{E}_t\left[q_t + u_{t+1} + v_{t+1}(i)\right] + \beta\theta a_3\mathbb{E}_t\left[q_t\right] + \beta\theta a_4\mathbb{E}_t\left[u_t\right] + \beta\theta a_5\mathbb{E}_t\left[v_t(i)\right] \\ &= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\mathbb{E}_t\left[p_t\right] \\ &\quad + \beta\theta\left(a_2 + a_3\right)\mathbb{E}_t\left[q_t\right] + \beta\theta\left(a_2\rho_u + a_4\right)\mathbb{E}_t\left[u_t\right] + \beta\theta\left(a_2\rho_v + a_5\right)\mathbb{E}_t\left[v_t(i)\right]. \end{aligned}$$

The term $\mathbb{E}_t\left[p_t\right]$ is given by:

$$\mathbb{E}_t\left[p_t\right] = \left[\theta + (1-\theta)\, a_1\right] p_{t-1} + (1-\theta)\, a_2\mathbb{E}_t\left[q_t\right] + (1-\theta)\, a_3 q_{t-1} + (1-\theta)\, a_4 u_{t-1},$$

which yields:

$$\begin{aligned}
p_t^*(i) &= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\,a_1\right]p_{t-1} \\
&\quad + \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_2 + \beta\theta\,(a_2+a_3)\right]\mathbb{E}_t\left[q_t\right] \\
&\quad + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_3 q_{t-1} \\
&\quad + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_4 u_{t-1} \\
&\quad + \beta\theta\left(a_2\rho_u + a_4\right)\mathbb{E}_t\left[u_t\right] + \beta\theta\left(a_2\rho_v + a_5\right)\mathbb{E}_t\left[v_t(i)\right] \\
&= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\,a_1\right]p_{t-1} \\
&\quad + \left[\left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_2 + \beta\theta\,(a_2+a_3)\right] + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_3\right]q_{t-1} \\
&\quad + \left[\left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_2 + \beta\theta\,(a_2+a_3)\right] + \beta\theta\left(a_2\rho_u + a_4\right)\right]\mathbb{E}_t\left[u_t\right] \\
&\quad + \beta\theta\left(a_2\rho_v + a_5\right)\mathbb{E}_t\left[v_t(i)\right] \\
&\quad + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_4 u_{t-1} \\
&= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\,a_1\right]p_{t-1} \\
&\quad + b_1 q_{t-1} + b_2\mathbb{E}_t\left[u_t\right] + b_3\mathbb{E}_t\left[v_t(i)\right] + b_4 u_{t-1}.
\end{aligned}$$

where

$$\begin{aligned}
b_1 &= \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_2 + \beta\theta\,(a_2+a_3)\right] + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_3, \\
b_2 &= \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_2 + \beta\theta\,(a_2+a_3)\right] + \beta\theta\left(a_2\rho_u + a_4\right), \\
b_3 &= \beta\theta\left(a_2\rho_v + a_5\right), \\
b_4 &= \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_4.
\end{aligned}$$

Since

$$\begin{aligned}
x_t(i) &= q_{t-1} + \rho_u u_{t-1} + e_t + \rho_v v_{t-1}(i) + \epsilon_t(i) \\
&\Leftrightarrow\; e_t = x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i) - \epsilon_t(i), \\
&\Leftrightarrow\; \epsilon_t(i) = x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i) - e_t,
\end{aligned}$$

the terms $\mathbb{E}_t\left[u_t\right]$ and $\mathbb{E}_t\left[v_t(i)\right]$ are equal to:

$$\begin{aligned}
\mathbb{E}_t\left[u_t\right] &= \rho_u u_{t-1} + \mathbb{E}_t\left[e_t\right] \\
&= \rho_u u_{t-1} + \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2}\left[x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i)\right] \\
\mathbb{E}_t\left[v_t(i)\right] &= \rho_v v_{t-1}(i) + \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\left[x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i)\right].
\end{aligned}$$

It follows that:

$$
\begin{aligned}
p_t^*(i) &= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\, a_1\right] p_{t-1} \\
&\quad + b_1 q_{t-1} + b_2 \mathbb{E}_t\left[u_t\right] + b_3 \mathbb{E}_t\left[v_t(i)\right] + b_4 u_{t-1} \\
&= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\, a_1\right] p_{t-1} \\
&\quad + b_2 \rho_u u_{t-1} + b_2 \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2}\left[x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i)\right] \\
&\quad + b_3 \rho_v v_{t-1}(i) + b_3 \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\left[x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i)\right] \\
&\quad + b_4 u_{t-1} + b_1 q_{t-1} \\
&= \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\, a_1\right] p_{t-1} \\
&\quad + \left[(1-\beta\theta)(1-r) + b_2 \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2} + b_3 \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\right] x_t(i) \\
&\quad + \left[b_1 - b_2 \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2} - b_3 \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\right] q_{t-1} \\
&\quad + \left[b_4 + (b_2 - b_3)\frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\rho_u\right] u_{t-1} + \left[b_3 - b_2\right]\frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2}\rho_v v_{t-1}(i),
\end{aligned}
$$

and thus the equilibrium conditions are:

$$
\begin{aligned}
a_1 &= \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\, a_1\right], \\
a_2 &= (1-\beta\theta)(1-r) + b_2 \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2} + b_3 \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}, \\
a_3 &= b_1 - b_2 \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2} - b_3 \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}, \\
a_4 &= b_4 + (b_2 - b_3)\frac{\tau_t^2}{\sigma_t^2 + \tau_t^2}\rho_u, \\
a_5 &= \left[b_3 - b_2\right]\frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2}\rho_v,
\end{aligned}
$$

By simplifying the conditions, we obtain:

$$
a_1 = \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\, a_1\right],
$$

$$\begin{aligned}
a_2 &= (1-\beta\theta)(1-r) \\
&\quad + \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\, a_2 + \beta\theta\left(a_2 + a_3\right)\right] \frac{\sigma_t^2}{\sigma_t^2+\tau_t^2} \\
&\quad + \beta\theta\left(a_2\rho_u + a_4\right)\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2} + \beta\theta\left(a_2\rho_v + a_5\right)\frac{\tau_t^2}{\sigma_t^2+\tau_t^2} \\
&= (1-\beta\theta)(1-r) \\
&\quad + \left[\left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta) + \beta\theta\right]\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2} + \beta\theta\left[\rho_u\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2} + \rho_v\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\right]\right] a_2 \\
&\quad + \beta\theta\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}a_3 + \beta\theta\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}a_4 + \beta\theta\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}a_5,
\end{aligned}$$

$$\begin{aligned}
a_3 &= \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\, a_2 + \beta\theta\left(a_2 + a_3\right)\right] \frac{\tau_t^2}{\sigma_t^2+\tau_t^2} \\
&\quad + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\, a_3 - \frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\beta\theta\left(a_2\rho_u + a_4\right) \\
&\quad - \frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\beta\theta\left(a_2\rho_v + a_5\right) \\
&= \left[\left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta) + \beta\theta\right]\frac{\tau_t^2}{\sigma_t^2+\tau_t^2} - \frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\beta\theta\rho_u - \frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\beta\theta\rho_v\right] a_2 \\
&\quad + \left[\beta\theta\frac{\tau_t^2}{\sigma_t^2+\tau_t^2} + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\right] a_3 \\
&\quad - \frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\beta\theta a_4 - \frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\beta\theta a_5,
\end{aligned}$$

$$\begin{aligned}
a_4 &= \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\, a_4 \\
&\quad + \left[\begin{array}{c} \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\, a_2 + \beta\theta\left(a_2 + a_3\right)\right] \\ + \beta\theta\left(a_2\rho_u + a_4\right) - \beta\theta\left(a_2\rho_v + a_5\right) \end{array}\right] \frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\rho_u \\
&= \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta) + \beta\theta + \beta\theta\rho_u - \beta\theta\rho_v\right]\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\rho_u a_2 + \beta\theta\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\rho_u a_3 \\
&\quad + \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta) + \beta\theta\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\rho_u\right] a_4 - \beta\theta\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\rho_u a_5,
\end{aligned}$$

$$\begin{aligned}
a_5 &= -\left[\begin{array}{c} \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\, a_2 + \beta\theta\left(a_2 + a_3\right)\right] \\ + \beta\theta\left(a_2\rho_u + a_4\right) - \beta\theta\left(a_2\rho_v + a_5\right) \end{array}\right] \frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\rho_v \\
&= -\left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta) + \beta\theta + \beta\theta\rho_u - \beta\theta\rho_v\right]\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\rho_v a_2 \\
&\quad - \beta\theta\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\rho_v a_3 - \beta\theta\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\rho_v a_4 + \beta\theta\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\rho_v a_5 . \square
\end{aligned}$$

In an extreme case of flexible prices, plugging $\theta = 0$ into conditions for $(a_1, a_2, a_3, a_4, a_5)$ yields:

$$a_1 = ra_1 = 0,$$

$$a_2 = (1-r) + ra_2\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2} = \frac{1-r}{1-r\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}}$$

$$a_3 = ra_2\frac{\tau_t^2}{\sigma_t^2+\tau_t^2} + ra_3 = \frac{r}{1-r}\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}a_2 = \frac{r}{1-r}\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\frac{1-r}{1-r\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}}$$

$$a_4 = ra_4 + ra_2\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\rho_u = \frac{r}{1-r}\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\rho_u a_2 = \frac{r}{1-r}\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}\rho_u\frac{1-r}{1-r\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}}$$

$$a_5 = -r\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\rho_v a_2 = -r\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}\rho_v\frac{1-r}{1-r\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}}.\square$$

D.5 Proof of Proposition 6

Based on the following relationship $\alpha_2 \equiv a_2$, $\alpha_3 \equiv a_3 + a_4$, $\alpha_4 \equiv -a_4$, and $\alpha_5 \equiv a_5$, α_2, α_3, α_4, and α_5 are transformed as follows.

$$\alpha_2 \equiv a_2 = \frac{1-r}{1-r\frac{1}{1+(\tau_t/\sigma_t)^2}}$$

$$\alpha_3 \equiv a_3 + a_4 = (1+\rho_u)\frac{r}{1-r}\frac{(\tau_t/\sigma_t)^2}{1+(\tau_t/\sigma_t)^2}\frac{1-r}{1-r\frac{1}{1+(\tau_t/\sigma_t)^2}}$$

$$\alpha_4 \equiv -a_4 = -\frac{r}{1-r}\frac{(\tau_t/\sigma_t)^2}{1+(\tau_t/\sigma_t)^2}\rho_u\frac{1-r}{1-r\frac{1}{1+(\tau_t/\sigma_t)^2}}$$

$$\alpha_5 \equiv a_5 = -r\frac{1}{1+(\tau_t/\sigma_t)^2}\rho_v\frac{1-r}{1-r\frac{1}{1+(\tau_t/\sigma_t)^2}}$$

Then the following inequalities hold:

$$\frac{\partial\alpha_2}{\partial(\tau_t/\sigma_t)} = -\frac{2r(1-r)(\tau_t/\sigma_t)}{((\tau_t/\sigma_t)^2+1-r)^2} < 0$$

$$\frac{\partial\alpha_3}{\partial(\tau_t/\sigma_t)} = \frac{2r(1-r)(1+\rho_u)(\tau_t/\sigma_t)}{((\tau_t/\sigma_t)^2+1-r)^2} > 0$$

$$\frac{\partial\alpha_4}{\partial(\tau_t/\sigma_t)} = -\rho_u\frac{2r(1-r)(\tau_t/\sigma_t)}{((\tau_t/\sigma_t)^2+1-r)^2} < 0$$

$$\frac{\partial\alpha_5}{\partial(\tau_t/\sigma_t)} = \rho_v\frac{2r(1-r)(\tau_t/\sigma_t)}{((\tau_t/\sigma_t)^2+1-r)^2}.\square$$

D.6 Proof of Corollary 1

If $\rho_u = \rho_v = 0$ holds, then the conditions become $a_4 = a_5 = 0$,

$$a_1 = \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\,a_1\right],$$

$$\begin{aligned} a_2 = (1-\beta\theta)(1-r) \qquad & + \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta) + \beta\theta\right]\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}a_2 \\ & + \beta\theta\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}a_3, \end{aligned}$$

and

$$\begin{aligned} a_3 \;\; = \;\; & \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta) + \beta\theta\right]\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}a_2 \\ & + \left[\beta\theta\frac{\tau_t^2}{\sigma_t^2+\tau_t^2} + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\right]a_3. \end{aligned}$$

Moreover, $a_1 + a_2 + a_3 = 1$ holds because if $a_1 + a_2 + a_3 = 1$ holds, in reality

$$\begin{aligned} a_1 + a_2 + a_3 \;\; = \;\; & \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\,a_1\right] \\ & + (1-\beta\theta)(1-r) + \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta) + \beta\theta\right]\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}a_2 \\ & + \beta\theta\frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}a_3 + \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta) + \beta\theta\right]\frac{\tau_t^2}{\sigma_t^2+\tau_t^2}a_2 \\ & + \left[\beta\theta\frac{\tau_t^2}{\sigma_t^2+\tau_t^2} + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\right]a_3 \\ = \;\; & \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\,a_1 + (1-\theta)a_2 + (1-\theta)\,a_3\right] \\ & + (1-\beta\theta)(1-r) + \beta\theta a_2 + \beta\theta a_3 \\ = \;\; & (1-\beta\theta)r + (1-\beta\theta)(1-r) + \beta\theta a_1 + \beta\theta a_2 + \beta\theta a_3 \\ = \;\; & 1 - \beta\theta + \beta\theta\left(a_1 + a_2 + a_3\right) = 1 \end{aligned}$$

holds. Next, given $a_1 + a_2 + a_3 = 1$ and cash-in-advance constraint $q_t = p_t + y_t$, the equation (26) is expressed as follows.

$$\begin{aligned} p_t - p_{t-1} \;\; = \;\; & \left[\theta + (1-\theta)a_1\right](p_{t-1} - p_{t-1}) + (1-\theta)\,a_2\left(q_t - p_{t-1}\right) + (1-\theta)\,a_3\left(q_{t-1} - p_{t-1}\right), \\ \Leftrightarrow \;\; & \pi_t = (1-\theta)\,a_2\left(\pi_t + y_t\right) + (1-\theta)\,a_3\left(y_{t-1}\right), \\ \Leftrightarrow \;\; & \pi_t = \frac{(1-\theta)\,a_2}{1-(1-\theta)\,a_2}y_t + \frac{(1-\theta)\,a_3}{1-(1-\theta)\,a_2}y_{t-1}.\square \end{aligned}$$

E Business Outlook Survey

The Business Outlook Survey, administered by the Ministry of Finance, covers 37 sectors of the economy from the second quarter of 2004 to the first quarter of 2023 fiscal year.[31] This survey analyzes business leaders' assessments and forecasts for the economy, providing essential information to track economic trends. It encompasses approximately 15,000 companies with headquarters or principal offices in Japan and capital stock of 10 million yen or more. Conducted through self-reporting questionnaires by mail or online, the survey takes place on the 15th day of May, August, November, and February. Tables A1, A2, A3, A4, A5, and A6 show the summary statistics of the sample sectors.

F Annual Survey of Corporate Behavior

The Annual Survey of Corporate Behavior (ASCB), conducted by the Cabinet Office of Japan, spans 33 sectors of the economy from the fiscal year 2003 to 2021.[32] The survey is conducted annually in January. The Economic and Social Research Institute in the Cabinet Office of Japan directly surveys approximately 1,000 public-listed Japanese firms on nominal and real growth rates of the Japanese economy as well as nominal and real growth rates of demand in their respective sectors. The Cabinet Office of Japan releases the arithmetic averages of the individual firms' expectations within each sector while retaining the data on the expectations of the individual firms confidential. Tables A7 and A8 show the summary statistics of the sample sectors.

G Financial Statements Statistics of Corporations Data

We use quarterly data on sector-level sales of Japanese firms from the Financial Statements Statistics of Corporations by Industry, compiled by the Ministry of Finance of Japan.[33] The data cover the period 1975:Q3-2022:Q4 for 29 major sectors in the economy. Table A9 reports summary statistics.

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[31] The data is available at https://www.mof.go.jp/english/pri/reference/bos/index.htm.

[32] The data is available at https://www.esri.cao.go.jp/en/stat/ank/ank-e.html.

[33] The data is available at http://www.mof.go.jp/english/pri/reference/ssc/index.htm.

Table A1: Summary statistics about Business Outlook Survey (Large firms, current)

Dataset: Business Outlook Survey; 37 industries; 2004/2Q-2023/1Q

Sector	*(1) Historical averages*		*(2) Historical standard deviation*		*(3) First-order auto correlation*	
	Own business conditions	*General business conditions*	*Own business conditions*	*General business conditions*	*Own business conditions*	*General business conditions*
Foods	-3.58	-3.41	12.89	18.39	-0.15	0.48
Textiles	-4.59	-4.24	15.18	22.28	0.36	0.46
Wood Products	0.24	0.66	37.88	33.65	0.14	0.38
Pulp and Paper	-4.68	-4.15	16.38	17.52	-0.14	0.49
Chemicals	-0.69	-0.87	12.09	18.11	0.30	0.54
Oil and Coal Products	-7.37	-0.55	22.19	22.80	0.24	0.33
Glass and Ceramics Products	-2.86	-1.39	15.77	23.07	0.43	0.58
Iron and Steel	-6.75	-1.77	22.53	26.19	0.39	0.54
Nonferrous Metals	-3.80	-2.23	18.89	22.56	0.50	0.50
Metal Product	-2.57	-2.81	18.21	22.96	0.31	0.54
General-Purpose Machinery	2.62	-0.30	17.60	20.47	-0.03	0.37
Production Machinery	5.10	2.89	20.21	20.39	0.31	0.33
Business Oriented Machinery	3.79	2.88	15.33	16.58	-0.26	0.14
Electrical Machinery	-0.17	-0.33	17.15	21.90	0.25	0.50
Electric Device	0.53	0.66	20.35	21.63	0.27	0.47
Cars and Related Products	-2.49	-0.34	29.10	28.84	0.06	0.19
Other Transportation Equipment	-6.81	-2.95	17.12	20.02	0.09	0.46
Other Products	-2.50	-1.67	14.67	21.27	0.42	0.57
Agriculture, Forestry, and Fishing	-1.68	6.47	38.12	32.89	-0.34	0.35
Mining and Quarrying of Stone and Gravel	-2.86	-2.67	13.16	12.84	-0.06	0.46
Construction	1.00	-1.72	17.30	20.49	-0.24	0.63
Electricity, Gas, Heat supply and Water	-2.50	2.17	8.94	16.98	-0.22	0.61
Information and Communications	0.64	-1.62	13.00	20.60	0.08	0.62
Transport and Postal Activities	-2.49	-1.18	14.89	22.04	0.17	0.47
Whole-sale	-0.78	-1.03	14.63	21.01	0.44	0.58
Retail	1.34	-4.25	14.54	24.18	0.25	0.50
Real Estate	-3.96	-4.99	13.09	21.83	0.36	0.59
Lease	-1.19	-2.18	15.37	21.09	0.45	0.61
Goods Rental and Leasing	-1.34	2.76	28.41	25.45	0.08	0.18
Accommodations, Eating and Drinking Services	-1.60	-2.15	27.17	31.58	-0.05	0.33
Living-Related and Personal Services	4.90	3.17	25.36	27.35	0.18	0.36
Services for Amusement and Hobbies	1.31	-3.49	24.34	26.78	-0.03	0.35
Scientific Research, Professional and Technical Services	0.52	-0.85	7.36	16.71	0.36	0.37
Healthcare and Education	8.32	0.50	17.33	26.36	0.20	0.48
Employment and Worker Dispatching Services	11.44	13.09	31.45	31.27	0.24	0.38
Other Service	2.66	0.37	9.59	16.39	0.08	0.32
Finance and Insurance	-3.02	0.99	11.92	27.66	0.62	0.64

Table A2: Summary statistics about Business Outlook Survey (Mid-sized firms, current)

Dataset: Business Outlook Survey; 37 industries; 2004/2Q-2023/1Q

Sector	*(1) Historical averages*		*(2) Historical standard deviation*		*(3) First-order auto correlation*	
	Own business conditions	*General business conditions*	*Own business conditions*	*General business conditions*	*Own business conditions*	*General business conditions*
Foods	-7.10	-8.84	16.73	24.06	-0.17	0.53
Textiles	-19.28	-19.85	21.05	23.35	0.17	0.56
Wood Products	-5.39	-7.46	28.45	31.07	0.17	0.48
Pulp and Paper	-11.14	-10.78	23.36	27.19	-0.05	0.37
Chemicals	-3.34	-2.73	15.38	22.24	0.22	0.58
Oil and Coal Products	1.04	2.88	28.81	27.82	0.05	0.51
Glass and Ceramics Products	-6.88	-7.58	19.72	25.54	0.35	0.65
Iron and Steel	-8.44	-7.17	24.12	28.12	0.36	0.50
Nonferrous Metals	-11.77	-9.69	22.77	26.59	0.32	0.47
Metal Product	-6.58	-5.54	22.57	25.06	0.39	0.47
General-Purpose Machinery	-1.51	-2.75	20.55	21.05	-0.07	0.20
Production Machinery	0.25	-3.52	16.32	20.40	0.26	0.51
Business Oriented Machinery	-1.73	-3.06	17.12	19.03	0.20	-0.05
Electrical Machinery	-3.21	-3.45	20.21	23.01	0.32	0.67
Electric Device	-4.40	-6.81	19.37	24.01	0.38	0.53
Cars and Related Products	-5.25	-2.83	30.45	30.30	0.12	0.26
Other Transportation Equipment	-4.21	-6.90	25.69	25.92	-0.24	0.20
Other Products	-9.51	-7.68	15.67	24.34	0.47	0.64
Agriculture, Forestry, and Fishing	-12.46	-12.94	19.13	25.35	0.31	0.43
Mining and Quarrying of Stone and Gravel	-10.01	-14.63	21.71	25.75	0.39	0.43
Construction	-4.05	-7.81	16.45	25.32	0.29	0.70
Electricity, Gas, Heat supply and Water	-6.31	-5.82	13.36	22.67	0.23	0.60
Information and Communications	-1.16	-5.16	14.84	24.15	0.31	0.68
Transport and Postal Activities	-9.98	-7.97	15.97	24.04	0.30	0.53
Whole-sale	-6.77	-7.63	14.60	23.83	0.45	0.65
Retail	-7.94	-8.26	16.18	25.68	0.13	0.51
Real Estate	-6.53	-9.65	9.63	22.88	0.52	0.69
Lease	-7.67	-6.53	16.80	24.11	0.32	0.64
Goods Rental and Leasing	-5.20	-12.64	27.49	27.29	-0.12	0.38
Accommodations, Eating and Drinking Services	-11.51	-8.44	26.32	30.59	0.05	0.41
Living-Related and Personal Services	-5.51	-8.07	24.46	26.58	0.19	0.41
Services for Amusement and Hobbies	-9.90	-11.18	21.28	25.70	-0.10	0.39
Scientific Research, Professional and Technical Services	-1.28	-5.40	12.54	19.83	0.20	0.52
Healthcare and Education	4.05	-3.27	16.74	26.28	0.24	0.54
Employment and Worker Dispatching Services	8.91	0.26	22.35	29.23	0.24	0.53
Other Service	-1.55	-5.45	11.71	19.85	0.19	0.41
Finance and Insurance	-6.47	-3.57	14.49	28.92	0.44	0.67

Table A3: Summary statistics about Business Outlook Survey (Small firms, current)

Dataset: Business Outlook Survey; 37 industries; 2004/2Q-2023/1Q

	(1) Historical averages		*(2) Historical standard deviation*		*(3) First-order auto correlation*	
Sector	*Own business conditions*	*General business conditions*	*Own business conditions*	*General business conditions*	*Own business conditions*	*General business conditions*
Foods	-22.97	-24.72	16.98	20.55	0.24	0.42
Textiles	-26.90	-28.83	15.82	22.08	0.35	0.41
Wood Products	-28.19	-25.77	20.23	23.34	0.40	0.62
Pulp and Paper	-22.07	-22.17	18.38	23.91	0.12	0.56
Chemicals	-12.66	-16.51	16.63	22.30	0.23	0.50
Oil and Coal Products	-17.25	-18.15	15.45	20.10	0.30	0.44
Glass and Ceramics Products	-22.26	-24.95	18.81	22.75	0.33	0.60
Iron and Steel	-14.78	-14.57	21.29	28.04	0.54	0.74
Nonferrous Metals	-17.88	-19.13	22.62	27.32	0.47	0.63
Metal Product	-17.58	-19.81	21.71	25.11	0.61	0.66
General-Purpose Machinery	-12.44	-17.96	19.56	25.37	0.53	0.68
Production Machinery	-10.96	-16.18	18.22	22.12	0.42	0.54
Business Oriented Machinery	-12.96	-14.52	17.28	20.60	0.45	0.36
Electrical Machinery	-16.08	-17.51	19.43	26.28	0.54	0.67
Electric Device	-15.83	-17.63	19.53	22.53	0.41	0.43
Cars and Related Products	-13.08	-16.44	27.06	30.75	0.42	0.44
Other Transportation Equipment	-19.63	-18.86	16.60	24.53	0.40	0.61
Other Products	-22.54	-25.20	13.47	19.83	0.53	0.70
Agriculture, Forestry, and Fishing	-15.65	-21.31	18.59	23.25	0.34	0.51
Mining and Quarrying of Stone and Gravel	-22.86	-26.76	19.09	21.70	0.33	0.56
Construction	-17.86	-21.35	14.63	21.26	0.65	0.81
Electricity, Gas, Heat supply and Water	-	-	-	-	-	-
Information and Communications	-9.44	-12.63	14.07	24.93	0.45	0.72
Transport and Postal Activities	-20.34	-21.06	16.45	22.30	0.41	0.69
Whole-sale	-23.21	-24.46	12.57	20.45	0.50	0.70
Retail	-27.28	-29.27	12.12	20.09	0.39	0.65
Real Estate	-12.36	-17.14	10.12	21.10	0.78	0.78
Lease	-16.62	-17.99	20.50	26.59	0.50	0.77
Goods Rental and Leasing	-19.06	-20.51	17.39	24.59	0.39	0.54
Accommodations, Eating and Drinking Services	-22.97	-24.54	20.52	26.39	0.08	0.31
Living-Related and Personal Services	-21.28	-21.73	16.51	25.47	0.25	0.65
Services for Amusement and Hobbies	-19.32	-20.38	17.97	22.85	0.15	0.56
Scientific Research, Professional and Technical Services	-12.90	-18.26	12.50	21.92	0.62	0.72
Healthcare and Education	-12.70	-17.56	13.73	22.78	0.22	0.61
Employment and Worker Dispatching Services	-11.90	-13.55	19.29	23.43	0.37	0.50
Other Service	-16.82	-20.74	12.54	20.52	0.51	0.66
Finance and Insurance	-	-	-	-	-	-

Table A4: Summary statistics about Business Outlook Survey (Large firms, future)

Dataset: Business Outlook Survey; 37 industries; 2004/2Q-2023/1Q

Sector	*(1) Historical averages*		*(2) Historical standard deviation*		*(3) First-order auto correlation*	
	Own business conditions	*General business conditions*	*Own business conditions*	*General business conditions*	*Own business conditions*	*General business conditions*
Foods	0.79	-0.20	9.43	10.22	-0.25	0.39
Textiles	2.42	1.19	9.04	13.35	0.26	0.48
Wood Products	5.03	5.76	30.09	27.01	0.11	0.17
Pulp and Paper	2.43	0.81	9.37	8.99	0.00	0.28
Chemicals	5.15	2.79	6.42	9.79	0.08	0.42
Oil and Coal Products	-1.80	-0.28	8.27	8.18	0.22	0.20
Glass and Ceramics Products	5.92	2.31	12.95	13.67	0.28	0.52
Iron and Steel	4.02	3.25	13.71	13.54	0.25	0.36
Nonferrous Metals	3.12	2.99	11.53	12.07	0.13	0.36
Metal Product	2.61	0.49	13.32	13.97	0.27	0.37
General-Purpose Machinery	7.41	4.40	11.88	12.23	-0.30	0.08
Production Machinery	8.05	5.55	10.66	10.59	0.10	0.31
Business Oriented Machinery	6.88	5.64	11.05	9.13	-0.26	0.35
Electrical Machinery	6.56	3.13	11.43	12.49	0.05	0.37
Electric Device	9.73	5.69	10.71	10.51	0.12	0.31
Cars and Related Products	3.16	2.07	16.46	15.77	0.20	0.37
Other Transportation Equipment	-3.16	0.50	13.85	11.97	0.14	0.47
Other Products	6.24	3.71	8.34	12.70	0.34	0.54
Agriculture, Forestry, and Fishing	-1.15	9.62	32.58	27.71	-0.15	0.18
Mining and Quarrying of Stone and Gravel	-1.67	-0.63	7.21	8.82	0.08	0.47
Construction	1.18	1.14	15.01	13.38	-0.47	0.61
Electricity, Gas, Heat supply and Water	-0.96	3.00	6.57	9.91	-0.34	0.62
Information and Communications	5.91	1.51	8.27	12.52	-0.03	0.69
Transport and Postal Activities	2.15	2.26	7.36	11.76	0.46	0.56
Whole-sale	4.71	2.71	9.30	12.45	0.41	0.53
Retail	5.99	0.34	10.72	16.04	0.09	0.37
Real Estate	-1.84	-1.66	8.01	13.09	0.65	0.68
Lease	3.69	1.36	9.87	12.97	0.25	0.52
Goods Rental and Leasing	1.72	3.24	20.96	20.44	0.09	-0.05
Accommodations, Eating and Drinking Services	6.58	3.31	16.96	18.92	0.27	0.57
Living-Related and Personal Services	13.49	7.51	14.60	17.20	-0.13	0.30
Services for Amusement and Hobbies	7.64	1.87	15.66	16.37	0.15	0.40
Scientific Research, Professional and Technical Services	3.41	2.47	4.09	9.56	0.05	0.26
Healthcare and Education	11.85	3.26	12.30	15.00	0.41	0.60
Employment and Worker Dispatching Services	13.70	7.50	17.09	13.94	0.39	0.12
Other Service	5.27	3.43	6.18	10.65	0.01	0.48
Finance and Insurance	2.87	5.69	7.41	17.43	0.77	0.68

Table A5: Summary statistics about Business Outlook Survey (Mid-sized firms, future)

Dataset: Business Outlook Survey; 37 industries; 2004/2Q-2023/1Q

Sector	*(1) Historical averages*		*(2) Historical standard deviation*		*(3) First-order auto correlation*	
	Own business conditions	*General business conditions*	*Own business conditions*	*General business conditions*	*Own business conditions*	*General business conditions*
Foods	-2.04	-4.73	14.06	16.37	-0.25	0.49
Textiles	-11.13	-11.18	18.32	21.05	0.29	0.41
Wood Products	-1.63	-3.87	21.86	21.48	0.10	0.15
Pulp and Paper	-1.32	-3.91	17.68	17.75	-0.11	0.24
Chemicals	3.24	0.05	10.39	14.29	-0.01	0.51
Oil and Coal Products	1.76	1.26	24.72	24.56	-0.04	0.06
Glass and Ceramics Products	1.35	-1.38	17.27	18.17	0.27	0.47
Iron and Steel	-0.76	-1.18	17.95	18.85	0.29	0.44
Nonferrous Metals	-2.23	-3.26	19.12	18.97	0.10	0.31
Metal Product	1.80	-0.59	15.61	17.76	0.25	0.47
General-Purpose Machinery	4.63	1.02	14.34	13.86	-0.16	0.18
Production Machinery	3.85	-0.94	11.45	14.59	0.29	0.27
Business Oriented Machinery	3.71	0.34	11.74	15.82	-0.13	0.36
Electrical Machinery	3.28	-0.81	15.68	17.69	0.25	0.50
Electric Device	6.57	2.26	14.93	14.07	0.10	0.29
Cars and Related Products	-0.33	-2.32	19.76	19.93	0.19	0.36
Other Transportation Equipment	-2.73	-5.49	20.23	17.12	-0.23	0.31
Other Products	2.55	-0.61	11.86	16.31	0.02	0.41
Agriculture, Forestry, and Fishing	-5.76	-7.84	17.66	17.32	0.22	0.05
Mining and Quarrying of Stone and Gravel	-7.55	-9.66	17.89	19.21	0.29	0.58
Construction	-2.24	-4.54	13.64	18.96	0.29	0.64
Electricity, Gas, Heat supply and Water	-1.09	-2.08	12.14	13.98	0.09	0.36
Information and Communications	4.57	-0.55	11.55	17.38	0.49	0.73
Transport and Postal Activities	-2.77	-2.74	11.50	15.25	0.22	0.53
Whole-sale	0.50	-2.33	10.29	16.74	0.44	0.55
Retail	-1.15	-3.98	12.88	18.66	0.13	0.51
Real Estate	-4.08	-6.67	7.28	16.67	0.65	0.72
Lease	-2.18	-0.11	13.57	17.52	0.21	0.52
Goods Rental and Leasing	7.14	-2.22	26.93	23.33	0.33	0.50
Accommodations, Eating and Drinking Services	-0.52	-2.29	17.74	20.66	0.34	0.59
Living-Related and Personal Services	2.62	-2.91	16.30	21.31	0.22	0.65
Services for Amusement and Hobbies	-2.59	-5.34	14.65	17.46	-0.06	0.54
Scientific Research, Professional and Technical Services	4.16	-0.99	7.56	13.12	0.30	0.50
Healthcare and Education	10.37	0.82	14.19	19.20	0.29	0.58
Employment and Worker Dispatching Services	14.23	5.69	21.95	22.28	0.11	0.57
Other Service	1.79	-1.07	7.09	11.86	0.32	0.39
Finance and Insurance	1.91	1.56	9.46	19.64	0.51	0.63

Table A6: Summary statistics about Business Outlook Survey (Small firms, future)

Dataset: Business Outlook Survey; 37 industries; 2004/2Q-2023/1Q

Sector	*(1) Historical averages*		*(2) Historical standard deviation*		*(3) First-order auto correlation*	
	Own business conditions	*General business conditions*	*Own business conditions*	*General business conditions*	*Own business conditions*	*General business conditions*
Foods	-9.51	-14.50	13.34	15.77	0.12	0.51
Textiles	-14.72	-17.84	11.78	16.69	0.24	0.29
Wood Products	-13.91	-16.87	16.04	16.12	0.16	0.43
Pulp and Paper	-13.22	-13.73	15.15	20.91	-0.12	0.32
Chemicals	-5.73	-9.11	11.35	15.34	0.29	0.48
Oil and Coal Products	-12.07	-14.09	12.54	16.03	0.32	0.50
Glass and Ceramics Products	-15.16	-17.27	13.94	18.17	0.46	0.54
Iron and Steel	-8.07	-9.36	14.17	20.12	0.40	0.52
Nonferrous Metals	-10.03	-13.83	16.78	20.27	0.31	0.42
Metal Product	-10.44	-13.00	13.55	17.49	0.56	0.62
General-Purpose Machinery	-9.46	-12.63	13.45	17.06	0.48	0.35
Production Machinery	-5.65	-9.90	11.08	14.72	0.24	0.49
Business Oriented Machinery	-4.91	-10.77	11.61	15.72	0.47	0.53
Electrical Machinery	-8.19	-11.03	15.97	20.04	0.61	0.65
Electric Device	-6.51	-11.46	13.38	15.60	0.21	0.40
Cars and Related Products	-9.49	-13.84	18.96	22.07	0.31	0.52
Other Transportation Equipment	-9.80	-13.27	15.05	19.49	0.51	0.62
Other Products	-12.07	-15.69	9.35	14.27	0.20	0.47
Agriculture, Forestry, and Fishing	-5.87	-13.62	13.16	17.56	0.07	0.37
Mining and Quarrying of Stone and Gravel	-12.36	-18.66	14.87	15.95	0.43	0.56
Construction	-11.38	-15.78	9.94	15.05	0.79	0.80
Electricity, Gas, Heat supply and Water	-	-	-	-	-	-
Information and Communications	-4.68	-9.42	10.74	19.49	0.49	0.73
Transport and Postal Activities	-10.88	-14.00	11.47	16.11	0.48	0.68
Whole-sale	-13.09	-16.71	9.84	15.50	0.34	0.58
Retail	-16.03	-21.07	8.38	15.07	0.46	0.60
Real Estate	-7.42	-12.41	7.19	15.71	0.81	0.77
Lease	-9.59	-12.98	16.54	19.98	0.32	0.66
Goods Rental and Leasing	-9.64	-14.82	12.93	16.91	0.50	0.54
Accommodations, Eating and Drinking Services	-13.33	-16.15	13.55	17.11	0.34	0.48
Living-Related and Personal Services	-11.37	-17.13	12.72	17.50	0.16	0.41
Services for Amusement and Hobbies	-8.82	-11.39	13.44	15.96	0.12	0.47
Scientific Research, Professional and Technical Services	-7.58	-13.33	8.90	15.38	0.66	0.72
Healthcare and Education	-5.71	-11.49	11.69	16.47	0.14	0.59
Employment and Worker Dispatching Services	-4.18	-6.27	12.61	17.50	0.55	0.41
Other Service	-9.99	-14.18	8.58	13.82	0.59	0.66
Finance and Insurance	-	-	-	-	-	-

Table A7: Summary statistics about survey data (nominal output growth expectations)

Dataset: Annual Survey of Corporate Behavior; 31 industries; 2003-2022

Sector	*(1) Historical* averages	*(2) Historical* standard deviation	*(3) First-order* auto correlation
Foods	1.12	0.73	0.42
Textiles & Apparels	1.11	0.74	0.29
Pulp & Paper	1.08	0.97	0.38
Chemicals	1.20	0.90	0.30
Oil & Coal Products	0.70	1.16	0.26
Glass & Ceramics Products	1.04	0.97	0.30
Iron & Steel	1.06	0.94	0.37
Nonferrous Metals	1.10	0.87	0.35
Metal Products	1.05	0.80	0.50
Machinery	1.16	0.87	0.45
Electric Appliances	1.21	0.88	0.47
Transportation Equipment	1.11	0.88	0.31
Precision Instruments	1.26	0.87	0.60
Other Products	1.16	0.81	0.54
Fishery, Agriculture & Forestry	0.83	1.96	0.42
Mining	1.98	0.41	-0.40
Construction	1.20	0.82	0.54
Wholesale Trade	1.13	0.85	0.40
Retail Trade	1.00	0.80	0.50
Real Estate	1.12	0.76	0.38
Land Transportation	1.22	0.80	0.57
Marine Transportation	1.37	0.81	0.64
Air Transportation	0.67	1.54	0.72
Warehousing & Harbor Transportation Services	1.22	0.64	0.29
Information & Communication	1.03	0.83	0.17
Electric Power & Gas	1.43	1.08	0.31
Services	1.04	0.75	0.46
Banks	1.34	1.00	0.41
Securities & Commodity Futures	1.30	1.14	0.34
Insurance	1.33	1.31	0.47
Other Financing Businesses	1.37	0.83	0.36
All	1.15	0.79	0.43

Table A8: Summary statistics about survey data (nominal sectoral demand growth expectations)

Dataset: Annual Survey of Corporate Behavior; 31 industries; 2003-2022

Sector	*(1) Historical* averages	*(2) Historical* standard deviation	*(3) First-order* auto correlation
Foods	0.53	0.51	0.61
Textiles & Apparels	0.39	0.93	0.15
Pulp & Paper	-0.06	1.68	0.17
Chemicals	1.19	1.05	0.28
Oil & Coal Products	-1.02	1.60	0.31
Glass & Ceramics Products	0.37	1.14	0.34
Iron & Steel	0.49	2.39	0.05
Nonferrous Metals	1.04	2.09	0.25
Metal Products	0.36	1.32	0.48
Machinery	1.27	2.02	0.00
Electric Appliances	1.76	1.27	0.22
Transportation Equipment	1.08	2.00	0.16
Precision Instruments	1.51	0.93	0.22
Other Products	0.55	0.83	0.43
Fishery, Agriculture & Forestry	1.20	0.99	0.26
Mining	1.81	0.44	0.20
Construction	-0.16	1.57	0.59
Wholesale Trade	0.77	1.02	0.43
Retail Trade	0.34	0.92	0.71
Real Estate	1.55	1.59	0.19
Land Transportation	0.42	0.69	0.79
Marine Transportation	2.14	1.59	0.01
Air Transportation	1.34	0.80	-0.91
Warehousing & Harbor Transportation Services	0.96	0.65	0.47
Information & Communication	1.75	1.29	0.36
Electric Power & Gas	1.42	0.92	0.10
Services	1.47	1.25	0.45
Banks	0.91	0.68	0.19
Securities & Commodity Futures	2.22	2.94	0.50
Insurance	1.00	1.36	0.64
Other Financing Businesses	0.58	2.62	0.50
All	0.96	1.07	0.42

Table A9: Summary statistics about sales data

Dataset: Financial statement statistics of corporations by industry, 29 sectors; 1975/3Q-2022/4Q

Sector	*(1) Historical averages*	*(2) Historical standard deviation*	*(3) First-order auto correlation*
Foods	0.58	3.93	-0.19
Textiles	-0.05	7.33	-0.11
Wood Products	0.21	10.42	-0.09
Pulp and Paper	0.34	6.15	0.02
Printing	0.33	7.21	-0.09
Chemicals	0.64	4.01	0.15
Oil and Coal Products	0.25	9.60	0.05
Glass and Ceramics Products	0.35	5.13	-0.10
Iron and Steel	0.39	5.64	0.25
Nonferrous Metals	0.78	6.55	0.28
Metal Product	0.70	6.54	-0.03
Machinery	0.87	4.62	0.14
Electric Device	0.94	4.64	0.23
Cars and Related Products	1.03	6.96	-0.03
Other Transportation Equipment	0.22	9.26	-0.23
Other Products	0.87	7.30	-0.22
Mining	0.33	11.46	-0.15
Construction	0.82	3.51	-0.02
Electric Power	1.20	5.08	-0.05
Gas and Water Supply	1.25	4.29	0.36
Information and Communication	1.71	4.95	-0.03
Land Transportation	0.95	5.18	-0.04
Water Transportation	0.29	6.12	0.12
Wholesale	0.39	4.23	0.01
Retail	1.24	3.91	0.06
Real Estate	1.13	9.10	-0.16
Hotel	0.69	13.19	-0.16
Living-Related Service	1.30	12.41	-0.07
Other Service	1.59	10.06	-0.29

H Extracting the Sequence of Shocks on Aggregate and Sector-Specific Components of Demand

To extract the sequence of shocks on aggregate and sector-specific components of demand ($e_t, \{\epsilon_t(i)\}_{i=1}^{29}$), we decompose fluctuations in aggregate and sector-specific components (i.e., $u_t, \{\widetilde{x}_t(i) - u_t\}_{i=1}^{29}$) into expected component and shocks for firms using the equations (4) and (5) and (6). More concretely, we use equation (4) that characterizes the law of motion of aggregate demand as:

$$u_t = \rho_u u_{t-1} + e_t,$$

to decompose aggregate demand into the expected component ($\mathbb{E}_{t-1}[u_t] = \rho_u u_{t-1}$) and shock ($e_t$). We estimate the parameter ρ_u and the unobservable shock e_t using the equation:

$$u_t = c_u + \rho_u u_{t-1} + e_t,$$

where c_u is a constant term that normalizes e_t to have mean zero. We then proxy the shock to aggregate demand as:

$$\widehat{e}_t = u_t - \widehat{c}_u - \widehat{\rho}_u u_{t-1},$$

and the variance of the shock $\sigma_t^2 = \mathbb{V}(e_t) = \mathbb{E}\left[e_t^2\right]$ is approximated by $\frac{1}{2k+1}\sum_{s=-k}^{k} \widehat{e}_t^2$.

Similarly, we use equation (5) that characterizes the law of motion of sector-specific demand ($\{\widetilde{v}_t(i)\}_{i=1}^{29}$) as:

$$\widetilde{v}_t(i) = v_t(i) - v_{t-1}(i) = \rho_v\left(v_{t-1}(i) - v_{t-2}(i)\right) + \epsilon_t(i) - \epsilon_{t-1}(i) = \rho_v \widetilde{v}_{t-1}(i) + \epsilon_t(i) - \epsilon_{t-1}(i),$$

to decompose sector-specific demand into the expected component ($\mathbb{E}_{t-1}[\widetilde{v}_t(i)] = \rho_v \widetilde{v}_{t-1}(i) - \epsilon_{t-1}(i)$) and shock ($\epsilon_t(i)$). Since ($\rho_v, \epsilon_t(i), \epsilon_{t-1}(i)$) are unobservable for us, we estimate them from following empirical equation to obtain ($\rho_v, \epsilon_t(i) - \epsilon_{t-1}(i)$) :

$$\left(\widetilde{x}_t(i) - u_t\right) = c_v(i) + \rho_v\left(\widetilde{x}_{t-1}(i) - u_{t-1}\right) + \left(\epsilon_t(i) - \epsilon_{t-1}(i)\right),$$

where $c_v(i)$ is a constant term to normalize $\epsilon_t(i) - \epsilon_{t-1}(i)$ as mean zero. We then obtain

$$\widehat{\epsilon}_t(i) - \widehat{\epsilon}_{t-1}(i) = \left(\widetilde{x}_t(i) - u_t\right) - \widehat{c}_v(i) - \rho_v\left(\widetilde{x}_{t-1}(i) - u_{t-1}\right)$$

as the proxy for shock on sector-specific demand ($\epsilon_t(i) - \epsilon_{t-1}(i)$). Using the cross-sectional variation of $\widehat{\epsilon}_t(i) - \widehat{\epsilon}_{t-1}(i)$, we approximate

$\tau_t^2 = \mathbb{V}\left(\epsilon_t(i)\right) = \mathbb{E}\left[\epsilon_t^2(i)\right]$ by $\frac{1}{2k+1}\sum_{s=-k}^{k}\left(\frac{1}{29}\sum_{i=1}^{29}\frac{(\widehat{\epsilon}_t(i)-\widehat{\epsilon}_{t-1}(i))^2}{2}\right)$.[34]

Table A10: Summary statistics about aggregate and sector-specific components of demand

Dataset: Financial statement statistics of corporations by industry, 29 sectors; 1975/4Q-2022/4Q

	Historical averages		*Historical standard deviation*		*First-order auto correlation*		*Historical standard deviation*	
Sector	*(1) Growth of aggregate demand*	*(2) Growth of sector specific demand*	*(3) Growth of aggregate demand*	*(4) Growth of sector-specific demand*	*(5) Growth of aggregate demand*	*(6) Growth of sector-specific demand*	*(7) Aggregate shocks*	*(8) Sector-specific shocks*
Foods	0.69	-0.11	3.12	4.31	0.33	-0.02	2.93	4.33
Textiles		-0.74		6.54		-0.15		6.54
Wood Products		-0.48		10.12		-0.15		10.00
Pulp and Paper		-0.36		5.91		0.00		5.92
Printing		-0.36		7.00		-0.06		6.97
Chemicals		-0.05		3.08		-0.08		3.09
Oil and Coal Products		-0.44		8.42		-0.13		8.31
Glass and Ceramics Products		-0.34		4.92		-0.17		4.88
Iron and Steel		-0.30		4.16		0.06		4.16
Nonferrous Metals		0.09		4.88		0.12		4.87
Metal Product		0.01		6.18		-0.15		6.19
Machinery		0.18		3.85		-0.19		3.81
Electric Device		0.25		3.53		-0.05		3.53
Cars and Related Products		0.34		5.26		-0.13		5.23
Other Transportation Equipment		-0.47		9.38		-0.22		9.28
Other Products		0.18		6.53		-0.27		6.47
Mining		-0.36		10.11		-0.25		9.89
Construction		0.12		4.07		0.04		4.07
Electric Power		0.51		5.40		-0.09		5.41
Gas and Water Supply		0.56		4.65		0.17		4.52
Information and Communication		1.02		5.17		-0.06		5.17
Land Transportation		0.26		5.40		-0.09		5.39
Water Transportation		-0.40		5.02		-0.06		5.03
Whole-sale		-0.30		3.16		-0.23		3.11
Retail		0.55		4.22		0.07		4.23
Real Estate		0.44		8.60		-0.11		8.63
Hotel		-0.01		12.10		-0.15		12.04
Living-Related Service		0.61		11.85		-0.09		11.87
Other Service.		0.90		9.84		-0.29		9.48

Table A10 reports summary statistics for estimates of the aggregate and sector-specific components of demand $\left(u_t, \{\widetilde{x}_t(i) - u_t\}_{i=1}^{29}\right)$ for the average (columns 1 and 2), standard deviation (columns 3 and 4), and first-order autocorrelation (columns 5 and 6) of the series. Columns (7) and (8) report standard deviation of $\widehat{e}_t$ and $\{\widehat{\epsilon}_t(i)\}_{i=1}^{29}$, respectively.

I Aggregate Demand and the Output Gap

To evaluate whether the extracted (unnormalized) changes in aggregate demand ($u_t = \sum_{i=1}^{29} \Lambda_i \widetilde{x}_t(i)$) is a plausible measure of aggregate disturbances, and it is consistent with alternative measures, we compare the eight-quarters backward moving averages of the changes

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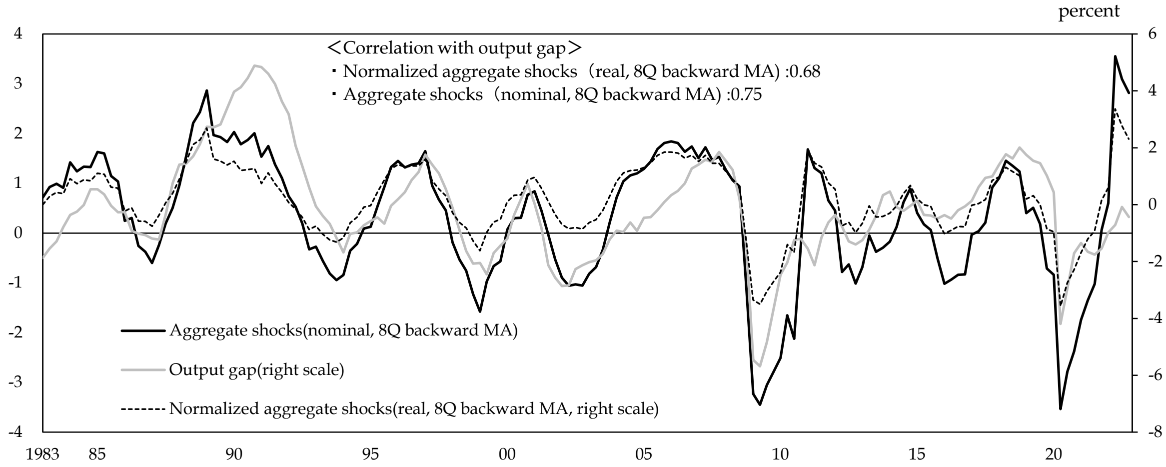
[34] Note that the following equation holds,

$$\begin{aligned}\mathbb{V}\left(\widehat{\epsilon}_t(i) - \widehat{\epsilon}_{t-1}(i)\right) &= \mathbb{E}\left[\left(\widehat{\epsilon}_t(i) - \widehat{\epsilon}_{t-1}(i)\right)^2\right] = 2\mathbb{V}\left(\epsilon_t(i)\right) \\ &\Leftrightarrow \mathbb{V}\left(\epsilon_t(i)\right) = \frac{1}{2}\mathbb{V}\left(\epsilon_t(i) - \epsilon_{t-1}(i)\right),\end{aligned}$$

and thus the variance of $\epsilon_t(i) - \epsilon_{t-1}(i)$ is monotonically increasing in τ_t^2.

Figure A1: Changes in aggregate demand and output gap



Sources: Ministry of Finance "Financial statements statistics of corporations by industry", Bank of Japan "Output Gap and Potential Growth Rate".

in aggregate demand, $\frac{1}{8}\sum_{s=0}^{7} u_{t-s}$,[35] with the averages of changes in total sectoral demand across sectors ($u_t = \frac{1}{29}\sum_{i=1}^{29} \widetilde{x}_t(i)$) and the output gap published by the Bank of Japan.[36]

Figure A1 examines the relation between the dynamics of our estimates for aggregate shocks and the output gaps. It shows that our measure of changes in aggregate demand highly co-moves with the averages of changes in sectoral demand across sectors, with a correlation coefficient equal to 0.75 (nominal and 0.68 (real), suggesting that our identified measure for the changes in aggregate demand is consistent with alternative measures of the changes in aggregate demand.

J Producer Price Index Data

We use monthly data on sector-level producer prices of Japanese firms from corporate Goods Price Index (CGPI), compiled by the Bank of Japan. The data cover the period 1961:M1 for 23 major sectors in the economy. The data is transformed to quarterly data by taking averages of samples in each quarter (i.e., three months) and matched with the database for

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[35] Our measure of the changes in aggregate demand is a flow rather than stock concept. By comparing moving averages of the changes in aggregate demand (i.e., the averages of flow data) with the output gap (i.e. stock data), we ensure that our measure is consistent with conventional measures.

[36] The series is available here. https://www.boj.or.jp/en/research/research_data/gap/index.htm/
The description of the methodology for the estimation is here https://www.boj.or.jp/en/research/brp/ron_2017/ron170531a.htm/.

industry-level sales data. Table A11 shows summary statistics of the sectoral inflation.

Table A11: Descriptive statistics about PPI data

Dataset: producer price index (seasonally adjusted, QoQ), 23sectors; 1975/4Q-2022/4Q

Sector	*(1) Historical averages*	*(2) Historical standard deviation*	*(3) First-order auto correlation*
Foods	0.36	0.84	0.59
Textiles & Apparels	0.17	1.05	0.46
Wood Products	0.56	3.51	0.51
Pulp and Paper	0.31	1.83	0.65
Chemicals	0.12	1.90	0.54
Oil and Coal Products	0.78	6.86	0.29
Glass and Ceramics Products	0.36	1.05	0.62
Iron and Steel	0.56	2.42	0.70
Nonferrous Metals	0.42	4.17	0.49
Metal Product	0.37	0.92	0.63
Machinery	0.20	0.59	0.41
Electric Device	-0.11	0.63	0.54
Transportation Equipment	-0.04	0.50	0.34
Mining and Quarrying of Stone and Gravel	0.57	1.84	0.63
Construction	0.34	1.06	0.41
Electricity	0.45	4.20	0.26
Gas, Heat supply and Water	0.61	5.70	0.42
Information and Communications	-0.19	0.64	0.23
Land Transportation	0.20	0.60	0.44
Water Transportation	0.13	2.61	0.33
Real Estate	0.19	0.89	0.43
Accommodations, Eating and Drinking Services	-0.17	4.23	0.10
Living-Related and Personal Services	-0.01	0.58	0.44

Note: The classification of the sectors in PPI data for Japan are matched with those from the sectoral sales data in Table A9.

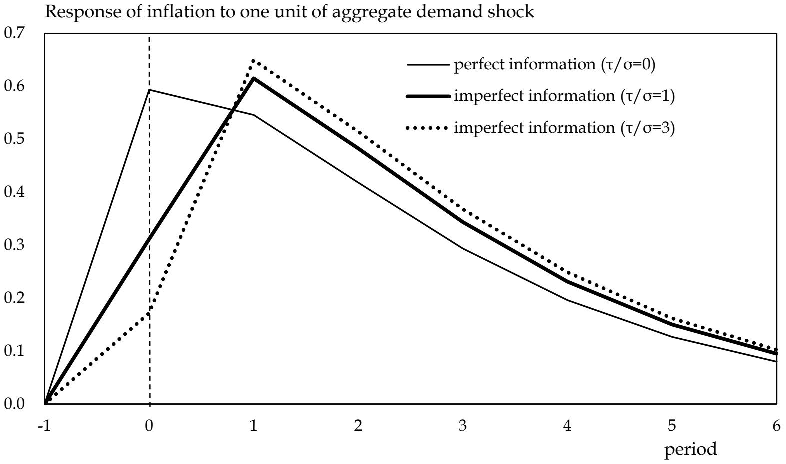
K IRF of Aggregate Inflation to Aggregate Demand Shocks

K.1 Numerical Assessment

How does the relative volatility of sector-specific demand shocks to aggregate shocks influence the sensitivity of inflation to changes in aggregate demand? To address this central question of our analysis, we simulate the model and determine the response of inflation to a one-period, positive aggregate demand shock for different values of τ_t/σ_t. Figure A2 shows that an increase in the ratio τ_t/σ_t reduces the response of inflation to changes in aggregate demand. Since the firm cannot disentangle changes in aggregate and sector-specific demand, it attributes changes in total sectoral demand partially to changes in sector-specific demand, which have no effect on the price-setting decisions of firms in other sectors in the economy.

Attributing part of the movement in total sectoral demand to sector-specific demand induces the firm to decrease the response of prices to aggregate shocks. Therefore, inflation becomes less responsive to changes in total sectoral demand. If the ratio of τ_t/σ_t is large, the firm conjectures that a large fraction of the changes in total sectoral demand occurs because of sector-specific shock. Consequently, the firm expects that the average price in the period remains almost the same as that in the previous period and adjusts its prices less strongly to changes in aggregate demand. This makes the response more persistent.

Figure A2: Impulse response functions of aggregate inflation to aggregate shocks



Response of inflation to one unit of aggregate demand shock

Notes: Parameters are $\theta = 0.3,\ r = 0.7,\ \beta = 0.99, \rho_u = 0.33,\ \rho_v = -0.09.$

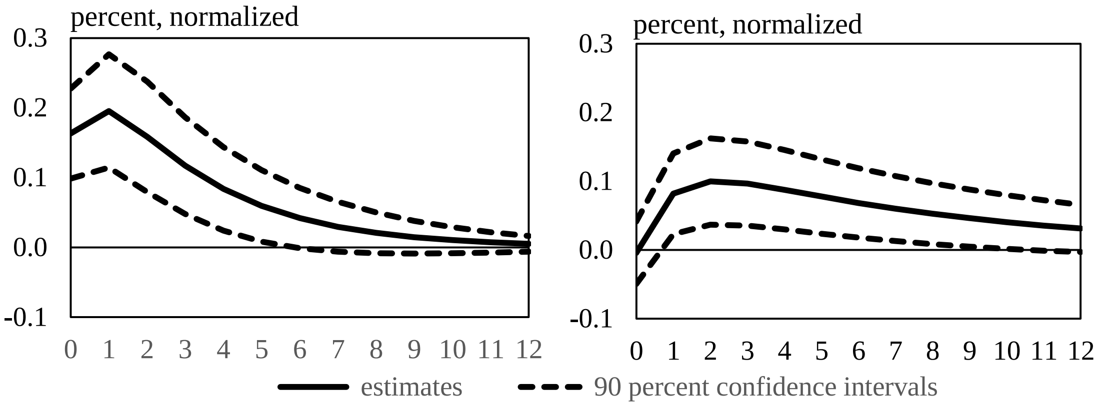
K.2 Empirical Assessment

As shown in Figure A2, in a reduced form the response of the aggregate inflation to aggregate demand shocks becomes more persistent as the shock heterogeneity τ_t/σ_t increases. In what follows, we investigate the difference in the dynamics responses of aggregte inflation to changes in aggregate demand. Specifically, we estimate the following Vector Auto-Regression model by dividing the samples to two groups, $\tau_t/\sigma_t <$ median with 94 samples and $\tau_t/\sigma_t >$ median with 92 samples. The number of lags is chosen based on Akaike's Information Criterion.

$$A_0 \begin{bmatrix} \Delta\text{demand}_t \\ \text{CPI}_t \end{bmatrix} \quad = \quad C + A_1 \begin{bmatrix} \Delta\text{demand}_{t-1} \\ \text{CPI sales}_{t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_{\text{demand}_t} \\ \epsilon_{\text{CPI-specific}_t} \end{bmatrix}$$

where the matrix A_0 is lower triangular, the vector C is of constant terms, the matrices A_1, A_2, and A_3 are for the lag terms, and $\epsilon_{\text{aggregate}_t}$ and $\epsilon_{\text{CPI-specific}_t}(i)$ are the exogenous aggregate and sector-specific shocks, respectively.

Figure A3: Responses of inflation to aggregate shocks



(a) Lower shock heterogeneity $({}^{\tau_t}/_{\sigma_t} < \boldsymbol{median})$ **(b) Higher shock heterogeneity** $({}^{\tau_t}/_{\sigma_t} > \boldsymbol{median})$

Note: Response to one standard deviation shock (the response in the initial period is normalized as one). Bold lines indicate the estimates and dotted lines indicate the 90 percent confidence intervals. The series for the core consumer price index is "all items, less fresh food and energy (impact of consumption taxes are adjusted)". Sample period is 1975Q4-2022Q4 (the number of observations for panel (a) is 94 and that for panel (b) is 92). Shocks are identified by Cholesky decomposition with the assumption that aggregate shock is faster than inflation specific shocks. The number of lags is one, chosen based on AIC.

Figure A3 shows the impulse responses of the inflation to aggregate shocks based on the estimated VAR model. The comparison of panels (a) and (b) shows the relationship that the response under lower shock heterogeneity exhibits lower persistence than that under higher shock heterogeneity in two aspects. First, the response of panel (a) is positive and significant up until five quarters while that of panel (b) is significant until nine quarters. Second, the peak of the response is the next quarter in panel (a) whereas the response of panel (a) has the peak two quarters later.

L Sensitivity of Sectoral Inflation to Sector-Specific Demand under Common Shock Heterogeneity

This appendix assesses the empirical validity of our model concerning sectoral inflation dynamics by assuming common shock heterogeneity across all firms. To this end, τ in Figure 2 is used, rather than $\tau(i)$ in Figure A4, to construct the proxy for shock heterogeneity in estimating equation (O.1).

Table A12: Estimation of the sectoral inflation dynamics

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2022/4Q			
Dependent Variable: sectoral of inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)			
	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Changes in sector-specific demand ($\hat{v}_t(i)$)	0.18 ***	0.19 ***	0.17 ***
	(0.05)	(0.05)	(0.05)
Changes in sector-specific demand ×time dummy (2000-2022) ($\hat{v}_t(i) \times 1_{\{2000-2022\}}$)	-0.003	-0.01	-0.005
	(0.03)	(0.02)	(0.03)
Changes in sector-specific demand ×shock heterogeneity ($\hat{v}_t(i) \times {}^{\tau_t}/_{\sigma_t}$)	**-0.02** ***	**-0.02** ***	**-0.01** ***
	(0.01)	(0.01)	(0.004)
Observations	3,897	3,897	3,897
Adjusted-R^2	0.27	0.26	0.27

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First lag of sector-specific demand is included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A12 shows the estimates for equation (O.1) for alternative measures of shock heterogeneity based on time windows of two quarters (column 1), four quarters (columns 2), and eight quarters (column 3), respectively. All entries show that the sector-specific component of inflation is positively correlated with current sector-specific demand ($x_t(i)$) at one percent significant level. Important for our analysis, the interaction term between sector-specific demand and the degree of shock heterogeneity ($x_t(i) \times \tau_t/\sigma_t$) is negative and significant in all entries.

To ensure that the inclusion of the time dummy is not driving the significance of the negative relation between $\tau_t(i)/\sigma_t$ and inflation, Table A13 presents results for the benchmark regression that abstracts from the indicator variable $\mathbf{1}_{\{2000-2022\}}$ by omitting the interaction term between past inflation and the indicator variable (i.e., $\pi_{t-1} \times \mathbf{1}_{\{2000-2022\}}$) and the interaction term between changes in demand and the indicator variable ($x_t(i) \times \mathbf{1}_{\{2000-2022\}}$) from equation (O.1). The regression coefficient on the term $x_t(i) \times (\tau_t/\sigma_t)$ (bold entry) remains significant and negative, as in the benchmark regression. These results then confirm the robustness of the finding in Section **??**

Table A13: Estimation of the sectoral inflation dynamics

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2022/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Changes in sector-specific demand ($\hat{v}_t(i)$)	0.18 ***	0.19 ***	0.20 ***
	(0.05)	(0.05)	(0.06)
Changes in sector-specific demand ×shock heterogeneity ($\hat{v}_t(i) \times {}^{\tau_t}/_{\sigma_t}$)	**-0.02 *****	**-0.02 *****	**-0.03 *****
	(0.01)	(0.01)	(0.01)
Observations	3,897	3,897	3,897
Adjusted-R^2	0.27	0.26	0.27

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First lag of sector-specific demand is included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

M Sensitivity of Sectoral Inflation to Total Sectoral Demand

This appendix assesses the empirical validity of our model from the perspective of total fluctuation of sectoral inflation dynamics. Equation (31) shows that the sensitivity of the sectoral inflation ($\pi_t(i)$) to changes in total sectoral demand ($x_t(i)$) depends on α_2, which we know from our previous analysis in Section **??** is negatively related to shock heterogeneity ($\tau_t(i)/\sigma_t$). In what follows, we investigate whether the model predictions are supported in the data.

To estimate the relation between the degree of shock heterogeneity and the sensitivity of the sectoral inflation to total sectoral demand, we follow the insights from the theoretical model, encapsulated by equation (31), and construct a panel dataset for the sectoral inflation rates ($\pi_t(i)$), total demand in each sector ($x_t(i) \equiv u_t + \widetilde{v}_t(i)$), and the measures for shock heterogeneity ($\tau_t(i)/\sigma_t$) that is heterogeneous across sectors. We use measures for aggregate inflation π_t, quarterly changes in consumer price index from Japanese Statistics Bureau, u_t, $\widetilde{v}_t(i)$ and $\tau_t(i)/\sigma_t$ from the Financial Statements Statistics of Corporations by Industry prepared by the Ministry of Finance, and we measure sectoral inflation $\pi_t(i)$ with the Producer Price index (PPI) in Japan, which is released by the Bank of Japan on a monthly basis.[37]

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[37] For details, see https://www.boj.or.jp/en/statistics/pi/cgpi_release/index.htm/. For the summary statistics of the PPI data, see Appendix J.

The empirical specification of sectoral inflation equation is:

$$\begin{aligned}\pi_t(i) =& d_1(i) + \underbrace{\left(d_2 + d_3\mathbf{1}_{\{2000-2022\}} + d_4\left(\tau_t(i)/\sigma_t\right)\right)}_{\alpha_1}\pi_{t-1} + \underbrace{\left(d_5 + d_6\mathbf{1}_{\{2000-2022\}} + d_7\left(\tau_t(i)/\sigma_t\right)\right)}_{\alpha_2}x_t(i) \\ &+ d_8u_{t-1} + d_9u_{t-2} + d_{10}\widetilde{v}_{t-1}(i) + \varepsilon_t^d, \qquad \text{(M.1)}\end{aligned}$$

where $d_1(i)$ is fixed-effect indicator variable, the parameters d_2-d_{10} are regression coefficients, $\mathbf{1}_{\{2000-2022\}}$ is an indicator variable equal to 1 for the period 2000-2022 to control for the years with exogenous fall in price stickiness, as in our benchmark specification, and ε_t^d is the error term.

Table A14: Estimation of the sectoral inflation dynamics

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2022/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Lag of inflation (π_{t-1})	0.27 ***	0.22 ***	0.22 ***
	(0.07)	(0.07)	(0.08)
Lag of inflation ×time dummy	0.05	0.07	0.06
(2000-2022) ($\pi_{t-1} \times 1_{\{2000-2022\}}$)	(0.15)	(0.16)	(0.16)
Lag of inflation	-0.003	0.01	0.01
×shock heterogeneity ($\pi_{t-1} \times {}^{\tau_t(i)}/_{\sigma_t}$)	(0.01)	(0.01)	(0.01)
Changes in total demand ($x_t(i)$)	0.13 ***	0.13 ***	0.12 ***
	(0.04)	(0.04)	(0.04)
Changes in total demand ×time dummy	0.02	0.01	0.02
(2000-2022) ($x_t(i) \times 1_{\{2000-2022\}}$)	(0.02)	(0.02)	(0.02)
Changes in total demand	**-0.01 *****	**-0.01 *****	**-0.01 ****
×shock heterogeneity ($x_t(i) \times {}^{\tau_t(i)}/_{\sigma_t}$)	(0.003)	(0.003)	(0.004)
Observations	3,874	3,874	3,874
Adjusted-R²	0.33	0.33	0.33

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First and second lags of changes in aggregate demand and the first lag of changes in sector-specific demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A14 shows the estimates for equation (M.1) for alternative measures of shock heterogeneity based on time windows of two quarters (column 1), four quarters (columns 2), and eight quarters (column 3), respectively. All entries show that the sector-specific component of inflation is positively correlated with current total demand ($x_t(i)$). Important for our analysis, the interaction term between total sectoral demand and the degree of shock heterogeneity ($x_t(i) \times \tau_t(i)/\sigma_t$) is negative and significant in all entries. Our results show that the data supports a decrease in the sensitivity of the sectoral inflation in response to a rise in shock heterogeneity, consistent with the prediction in our theoretical model.

To ensure that the inclusion of the time dummy is not driving the significance of the negative relation between $\tau_t(i)/\sigma_t$ and inflation, Table A15 presents results for the benchmark regression that abstracts from the indicator variable $\mathbf{1}_{\{2000-2022\}}$ by omitting the interaction term between past inflation and the indicator variable (i.e., $\pi_{t-1} \times \mathbf{1}_{\{2000-2022\}}$) and the interaction term between changes in demand and the indicator variable ($x_t(i) \times \mathbf{1}_{\{2000-2022\}}$) from equation (M.1). The regression coefficient on the term $x_t(i) \times (\tau_t(i)/\sigma_t)$ (bold entry) remains significant and negative, as in the benchmark regression.

Finally, to consider the possibility that firms set prices flexibly, Table A16 shows results for the benchmark regression that dropped lagged inflation (π_{t-1}) from equation (M.1). The regression coefficient on the term $x_t(i) \times (\tau_t(i)/\sigma_t)$ (bold entry) remains significant and negative, as in the benchmark regression. These estimation results confirm the theoretical prediction.

Table A15: Estimation of the sectoral inflation dynamics

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2022/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Lag of inflation (π_{t-1})	0.30 ***	0.27 ***	0.27 ***
	(0.09)	(0.09)	(0.08)
Lag of inflation	-0.005	0.01	0.01
×*shock heterogeneity* ($\pi_{t-1} \times 1_{\{2000-2022\}}$)	(0.01)	(0.01)	(0.01)
Changes in total demand ($x_t(i)$)	0.14 ***	0.14 ***	0.13 ***
	(0.04)	(0.04)	(0.04)
Changes in total demand	**-0.01 *****	**-0.01 *****	**-0.01 ****
×***shock heterogeneity*** ($\boldsymbol{x_t(i) \times {}^{\tau_t(i)}/_{\sigma_t}}$)	(0.003)	(0.003)	(0.004)
Observations	3,874	3,874	3,874
Adjusted-R^2	0.33	0.33	0.33

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First and second lags of changes in aggregate demand and the first lag of changes in sector-specific demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

N Robustness of the Regression Results

The estimation results in the main text and Appendix M cover 1976-2022 as samples. This Appendix examines the robustness of the results if we exclude the period of Covid-19 pandemic from the samples, given that the nature of business cycles and inflation environments during the pandemic was critically different from standard ones. Specifically, regarding ag-

Table A16: Estimation of the sectoral inflation dynamics

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2022/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Changes in total demand ($x_t(i)$)	0.17 ***	0.17 ***	0.17 ***
	(0.05)	(0.05)	(0.05)
Changes in total demand	**-0.01 *****	**-0.01 *****	**-0.01 *****
×shock heterogeneity ($x_t(i) \times {}^{\tau_t(i)}/_{\sigma_t}$)	(0.003)	(0.004)	(0.005)
Observations	3,883	3,883	3,883
Adjusted-R²	0.33	0.33	0.33

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First and second lags of changes in aggregate demand and the first lag of changes in sector-specific demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

gregate inflation dynamics, Tables A17 and A18 are, respectively, the counterparts of Tables 4 and 5, and Table A19 corresponds with Table 6.

Moreover, in terms of sectoral inflation dynamics, Table A20 is the counterpart of Table A27 and A21 corresponds with Table A28. Then, Table A22 is the counterpart of Table A12 and A23 corresponds with Table A13. Finally, Table A24 is the counterpart of Table A14, and A25 and A26, respectively, correspond to Tables A15 and A16. Importantly, the estimation results of these Tables remain broadly unchanged if samples during the Covid-19 pandemic are excluded.

O Robustness for Sectoral Inflation Dynamics

In this Appendix, we further examine the validity of our theoretical framework using data on sectoral inflation in Japan.[38] Proposition 4 and Proposition 5 include theoretical prediction regarding sectoral price and sectoral inflation, which imply that sectoral shock heterogeneity (τ_t/σ_t) can affect sectoral price differently under imperfect information. We examine the plausibility of our theoretical framework by evaluating the empirical validity of these

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[38] Empirical literature on sectoral inflation under imperfect information is highly limited. For example, Mackowiak et al. (2009) find that sectoral prices respond immediately to sector-specific shocks, whereas their response to aggregate shocks is gradual, and they further demonstrate that rational inattention models can broadly match it. Kato and Okuda (2017) and Kato et al. (2021b) find that sectoral inflation persistence decreases with market concentration and demonstrate that this fact can be reconciled by dispersed information models. Okuda and Tsuruga (2025) indicate that the degree of fragmentation of information about sectoral costs within each sector plays a crucial role in explaining empirical facts about Japanese firms' pricing behaviors. This study examines the implications of across-sector heterogeneity of shocks for sectoral inflation dynamics.

Table A17: Estimation of aggregate inflation dynamics: before the pandemic

Dataset: Financial statement statistics of corporations by industry, consumer price index; 29 sectors; 1976/2Q-2019/4Q

Dependent Variable: Inflation rate (π_t, core consumer price index, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Constant	0.05 **	0.05 **	0.04
	(0.03)	(0.03)	(0.03)
Lag of inflation (π_{t-1})	0.68 ***	0.67 ***	0.67 ***
	(0.11)	(0.13)	(0.15)
Lag of inflation×time dummy (2000-2019) ($\pi_{t-1} \times 1_{\{2000-2019\}}$)	-0.25 *	-0.25 *	-0.24
	(0.13)	(0.14)	(0.15)
Lag of inflation ×shock heterogeneity ($\pi_{t-1} \times {}^{\tau_t}/_{\sigma_t}$)	0.01	0.02	0.02
	(0.01)	(0.01)	(0.03)
Changes in aggregate demand (u_t)	0.09 ***	0.10 ***	0.11 ***
	(0.03)	(0.03)	(0.03)
Changes in aggregate demand ×time dummy (2000-2019) ($u_t \times 1_{\{2000-2019\}}$)	-0.01	-0.01	-0.02
	(0.03)	(0.03)	(0.03)
Changes in aggregate demand ×shock heterogeneity ($\boldsymbol{u_t \times {}^{\tau_t}/_{\sigma_t}}$)	**-0.02** ***	**-0.02** ***	**-0.02** ***
	(0.005)	(0.005)	(0.01)
Observations	176	176	176
Adjusted-R²	0.77	0.77	0.77

Note: Estimated by ordinary-least-squares. The standard errors are HAC estimators. First and second lags of changes in aggregate demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity. The series for the core consumer price index is "all items, less fresh food and energy (impact of consumption taxes are adjusted)".

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A18: Estimation of aggregate inflation dynamics: before the pandemic

Dataset: Financial statement statistics of corporations by industry, consumer price index; 29 sectors; 1976/2Q-2019/4Q

Dependent Variable: Inflation rate (π_t, core consumer price index, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Constant	0.06 ***	0.06 **	0.05 **
	(0.02)	(0.02)	(0.02)
Lag of inflation (π_{t-1})	0.71 ***	0.71 ***	0.69 ***
	(0.10)	(0.10)	(0.13)
Lag of inflation ×shock heterogeneity ($\pi_{t-1} \times {}^{\tau_t}/_{\sigma_t}$)	0.01	0.02	0.02
	(0.01)	(0.01)	(0.03)
Changes in aggregate demand (u_t)	0.09 ***	0.10 ***	0.11 ***
	(0.02)	(0.02)	(0.02)
Changes in aggregate demand ×shock heterogeneity ($\boldsymbol{u_t \times {}^{\tau_t}/_{\sigma_t}}$)	**-0.02** ***	**-0.02** ***	**-0.02** ***
	(0.01)	(0.01)	(0.01)
Observations	176	176	176
Adjusted-R²	0.75	0.75	0.75

Note: Estimated by ordinary-least-squares. The standard errors are HAC estimators. First and second lags of changes in aggregate demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity. The series for the core consumer price index is "all items, less fresh food and energy (impact of consumption taxes are adjusted)".

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A19: Estimation of aggregate inflation dynamics: before the pandemic

Dataset: Financial statement statistics of corporations by industry, consumer price index; 29 sectors; 1976/1Q-2019/4Q

Dependent Variable: Inflation rate (π_t, core consumer price index, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Constant	0.25 ***	0.23 ***	0.23 ***
	(0.05)	(0.05)	(0.05)
Changes in aggregate demand (u_t)	0.10 ***	0.11 ***	0.11 ***
	(0.03)	(0.03)	(0.02)
Changes in aggregate demand ×shock heterogeneity ($u_t \times \tau_t/\sigma_t$)	**-0.02 ****	**-0.02 ****	**-0.02 ****
	(0.01)	(0.01)	(0.01)
Observations	176	176	176
Adjusted-R^2	0.29	0.28	0.28

Note: Estimated by ordinary-least-squares. The standard errors are HAC estimators. First and second lags of changes in aggregate demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity. The series for the core consumer price index is "all items, less fresh food and energy (impact of consumption taxes are adjusted)".

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A20: Estimation of sectoral inflation dynamics: before the pandemic

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2019/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Changes in sector-specific demand ($\hat{v}_t(i)$)	0.17 ***	0.18 ***	0.17 ***
	(0.05)	(0.05)	(0.05)
Changes in sector-specific demand ×time dummy (2000-2019) ($\hat{v}_t(i) \times 1_{\{2000-2019\}}$)	-0.01	-0.02	-0.02
	(0.02)	(0.02)	(0.02)
Changes in sector-specific demand ×shock heterogeneity ($\hat{v}_t(i) \times \tau_t(i)/\sigma_t$)	**-0.01 *****	**-0.01 *****	**-0.01 *****
	(0.004)	(0.004)	(0.005)
Observations	3,621	3,621	3,621
Adjusted-R^2	0.26	0.26	0.26

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First lag of sector-specific demand is included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A21: Estimation of sectoral inflation dynamics: before the pandemic

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2019/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Changes in sector-specific demand ($\hat{v}_t(i)$)	0.16 ***	0.16 ***	0.16 ***
	(0.06)	(0.05)	(0.05)
Changes in sector-specific demand ×shock heterogeneity ($\hat{v}_t(i) \times \tau_t(i)/\sigma_t$)	**-0.01** ***	**-0.01** ***	**-0.01** ***
	(0.004)	(0.004)	(0.005)
Observations	3,621	3,621	3,621
Adjusted-R²	0.26	0.26	0.26

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First lag of sector-specific demand is included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A22: Estimation of sectoral inflation dynamics: before the pandemic

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2019/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Changes in sector-specific demand ($\hat{v}_t(i)$)	0.18 ***	0.19 ***	0.17 ***
	(0.06)	(0.06)	(0.05)
Changes in sector-specific demand ×time dummy (2000-2019) ($\hat{v}_t(i) \times 1_{\{2000-2019\}}$)	-0.01	-0.01	-0.02
	(0.02)	(0.02)	(0.02)
Changes in sector-specific demand ×shock heterogeneity ($\hat{v}_t(i) \times \tau_t/\sigma_t$)	**-0.02** **	**-0.02** **	**-0.01** ***
	(0.01)	(0.01)	(0.005)
Observations	3,621	3,621	3,621
Adjusted-R²	0.26	0.25	0.26

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First lag of sector-specific demand is included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A23: Estimation of sectoral inflation dynamics: before the pandemic

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2019/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Changes in sector-specific demand ($\hat{v}_t(i)$)	0.16 ***	0.16 ***	0.16 ***
	(0.06)	(0.05)	(0.05)
Changes in sector-specific demand ×shock heterogeneity ($\hat{v}_t(i) \times \tau_t/\sigma_t$)	**-0.01** ***	**-0.01** ***	**-0.01** ***
	(0.004)	(0.004)	(0.005)
Observations	3,621	3,621	3,621
Adjusted-R²	0.26	0.26	0.26

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First lag of sector-specific demand is included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A24: Estimation of sectoral inflation dynamics: before the pandemic

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2019/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Lag of inflation (π_{t-1})	0.30 ***	0.26 ***	0.27 ***
	(0.08)	(0.07)	(0.08)
Lag of inflation × time dummy	0.07	0.08	0.08
(2000-2019) ($\pi_{t-1} \times 1_{\{2000-2019\}}$)	(0.11)	(0.11)	(0.11)
Lag of inflation	-0.01	-0.002	-0.01
×shock heterogeneity ($\pi_{t-1} \times {}^{\tau_t(i)}/_{\sigma_t}$)	(0.01)	(0.01)	(0.005)
Changes in total demand ($x_t(i)$)	0.13 ***	0.13 ***	0.12 ***
	(0.04)	(0.04)	(0.04)
Changes in total demand ×time dummy	0.01	0.002	0.002
(2000-2022) ($x_t(i) \times 1_{\{2000-2019\}}$)	(0.02)	(0.02)	(0.02)
Changes in total demand	**-0.01** **	**-0.01** ***	**-0.01** **
×shock heterogeneity ($\boldsymbol{x_t(i) \times {}^{\tau_t(i)}/_{\sigma_t}}$)	(0.003)	(0.003)	(0.003)
Observations	3,598	3,598	3,598
Adjusted-R²	0.33	0.33	0.33

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. *First and second lags of changes in aggregate demand and the first lag of changes in sector-specific demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.*

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A25: Estimation of sectoral inflation dynamics: before the pandemic

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2019/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Lag of inflation (π_{t-1})	0.34 ***	0.31 ***	0.32 ***
	(0.04)	(0.04)	(0.05)
Lag of inflation	-0.01 *	-0.002	-0.01
×shock heterogeneity ($\pi_{t-1} \times 1_{\{2000-2019\}}$)	(0.01)	(0.01)	(0.004)
Changes in total demand ($x_t(i)$)	0.13 **	0.13 ***	0.12 ***
	(0.05)	(0.05)	(0.04)
Changes in total demand	**-0.01** *	**-0.01** ***	**-0.01** ***
×shock heterogeneity ($\boldsymbol{x_t(i) \times {}^{\tau_t(i)}/_{\sigma_t}}$)	(0.003)	(0.003)	(0.003)
Observations	3,598	3,598	3,598
Adjusted-R²	0.33	0.33	0.33

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. *First and second lags of changes in aggregate demand and the first lag of changes in sector-specific demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.*

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Table A26: Estimation of sectoral inflation dynamics: before the pandemic

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2019/4Q			
Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)			
	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Changes in total demand ($x_t(i)$)	0.16 ***	0.16 ***	0.16 ***
	(0.05)	(0.05)	(0.05)
Changes in total demand	**-0.01 *****	**-0.01 *****	**-0.01 ****
×shock heterogeneity ($x_t(i) \times {}^{\tau_t(i)}/_{\sigma_t}$)	(0.003)	(0.004)	(0.004)
Observations	3,607	3,607	3,607
Adjusted-R^2	0.27	0.26	0.26

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First and second lags of changes in aggregate demand and the first lag of changes in sector-specific demand are included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

predictions using historical data of sectoral prices in Japan.

First, we estimate the ratio between the volatility of the sector-specific component and the aggregate component of demand for each sectors. While the model assumes homogeneous τ_t across industries, this empirical analysis allows the possibility of heterogeneous τ_t.[39] We then test the empirical relevance of the increases in the relative volatility of sector-specific shocks for the reduced sensitivity of sectoral inflation to changes in sector-specific demand.

Estimation of $\tau_t(i)/\sigma_t$. To estimate the proxy for the shock heterogeneity in each sector, i.e. the ratio $\tau_t(i)/\sigma_t$, we follow the methodology in the previous section except that we do not take averages across sectors in equation (36) so that we can estimate heterogeneous $\tau_t(i)$[40]. We also normalize the series in each sector in order that the series has mean zero and the standard deviation is one. To match the data on shock heterogeneity with the sectoral inflation, we consider series for 23 industries.

Figure A4 shows the median of the 23 estimated series for the ratio of the variance of sector-specific shocks to the variance of aggregate shocks ($\tau_t(i)/\sigma_t$) for the alternative time windows: two quarters ($k = 1$), four quarters ($k = 2$), and eight quarters ($k = 4$). Similar to the developments in figure 2, entries show that the ratio $\tau_t(i)/\sigma_t$ substantially varies throughout the sample period.

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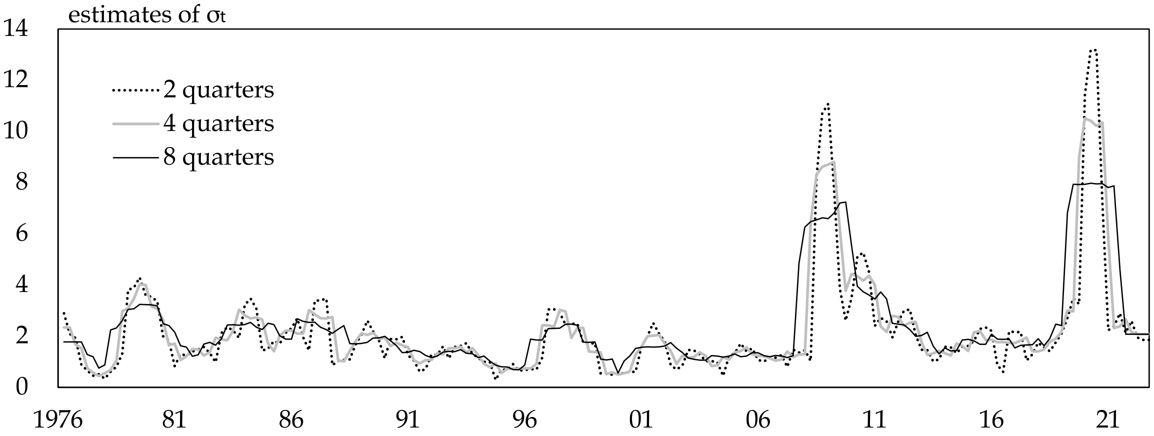
[39] For robustness, Appendix L conducts the same analysis assuming common shock heterogeneity across sectors ($\tau(i) = \tau$)

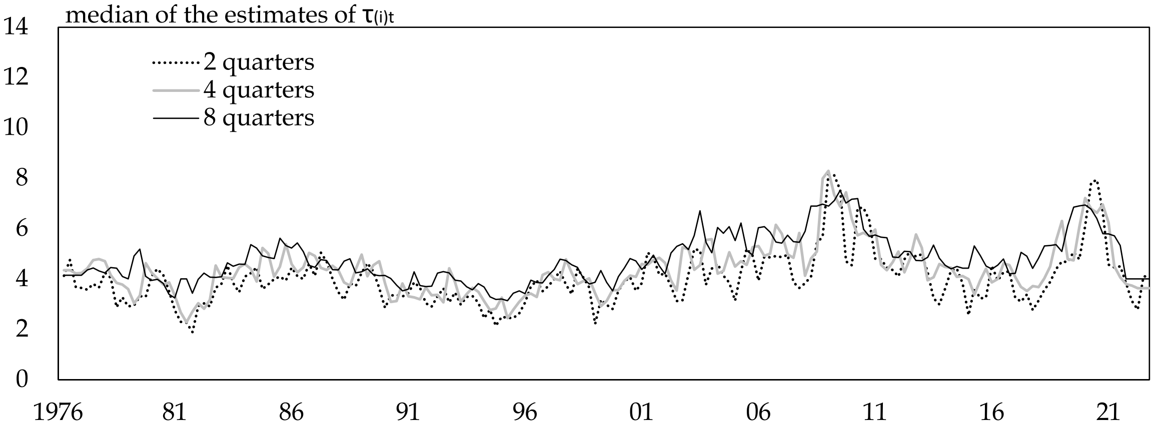
[40] Namely, $\tau_t^2(i) = \frac{1}{2k+1}\sum_{s=-k}^{k}\frac{(\hat{\epsilon}_{t-s}-\hat{\epsilon}_{t-s-1})^2}{2}$.

Figure A4: Median of estimated shock heterogeneity in each sector ($\tau_t(i)/\sigma_t$)

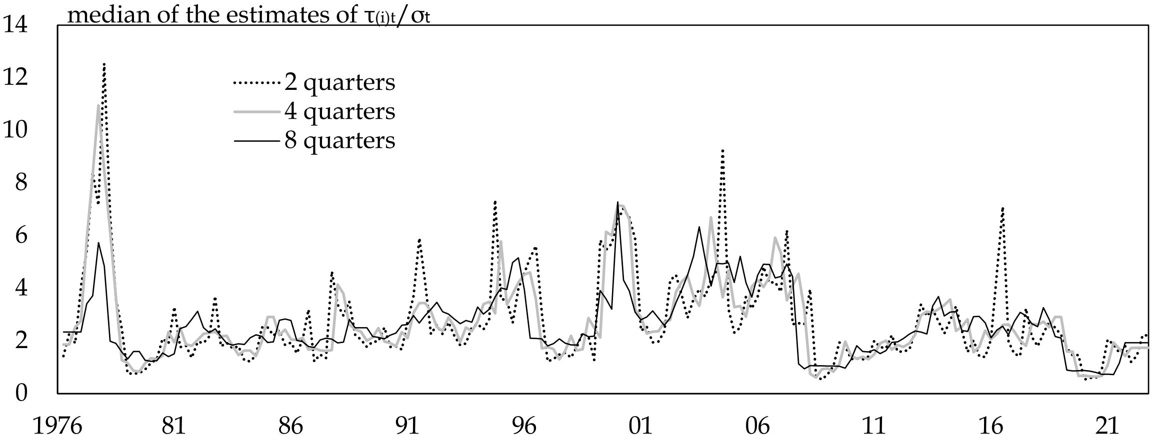
(a) Standard deviation of aggregate shocks



(b) Standard deviation of sector-specific shocks



(c) Shock heterogeneity



Source: Ministry of Finance "Financial statements statistics of corporations by industry".

Sensitivity of Sectoral Inflation to Sector-specific Demand. Equation (31) shows that the sensitivity of the sectoral inflation ($\pi_t(i)$) to changes in sector-specific demand ($\widetilde{v}_t(i)$) depends on α_2, which is negatively related to shock heterogeneity ($\tau_t(i)/\sigma_t$) as shown in section 4.1. In what follows, we investigate whether the model predictions are supported in the data.

To estimate the relation between the degree of shock heterogeneity and the sensitivity of the sectoral inflation to sector-specific demand, we follow the insights from the theoretical model, encapsulated by equation (31), and construct a panel dataset for the sectoral inflation rates ($\pi_t(i)$), sector-specific demand in each sector ($\widetilde{v}_t(i)$), and the measures for shock heterogeneity ($\tau_t(i)/\sigma_t$) that is heterogeneous across sectors. We use measures for aggregate inflation π_t, quarterly changes in consumer price index from Japanese Statistics Bureau, $\widetilde{v}_t(i)$ and $\tau_t(i)/\sigma_t$ from the Financial Statements Statistics of Corporations by Industry prepared by the Ministry of Finance, and we measure sectoral inflation $\pi_t(i)$ with the Producer Price index (PPI) in Japan, which is released by the Bank of Japan on a monthly basis.[41]

$$\pi_t(i) - \pi_t = d_1(i) + \underbrace{\left(d_2 + d_3\mathbf{1}_{\{2000-2022\}} + d_4\left(\tau_t(i)/\sigma_t\right)\right)}_{\alpha_2}\widetilde{v}_t(i) + d_5\widetilde{v}_{t-1}(i) + \varepsilon_t^d, \qquad (O.1)$$

where $d_1(i)$ is fixed effect indicator variable, parameters $(d_2, \ldots, d_5)$ are regression coefficients, $\mathbf{1}_{\{2000-2022\}}$ is an indicator variable equal to 1 for the period 2000-2022 to control for the years with exogenous fall in price stickiness, as in our benchmark specification, and ε_t^d is the error term.

Table A27 shows the estimates for equation (O.1) for alternative measures of shock heterogeneity based on time windows of two quarters (column 1), four quarters (columns 2), and eight quarters (column 3), respectively. All entries show that sectoral inflation is positively correlated with current sector-specific demand ($\widetilde{v}_t(i)$). Important for our analysis, the interaction term between sector-specific demand and the degree of shock heterogeneity ($\widetilde{v}_t(i) \times \tau_t(i)/\sigma_t$) is negative and significant in all entries. Our results show that the data support a decrease in the sensitivity of sectoral inflation in response to a rise in shock heterogeneity, consistent with the prediction in our theoretical model.[42]

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[41] For details, see https://www.boj.or.jp/en/statistics/pi/cgpi_release/index.htm/. For the summary statistics of the PPI data, see Appendix J.

[42] Appendix L confirms that this relationship continues to be observed if shock heterogeneity is assumed to be common across sectors ($\tau(i) = \tau$).

Table A27: Estimation of the sectoral inflation dynamics

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2022/4Q

Dependent Variable: sectoral of inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Changes in sector-specific demand ($\hat{v}_t(i)$)	0.17 ***	0.18 ***	0.17 ***
	(0.05)	(0.05)	(0.05)
Changes in sector-specific demand ×time dummy (2000-2022) ($\hat{v}_t(i) \times 1_{\{2000-2022\}}$)	-0.004	-0.01	-0.004
	(0.03)	(0.02)	(0.03)
Changes in sector-specific demand ×shock heterogeneity ($\hat{v}_t(i) \times {}^{\tau_t(i)}/_{\sigma_t}$)	**-0.01** ***	**-0.01** ***	**-0.01** ***
	(0.003)	(0.004)	(0.004)
Observations	3,897	3,897	3,897
Adjusted-R^2	0.27	0.27	0.27

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First lag of sector-specific demand is included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.

**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

Figure A5 compares the estimates for the coefficient d_4 on the interaction term $(\tilde{v}_t(i) \times \tau_t/\sigma_t)$ for the alternative time windows of two, four, and eight quarters for the computation of the variance (dark diamond) against the coefficient α_2 on the interaction term $\tilde{v}_t(i) \times \tau_t/\sigma_t$ in equation (30), which represents the theoretical interaction between shock heterogeneity and sector-specific demand (white diamond).[43] The bands for the dark diamond show 90 percent confidence intervals of the empirical estimates. The figure shows that the estimates from the data are remarkably close to those generated by the theoretical model, and our theoretical framework is consistent with the estimates in the data.

Finally, to ensure the robustness of significance of the negative relation between $\tau_t(i)/\sigma_t$ and sectoral inflation, Table A28 presents results for the benchmark regression in equation (O.1) without the interaction term between past inflation and the indicator variable (i.e., $\pi_{t-1} \times \mathbf{1}_{\{2000-2022\}}$) and the interaction term between changes in demand and the indicator variable $(\widetilde{v}_t(i) \times \mathbf{1}_{2000-2022})$. The regression coefficient on the term $\widetilde{v}_t(i) \times (\tau_t(i)/\sigma_t)$ (bold entry) remains significant and negative, as in the benchmark regression.[44] Note that this equation also corresponds to equation 33 for the case of flexible prices.

Our findings indicate that imperfect information regarding sectoral demand, coupled with shifts in shock heterogeneity, has played a role in the time-varying response of inflation to sector-specific demand shocks in Japan. Appendix N also shows that all results in this

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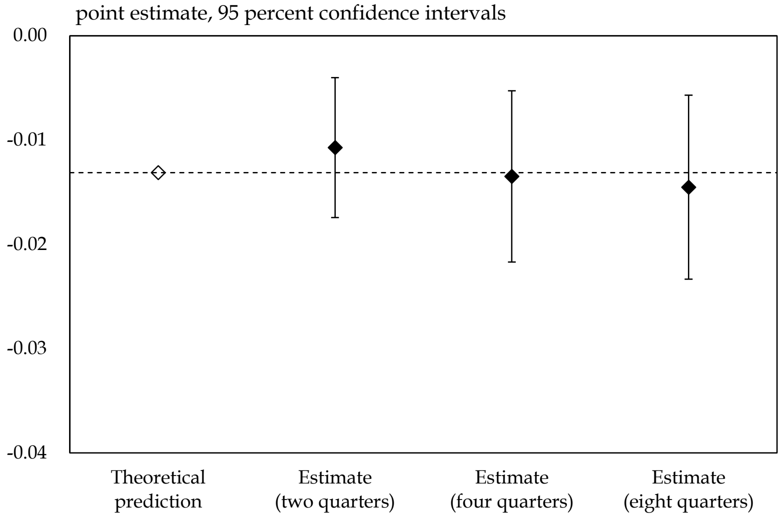
[43] The theoretical prediction is calculated as the changes in α_2 consistent with changes in τ_t/σ_t from 2.5 to 4.5, divided by the changes in τ_t/σ_t (i.e. 4.5-2.5=2) under the same calibration of Figure 1.

[44] Appendix M examines the sensitivity of sectoral inflation to changes in total sectoral demand using the same dataset. The estimation results confirm the theoretical prediction.

Figure A5: Shock heterogeneity and sensitivity of inflation to changes in sector-specific demand



Notes: Theoretical prediction is calculated as the slope of α_2 *at* $\tau/\sigma = 3.5$ *in Figure 1 (a).*
Parameters for theoretical prediction are $\theta = 0.3,\ r = 0.7,\ \beta = 0.99, \rho_u = 0.33,\ \rho_v = -0.09$

Table A28: Estimation of the sectoral inflation dynamics

Dataset: Financial statement statistics of corporations by industry, producer price index; 23 sectors; 1985/2Q-2022/4Q

Dependent Variable: sectoral inflation rate ($\pi_t(i)$, seasonally adjusted, QoQ)

	(i) two quarters	*(ii) four quarters*	*(iii) eight quarters*
Changes in sector-specific demand ($\hat{v}_t(i)$)	0.17 ***	0.17 ***	0.17 ***
	(0.05)	(0.05)	(0.05)
Changes in sector-specific demand	**-0.01** ***	**-0.01** ***	**-0.01** ***
×shock heterogeneity ($\hat{v}_t(i) \times \tau_t(i)/\sigma_t$)	(0.003)	(0.004)	(0.005)
Observations	3,897	3,897	3,897
Adjusted-R^2	0.27	0.27	0.27

Note: Estimated by ordinary-least-squares with fixed- and time-effect models. The standard errors are cross-section (sector) cluster robust standard errors. First lag of sector-specific demand is included in estimation as control variables. Data extrapolation using the values in the closest periods is applied for the missing values in the estimates of shock heterogeneity.
**** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.*

section remain broadly intact if we exclude the samples since the Covid-19 pandemic.