Imperfect Information, Heterogeneous Demand Shocks, and Inflation Dynamics*

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February 2024

Abstract

We use new survey data for the universe of Japanese firms to establish that expectations about aggregate demand positively co-move with the expectations about sector-specific demand. We show that a simple model based on the seminal island framework in Lucas (1972) with imperfect information on the *current* aggregate and sector-specific components of demand explains the positive co-movement in the expectations of the different components of demand, and an increase in the volatility of sector-specific demand reduces the sensitivity of inflation to changes in real activity. We test and corroborate this theoretical prediction on Japanese data, showing that the movements in the volatility of sector-specific shocks explains the changes in the sensitivity of inflation to economic activity in Japan over the past three decades.

JEL Classification: E31, D82, C72.
Keywords: Imperfect information, Shock heterogeneity, Inflation dynamics, Survey of expectations to Japanese firms.

*This paper subsumes previous work circulated under the title: "Imperfect Information, Shock Heterogeneity, and Inflation Dynamics." We would like to thank Jesus Fernandez-Villaverde, Gaetano Gaballo, Laura Gati, Nobuhiro Kiyotaki, Jennifer La'O, Xiaowen Lei, Alistair Macaulay, Sophocles Mavroeidis, Taisuke Nakata, Shigenori Shiratsuka, Chris Sims, Wataru Tamura, Takayuki Tsuruga, Laura Veldkamp, Mirko Wiederholt, Xiaowen Wang, Yifan Zhang, and seminar participants at the University of Oxford, SWET 2018, 2018 JEA Autumn Meeting, WEAI 2019, Inflation: Drivers and Dynamics Conference 2019, Econometric Society European Winter Meeting 2020, Econometric Society North American Summer Meeting 2021, workshop on New Directions in Inflation Forecasting, Royal Economic Society 2022 Annual Conference, and the ECB-Cleveland Fed Conference 2022 for extremely valuable comments and suggestions. The views expressed in this paper are those of the authors and do not necessarily represent the views of the IMF, its Executive Board, or IMF management.

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1 Introduction

A large class of macroeconomic models builds on the premise that firms set prices to fulfil demand, and several studies show that shocks to demand are heterogeneous and reflect aggregate and sector-specific disturbances.[1] Depending on the source of the disturbance to demand, the implication for the optimal price setting is different. 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 observe the source of the changes in demand in real time. Thus, firms optimally adjust prices based on the expectations on 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 the expectations on 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 new 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 to explain the observed positive comovement in the expectations on the different components of demand and to account for the reduction 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 three sector-level surveys 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 postulated by models based on perfect information.

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

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

critical to generate the observed positive co-movement in the 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 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 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 lead 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 disentangle 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 use the predictions from the model on the inverse relation between the volatility of sector-specific shocks and the response of inflation to aggregate demand to test the relevance of imperfect information for the reduction in the sensitivity of inflation to 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 our 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.

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. We relate to 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., 2021) 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 disaggregate 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 congruous 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, and L'Huillier and Zame, 2020), the increase in competition in the goods market (Sbordone, 2008, and Zanetti, 2009), downward wage rigidities (Akerlof et al., 1996), structural reforms

(Thomas and Zanetti, 2009, Zanetti, 2011, and Cacciatore and Fiori, 2016), and lower trend inflation (Ball and Mazumder, 2011).[2] Unlike these studies, however, our focus is on the relation 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, and Kumar et al., 2015 use a survey of firms in New Zealand). 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 study the relation between the firms' expectations about aggregate and sector-specific components of total sectoral demand. To this end, we conduct the three types of analysis. First, we estimate the relationship between firms' expectations about their own current industry-specific demand and current aggregate demand. Second, we estimate the relationship between firms' expectations about the future growth rate of their own sector-specific demand and that of the aggregate demand. Third, we estimate the relationship between firms' expectations about the current industry-specific demand and their expectations about the future aggregate demand.

We then find that all analyses lead to the same conclusion: a positive and significant co-movement exists between firms' expectations regarding sector-specific and aggregate compo-

[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 on Japanese data.

nents of demand. In the following, we first explain the data used in the regression analyses. We then explain the empirical equations for the analyses and report the estimation results.

Business Outlook Survey. We use the Business Outlook Survey.[3] The survey has been administered jointly by the Cabinet Office and the Ministry of Finance starting from 2004. The survey is conducted on a quarter basis and covers corporations with capital of 10 million yen or more (about 10 thousands firms) in 37 sectors and three types of firms sizes: large firms with capital of one billion yen or over, medium-sized firms with capital of 100 million to one billion yen, and small firms with capital of 10 million to 100 million yen.

The survey has qualitative survey items about the changes in current and future "Business conditions" and "Domestic economic conditions." Specifically, firms are asked about their assessment and projections on their own business conditions and macroeconomic conditions compared with those of the previous quarter, and are required to choose their answers from "Rise," "Unchanged," "Fall," and "Unknown." Then the Business Survey Index (BSI), i.e. indicator which is calculated as the composition ratio of firms which choose "Rise" minus the ratio of firms which choose "Fall", is published by sector and by firm size level. This analysis uses these indicators as variables for regressions and interprets them as follows.

We regard sector-level BSIs and sector and firm size-level BSIs as sectoral averages of the firms' expectations, where firm-specific noises in expectations are washed out in aggregation. Specifically, we employ the current, one-quarter ahead, and two quarters ahead BSIs about their business conditions (industry conditions) and domestic economic conditions (aggregate conditions). We view them as firms' expectations about the current, one-quarter ahead, and two-quarters ahead growth rates of their own industry demand and aggregate demand.

Annual Survey of Corporate Behavior. We use the Annual Survey of Corporate Behavior (ASCB).[4] The survey is administered by the Cabinet Office of Japan across 33 sectors over the period 2003-2021. Firms complete a quantitative questionnaire that records the separate expectations about the growth rate of total sectoral and aggregate demand, thus providing an account on the firms' expectations about the different aggregate and sector-specific components of total sectoral demand.[5]

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

[4] Appendix G provides a description and summary statistics for the ASCB.

[5] 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

Tankan Survey. We use the Tankan (Short-Term Economic Survey of Enterprises in Japan).[6] The survey has been administered by the Bank of Japan since 1974. The survey is conducted on a quarter basis and covers corporations with capital of 20 million yen or more (about 10 thousand firms) in 31 sectors.

The survey has qualitative survey items about the level of "Domestic supply and demand conditions for products and services."[7] Specifically, firms are asked about their judgment of domestic supply and demand conditions for major products or services in the industry of responding firms, taking into account customer trends, order arrival, and movements of goods if necessary. They are required to choose their answers from "Excess demand," "Almost balanced," and "Excess supply." Then sample firm responses are aggregated into the diffusion index (DI) by subtracting the percentage share of the number of respondents choosing "Excess supply" from that of the number of respondents choosing "Excess demand." The DI is published at the sector level. This analysis uses these indicators as variables for regressions and interprets them as follows.

We regard the sector-level DI as sectoral averages of the firms' expectations, where firm-specific noises in expectations are washed out in aggregation. Specifically, we employ the DI on current demand and supply conditions as the proxy for their own industry conditions.

(i) Expectations on current sector-specific and aggregate demands. Using the data above, we estimate three types of empirical equations. The first equation estimates the sensitivity of unexpected changes in the sector-level assessment of aggregate demand to unexpected changes in the sector-level assessment of own demand by controlling the impact of the aggregate demand on own demand with period effects. Hence, the estimates of the sensitivity capture sensitivity to unexpected changes in the assessment of industry-specific demand because firm-specific demand in own demand is washed out through aggregation and aggregate demand in own demand is absorbed in the period effects. We also control industry-level characteristics by including industry-fixed effects. The sample includes 33 industries and three types of firm size from the second quarter of 2004 to the first quarter of 2023.

Both explained and explanatory variables are taken from Business Outlook Survey.

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.

[6] Appendix I provides a description and summary statistics for the Tankan Survey.

[7] The questionnaire of the survey is available at: https://www.boj.or.jp/en/statistics/outline/exp/tk/extk01.htm.

Table 1: Firms' expectations on current aggregate and sector-specific demands

(a) Economic conditions in the current quarter

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

Dependent Variable: Assessment of aggregate economic conditions in the current quarter$_t$ – assessment of one-quarter ahead aggregate economic conditions$_{t-1}$

	(1) All samples	(2) Large firms	(3) Mid-sized firms	(4) Small firms
Assessment of own economic conditions in the current quarter$_t$ – assessment of one-quarter ahead own economic conditions$_{t-1}$	0.15***	0.08***	0.14***	0.24***
	(0.02)	(0.02)	(0.03)	(0.02)
Fixed effect	Yes	Yes	Yes	Yes
Period effect	Yes	Yes	Yes	Yes
Observations	7,755	2,635	2,635	2,485
Cross Section	109	37	37	35
Adjusted-R^2	0.41	0.45	0.41	0.46

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.*

(b) One-quarter ahead economic conditions

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

Dependent Variable: Assessment of one-quarter ahead aggregate economic condition$_t$ – assessment of two-quarter ahead aggregate economic conditions$_{t-1}$

	(1) All samples	(2) Large firms	(3) Mid-sized firms	(4) Small firms
Assessment of one-quarter ahead own economic conditions$_t$ – assessment of two-quarter ahead own economic conditions$_{t-1}$	0.45***	0.41***	0.44***	0.48***
	(0.02)	(0.03)	(0.03)	(0.03)
Fixed effect	Yes	Yes	Yes	Yes
Period effect	Yes	Yes	Yes	Yes
Observations	7,755	2,635	2,635	2,485
Cross Section	109	37	37	35
Adjusted-R^2	0.48	0.47	0.49	0.50

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.

Specifically, two sets of variables, what we call specs (a) and (b), are examined. In spec (a), unexpected changes in the assessment of aggregate economic conditions are defined as the difference between an assessment of current aggregate economic conditions and that of one-quarter ahead aggregate economic conditions, forecasted in the previous quarter. Unexpected changes in the assessment of own economic conditions are then defined as the difference between an assessment of own economic conditions in the current quarter and that of one-quarter ahead of own economic conditions, forecasted in the previous quarter. Next, in spec (b), unexpected changes in the assessment of aggregate economic conditions are defined as the difference between an assessment of one-quarter ahead aggregate economic conditions and that of two-quarter ahead aggregate economic conditions, forecasted in the previous quarter. Unexpected changes in the assessment of own economic conditions are then defined as the difference between an assessment of one-quarter ahead own economic conditions and that of one-quarter ahead of own economic conditions, forecasted in the previous quarter.

Table 1 (a) shows the estimation results of spec (a). The first column shows the estimates with all samples, and the other columns indicate the estimates when focusing on samples in each firm size. The table indicates that all of the estimates of the sensitivity are positive and statistically significant. Table 1 (b) shows the estimation results of spec (b) and the results are consistent with those in table (b). Combining these results suggests that firms' expectations about industry-specific demand are correlated with their expectations regarding aggregate demand irrespective of firm size.

(ii) Expectations on future sector-specific and aggregate demands. We next estimate the sensitivity of the firms' expectations about future (one-year ahead) nominal output growth to expectations about nominal sectoral demand growth. Both variables are taken from Annual Survey of Corporate Behavior. In the equation, in addition to these variables, we include industry-level fixed effects and period effects. The period effects are used to control the impact of firms' expectations about aggregate demand growth on their expectations about sectoral demand growth.[8] Moreover, we include firms' expectations about three- and five-year ahead nominal output growth to control the impact of the changes in their expectations on economic structures on the estimates. The sample includes 33 industries from

[8]Appendix B shows the consistency of the survey data with the Dixit-Stiglitz demand function that we use in the model.

2003-2021.

Columns (1)-(3) in Table 2 show the estimation results under these specifications depending on the set of controls, and they all show that the estimates for the sensitivity are positive and statistically significant. Columns (4)-(6) show the estimation results if we include different expectations for placebo tests. The expectations are selected as follows: we regress each industry's expectations about one-year ahead nominal sectoral demand growth on the other industries' same expectations to obtain the estimates of the coefficients. We then select the expectations which have the smallest coefficients in an absolute value. The estimation results in columns (4)-(6) in Table 2 show that the estimates of the coefficient for the placebo expectations are very close to zero and insignificant, and the estimates for the sensitivity continue to be positive and significant in most specifications.

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

Dataset: Annual Survey of Corporate Behavior; 2003-2021

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

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Expectations about nominal sectoral demand growth (one-year ahead)	0.06***	0.03*	0.05**	0.05***	0.02	0.04*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Placebo expectations about nominal sectoral demand growth (one-year ahead)				-0.004	-0.002	-0.003
				(0.02)	(0.02)	(0.02)
Expectations about nominal output growth$_t$ (three-year ahead)		0.93***			0.95***	
		(0.12)			(0.13)	
Expectations about nominal output growth$_t$ (five-year ahead)			0.69***			0.71***
			(0.13)			(0.14)
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Period effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	574	573	572	528	527	527
Cross Section	33	33	33	33	33	33
Adjusted-R^2	0.86	0.93	0.90	0.86	0.92	0.89

*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.*

For robustness, Table 3 shows the estimation results if all the expectations about the nominal variables are replaced by those about the real variables. The results in the table are broadly the same as those in Table 2.

(iii) Expectations on current sector-specific demand and future aggregate demand. We finally estimate the sensitivity of the firms' expectations about future (one-year ahead) nominal output growth to the unexpected changes in their current demand.

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

Dataset: Annual Survey of Corporate Behavior; 2003-2021						
Dependent Variable: Expectations about real output growth (one-year ahead)						
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Expectations about real sectoral demand growth (one-year ahead)	0.06	0.04**	0.05*	0.06	0.04**	0.04**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)
Placebo expectations about real sectoral demand growth (one-year ahead)				0.005	0.02	0.01
				(0.02)	(0.02)	(0.02)
Expectations about real output growth$_t$ (three-year ahead)		0.84***			0.86***	
		(0.08)			(0.07)	
Expectations about real output growth$_t$ (five-year ahead)			0.69***			0.71***
			(0.12)			(0.12)
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Period effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	578	573	572	535	530	529
Cross Section	33	33	33	33	33	33
Adjusted-R^2	0.86	0.92	0.90	0.86	0.92	0.90

*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.*

While the first variable continues to be taken from Annual Survey of Corporate Behavior, the second variable is calculated based on the variables in Tankan Survey as follows: The unexpected changes in their current demand are defined as the DIs for current demand in the current period minus the DIs for one-period (quarter) ahead demand in the previous period. Note that because the DIs are the sums of the qualitative answers, this estimation does not provide quantitative implications. As before, we include industry-level fixed effects, period effects, and firms' expectations about three- and five-year ahead nominal output growth as control variables. Additionally, following the same methodology in the second regression analysis, we conduct placebo tests too. The matched sample of Annual Survey of Corporate Bahvior and Tankan survey consists of 20 industries from 2003-2021.

Tables 4 and 5 show the estimation results for the expectations on nominal and real variables, respectively, and they indicate that all of the estimates for the sensitivity are positive, and most of them are significant while those for placebo expectations are very close to zero and insignificant.[9]

[9] Appendix J estimates the same model using firms' inflation expectations as a proxy for their expectations on aggregate demand, and the estimation results are broadly the same as Tables 4 and 5.

Table 4: Firms' expectations on aggregate and sector-specific demands

Dataset: Annual Survey of Corporate Behavior, Tankan Survey; 2003-2021

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

	(1)	(2)	(3)	(4)	(5)	(6)
Demand DI_t (current) -Demand DI_{t-1}(one-period ahead)	0.004	0.007**	0.007*	0.005	0.007**	0.007**
	(0.005)	(0.003)	(0.004)	(0.004)	(0.003)	(0.003)
Placebo Demand DI_t (current) -Placebo Demand DI_{t-1} (one-period ahead)				0.001	0.0003	-0.0003
				(0.006)	(0.004)	(0.005)
Expectations about nominal output growth$_t$ (three-year ahead)		0.760***			0.760***	
		(0.058)			(0.058)	
Expectations about nominal output growth$_t$ (five-year ahead)			0.553***			0.553***
			(0.044)			(0.044)
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Period effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	339	339	339	339	339	339
Cross Section	20	20	20	20	20	20
Adjusted-R^2	0.93	0.96	0.95	0.93	0.96	0.95

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.*

Table 5: Firms' expectations on aggregate and sector-specific demands

Dataset: Annual Survey of Corporate Behavior, Tankan Survey; 2003-2021

Dependent Variable: Expectations about real output growth (one-year ahead)

	(1)	(2)	(3)	(4)	(5)	(6)
Demand DI_t (current) -Demand DI_{t-1}(one-period ahead)	0.004	0.009***	0.008**	0.004	0.009***	0.008**
	(0.004)	(0.003)	(0.004)	(0.004)	(0.003)	(0.003)
Placebo Demand DI_t (current) -Placebo Demand DI_{t-1} (one-period ahead)				0.001	-0.0002	-0.001
				(0.006)	(0.004)	(0.005)
Expectations about real output growth$_t$ (three-year ahead)		0.821***			0.821***	
		(0.088)			(0.087)	
Expectations about real output growth$_t$ (five-year ahead)			0.569***			0.571***
			(0.108)			(0.105)
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Period effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	339	339	339	339	339	339
Cross Section	20	20	20	20	20	20
Adjusted-R^2	0.92	0.95	0.94	0.92	0.95	0.94

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.*

2.1 Expectations under Imperfect Information

We develop a parsimonious model of imperfect information on the different components of demand that explains the positive co-movement of the firms' expectations about the components of aggregate and sector-specific demand observed in survey data. We will extend the model to a general equilibrium framework to study 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 ($v_t(i)$).[10] Aggregate demand follows the stochastic process:

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

where u_t is an AR(1) process:

$$u_t = \rho_u u_{t-1} + e_t, \tag{2}$$

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:

$$v_t(i) = \rho_v v_{t-1}(i) + \epsilon_t(i), \tag{3}$$

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

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.[11] 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 $v_t(i) \sim \mathcal{N}\left(\rho_v v_{t-1}(i), \tau_t^2\right)$.[12]

[10] 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 generate realistic business cycle statistics.

[11] 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).

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

Hence, in each period t, the information set for the firms in sector i is:

$$\mathcal{H}_t(i) \equiv \left\{ \{x_s(i)\}_{s=0}^{t}, \{q_s, u_s, v_s(i), e_s, \epsilon_s(i)\}_{s=0}^{t-1} \right\}, \tag{4}$$

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. The model characterizes the expectations on the *level* of total sectoral demand and its different components whereas the data refer to the expectations on the *changes* of total sectoral demand and its aggregate and sector-specific components. To link the model with the empirical measurements, we focus on the changes in total sectoral demand and its separate components by taking the first difference of $x_t(i)$: $\Delta x_t(i) = \Delta q_t + \Delta v_t(i)$.

To simplify notation, we label $\widetilde{x}_t(i) = \Delta x_t(i)$, $\widetilde{v}_t(i) = \Delta v_t(i)$, and by using equation (1), $u_t = \Delta q_t$. Combining equations (2)-(3), 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, $\widetilde{v}_t(i)$:

$$\widetilde{x}_t(i) = u_t + \widetilde{v}_t(i). \tag{5}$$

Equation (5) shows that the change in total sectoral demand in the model comprises the changes in aggregate and sector-specific demand, as in the data. In the remaining part of this section, we use equation (5) to study the effect of imperfect information for the co-movement between changes in expectations about aggregate and sector-specific demand.

The formation of expectations and co-movements in the components of total sectoral demand. Using equation (5), current expectations about total demand in k-period ahead are equal to:

$$\mathbb{E}_t\left[\sum_{h=1}^{k} \widetilde{x}_{t+h}(i)\right] = \mathbb{E}_t\left[\sum_{h=1}^{k} u_{t+h}\right] + \mathbb{E}_t\left[\sum_{h=1}^{k} \widetilde{v}_{t+h}(i)\right]. \tag{6}$$

Equation (6) shows that the current expectations of total demand k-period ahead comprises the expectations of the aggregate and sector-specific components of demand in k-period ahead. If firms are able to observe separately the components of aggregate and sector-specific demand, such that $\mathbb{E}_t [u_t] = u_t$ and $\mathbb{E}_t [\widetilde{v}_t] = \widetilde{v}_t$, the expectations of the different components of total sectoral demand are independent of each other and the co-movement between them is equal to zero. The next proposition shows that imperfect information renders the expectations on the separate components of demand dependent on the common change in total sectoral demand, therefore generating a co-movement in expectations.

Proposition 1 *Under imperfect information, the expectations at time t about the changes in aggregate and sector-specific demands are equal to:*

$$\mathbb{E}_t [u_t] = \rho_u u_{t-1} + \frac{\sigma_t^2}{\sigma_t^2 + \tau_t^2} [e_t + \epsilon_t(i)] \tag{7}$$

and

$$\mathbb{E}_t [\tilde{v}_t(i)] = (\rho_v - 1) v_{t-1}(i) + \frac{\tau_t^2}{\sigma_t^2 + \tau_t^2} [e_t + \epsilon_t(i)] \,, \tag{8}$$

respectively.

Proof: See Appendix E.1. □

Equations (7) and (8) show that the firm's expectations on the changes in aggregate and sector-specific demand depend on the changes in total 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 on 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 proposition characterizes the sign of the co-movement between the expectations of aggregate and sector-specific demand, showing that our theoretical results are consistent with the empirical findings (i)-(iii) in Section 2.

Proposition 2 *Under imperfect information, the following relationships hold:*

$$\begin{aligned} \textit{(i)}\ \mathbb{C}(\mathbb{E}_t [q_t] - \mathbb{E}_{t-1} [q_t] \,, \mathbb{E}_t [v_t(i)] - \mathbb{E}_{t-1} [v_t(i)]) &> 0, \\ \mathbb{C}(\mathbb{E}_t [q_{t+1}] - \mathbb{E}_{t-1} [q_{t+2}] \,, \mathbb{E}_t [v_{t+1}(i)] - \mathbb{E}_{t-1} [v_{t+1}(i)]) &> 0 \end{aligned} \tag{9}$$

$$\textit{(ii)}\ \mathbb{C}\left(\mathbb{E}_t\left[\sum_{h=1}^{4} u_{t+h}\right], \mathbb{E}_t\left[\sum_{h=1}^{4} \widetilde{v}_{t+h}(i)\right]\right) > 0. \tag{10}$$

$$\textit{(iii)}\ \mathbb{C}\left(\mathbb{E}_t\left[\sum_{h=1}^{4} u_{t+h}\right], \mathbb{E}_t\left[v_t(i)\right] - \mathbb{E}_{t-1}\left[v_t(i)\right]\right) > 0. \tag{11}$$

Proof: See Appendix E.2. □

Proposition 2 shows that our model matches the three observed positive correlation between firm's expectations about the aggregate demand and sector-specific demand.[13] In particular, we note that: (i) Equation (9) shows that the firm' expectations about industry-specific demand ($\mathbb{E}_t\left[v_t(i)\right] - \mathbb{E}_{t-1}\left[v_t(i)\right]$, $\mathbb{E}_t\left[v_{t+1}(i)\right] - \mathbb{E}_{t-1}\left[v_{t+1}(i)\right]$) are positively correlated with the firm's expectations of aggregate demand ($\mathbb{E}_t\left[q_t\right] - \mathbb{E}_{t-1}\left[q_t\right]$, $\mathbb{E}_t\left[q_{t+1}\right] - \mathbb{E}_{t-1}\left[q_{t+2}\right]$); (ii) the firm's expectations on the changes of one-year ahead aggregate ($\mathbb{E}_t\left[\sum_{h=1}^{4} u_{t+h}\right]$) and industry-specific demands ($\mathbb{E}_t\left[\sum_{h=1}^{4} \widetilde{v}_{t+h}(i)\right]$) are positively correlated; and (iii) the firm's expectations on changes of one-year aggregate demand ($\mathbb{E}_t\left[\sum_{h=1}^{4} u_{t+h}\right]$) have positive correlation with the expectations about industry-specific demand ($\mathbb{E}_t\left[v_t(i)\right] - \mathbb{E}_{t-1}\left[v_t(i)\right]$). These results are explained by the fact that firms are unable to fully differentiate between changes in aggregate demand and industry-specific demand, as shown in Proposition 1.

3 General Equilibrium

This section embeds the empirically-congruous expectations based on imperfect information in a general equilibrium framework to study the sensitivity of inflation to aggregate demand.

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,

[13] Note that this model abstracts firm-specific demand, meaning that individual expectations of firms within a sector are identical to the sector-level expectations.

as described in equations (1), (2), and (3). 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 (4).

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 as "firm (i,j)") faces the following demand:

$$C_t(i,j) = \Theta_t^{\eta-1}(i) \left(\frac{P_t(i,j)}{P_t(i)}\right)^{-\widetilde{\eta}} \left(\frac{P_t(i)}{P_t}\right)^{-\eta} C_t, \tag{12}$$

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).[14]

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

$$Y_t(i,j) = AL_t^{\epsilon}(i,j), \tag{13}$$

[14]See Appendix A for the derivation of the demand function for each firm (i,j) and price indexes. Appendix B shows that total sectoral demand in equation (12) entails independent aggregate and sector-specific components consistent with the empirical analysis.

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 logarithms of the corresponding upper-case variables (i.e., $x_t \equiv \log X_t$).

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:

$$p_t(i,j) = \mu + mc_t(i,j), \tag{14}$$

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:

$$mc_t(i,j) = w_t + (1-\epsilon)\, l_t(i,j) - a - log(\epsilon). \tag{15}$$

Using the production technology in equation (13), we express labor input as: $l_t(i,j) = [y_t(i,j) - a]/\epsilon$, and we use it in equation (15) 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:

$$w_t - p_t = c_t, \tag{16}$$

and the linearized consumer demand in equation (12) is:

$$c_t(i,j) = -\widetilde{\eta}\,(p_t(i,j) - p_t(i)) - \eta\,(p_t(i) - p_t) + c_t + (\eta - 1)\,\theta_t(i), \tag{17}$$

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

$$\theta_t(i) = \rho_v \theta_{t-1}(i) + \widetilde{\epsilon}_t(i), \tag{18}$$

and $\widetilde{\epsilon}_t(i) \sim \mathcal{N}(0, (1-\epsilon)^{-2} (\eta-1)^{-2} \tau_t^2)$.[15]

We derive the optimal price-setting rule for firm (i,j) by using equations (16), (17), 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:[16]

$$p_t(i,j) = r_1 p_t(i) + r_2 p_t + (1 - r_1 - r_2)\, x_t(i) + \xi, \tag{19}$$

where

$$\begin{aligned}
x_t(i) &= q_t + v_t(i), && (20)\\
v_t(i) &= (1-\epsilon)\,(\eta-1)\,\theta_t(i), && (21)\\
\xi &= \frac{\epsilon}{\epsilon + \widetilde{\eta}\,(1-\epsilon)}(\mu - \frac{1}{\epsilon}a - log(\epsilon)), && (22)\\
r_1 &= \frac{(\widetilde{\eta}-\eta)\,(1-\epsilon)}{\epsilon + \widetilde{\eta}\,(1-\epsilon)}, && (23)\\
r_2 &= \frac{(\eta-1)\,(1-\epsilon)}{\epsilon + \widetilde{\eta}\,(1-\epsilon)}, && (24)
\end{aligned}$$

and $p_t = \int_0^1 p_t(i)di$.[17] Equation (19) 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 (19) 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 (20) shows that total sectoral demand ($x_t(i)$) additively combines the aggregate (q_t) and sector-specific components ($v_t(i)$). Equation (21) shows that the sector-specific demand depends on the sector-specific preference shock $\theta_t(i)$. The constant parameter ξ, defined by equation (22), 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.[18]

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 (19) reduces

[15] 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.

[16] Appendix D shows the derivation of the price setting rule.

[17] Appendix C shows the derivation of the index of aggregate prices.

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

to:

$$p_t(i) = rp_t + (1-r)\, x_t(i), \tag{25}$$

where

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

Equation (25) 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 (19).[19]

3.2 Nominal Price Rigidities

To link expectations about total sectoral demand to 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. In this environment, the optimal price depends on the expectations of future demand, which in our framework, reflects both the different aggregate and sector-specific components. Therefore, the co-movement between those expectations plays a critical role for the price-setting decision and ultimately inflation dynamics.

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:

$$\begin{aligned} p_t^*(i) &= (1-\beta\theta)\sum_{j=0}^{\infty}(\beta\theta)^j \mathbb{E}_t[p_{t+j}(i)] \\ &= (1-\beta\theta)\sum_{j=0}^{\infty}(\beta\theta)^j \left[r\mathbb{E}_t[p_{t+j}] \ + (1-r)\mathbb{E}_t[x_{t+j}(i)]\right], \end{aligned} \tag{26}$$

where the second equation is derived by substituting the optimal pricing rule in equation (25). Unlike standard full-information rational expectations models, the expectations in equation

[19] Equation (25) shows that if production technology converges to constant returns (i.e., $\epsilon \to 1$), average 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 $p_t(i) = q_t + \xi$.

(26) are formed under imperfect information, and they are determined in accordance to Proposition 1. Equation (26) 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, as shown in equation (5), the co-movement of these components is critical to set the price.

The Equilibrium Average Price. Equation (26) 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 3 *The equilibrium average price and sectoral price are given by:*

$$p_t = [\theta + (1-\theta)a_1]\, p_{t-1} + (1-\theta)\, a_2 q_t + (1-\theta)\, a_3 q_{t-1} + (1-\theta)\, a_4 u_{t-1}, \tag{27}$$

$$p_t(i) = p_t + (1-\theta)\, a_2 v_t(i) + a_5 v_{t-1}(i) \tag{28}$$

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).

Proof: See Appendix E.3. □

Equations (27) and (28) show that the equilibrium aggregate and sectoral price depends on the equilibrium price in the period $t-1$ (p_{t-1}) and the sequence of present and past demands ($q_t, v_t(i), q_{t-1}, v_{t-1}(i)$). 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 (27), we derive the analytical solution for the inflation rate, defined as the change in the average price from period $t-1$ to period t ($\pi_t \equiv p_t - p_{t-1}$), as characterized by the next proposition.

Proposition 4 *Under imperfect information on aggregate and sector-specific demand shocks, sectoral and average price inflation are equal to:*

$$\begin{aligned} \pi_t &= [\theta + (1-\theta)a_1]\,\pi_{t-1} + (1-\theta)\,a_2 u_t + (1-\theta)\,(a_3 + a_4)\,u_{t-1} - (1-\theta)\,a_4 u_{t-2} \\ &= \alpha_1 \pi_{t-1} + \alpha_2 u_t + \alpha_3 u_{t-1} + \alpha_4 u_{t-2}, \end{aligned} \tag{29}$$

$$\pi_t(i) = \pi_t + (1-\theta)\,a_2 \widetilde{v}_t(i) + a_5 \widetilde{v}_{t-1}(i) = \pi_t + \alpha_2 \widetilde{v}_t(i) + \alpha_5 \widetilde{v}_{t-1}(i), \tag{30}$$

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* $\alpha_5 \equiv (1-\theta)a_5$.

Proof: Taking the first difference of the equations (27) and (28) yields equations (29) and (30), respectively.□

Equations (29) and (30) provide the analytical solution for aggregate and sectoral inflation under imperfect information, respectively. Equation (29) 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.[20] Similarly, equation (30) 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.[21] Proposition 4 shows 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 (29) and (30), $\alpha_1, \alpha_2, \alpha_3, \alpha_4$, 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, developed in the next subsection.

We derive the Phillips curve under the simplified assumption $\rho_u = \rho_v = 0$.

[20] 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.

[21] See Appendix E.3 for the characterization of parameters a_1, a_2, a_3, a_4.and a_5.

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

$$\pi_t = \frac{\alpha_2}{1-\alpha_2} y_t + \frac{\alpha_3}{1-\alpha_2} y_{t-1}, \tag{31}$$

Proof: See Appendix E.4.□

Corollary 1 shows the equation for aggregate inflation which has no term of lagged inflation (i.e. inflation persistence), as in the standard New Keynesian Phillips curve.[22] 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 demands 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 (29) and (30). In this section, we use numerical simulations to study the sensitivity of inflation to demand.

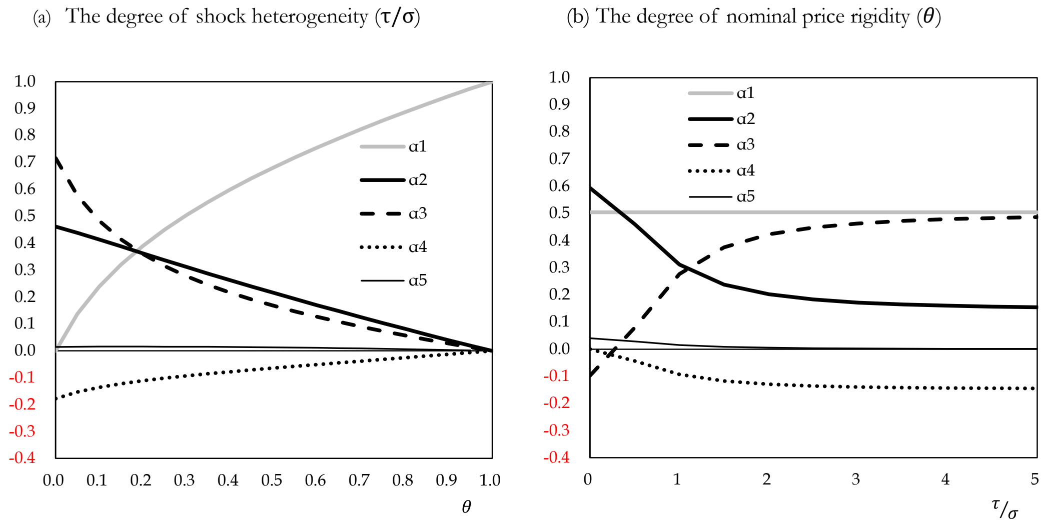
Sensitivity of Inflation to Changes in Demand. We simulate the model using a standard calibration. We set $\beta = 0.99$, $\eta = 8$, $\epsilon = 2/3$, and $r = [(\eta-1)(1-\epsilon)]/[\epsilon+\eta(1-\epsilon)] = 0.7$.

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. We will estimate this 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. 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 27 for both the aggregate and the median of sector-specific components of demand.

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

[22] Inflation expectations vanish from 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.

Figure 1: Sensitivity of coefficients



Notes: Parameters are $\tau/\sigma = 1,\ r = 0.7,\ \beta = 0.99,\ \rho_u = 0.33,\ \rho_v = -0.09$ *for (a), and* $\theta = 0.3\ r = 0.7,\ \beta = 0.99, \rho_u = 0.33,\ \rho_v = -0.09$ *for (b).*

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 (25), 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) increases 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.

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 (29). 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).[23]

4.2 Empirical Analysis on the Aggregate Inflation Dynamics

This section estimates the ratio of the volatility of the sector-specific component to the aggregate component of demand using principal component analysis on Japanese data. It then tests 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 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.[24]

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 $\sum_{i=1}^{29}\widetilde{x}_t(i)$.[25] We proxy sector-specific demand, $\widetilde{v}_t(i)$, by subtracting the estimated principal component from changes in total sectoral demand:[26] $\widetilde{x}_t(i) - u_t = \widetilde{x}_t(i) - (\sum_{i=1}^{29}\Lambda_i)^{-1}\sum_{i=1}^{29}\Lambda_i\widetilde{x}_t(i)$.[27]

[23] Appendix N.1 shows the impulse response function of the inflation to aggregate demand.

[24] Appendix H provides a description of the data.

[25] 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.

[26] 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.

[27] Appendix K 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 L 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.

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

$$\sigma_t{}^2 = \frac{1}{2k+1} \sum\nolimits_{s=-k}^{k} \widehat{e}_{t-s}^2. \tag{32}$$

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 (3) across sectors for alternative moving windows of size $2k+1$:

$$\tau_t{}^2 = \frac{1}{2k+1} \sum\nolimits_{s=-k}^{k} \left(\frac{1}{29} \sum\nolimits_{i=1}^{29} \frac{\left(\widehat{\epsilon}_{t-s}(i) - \widehat{\epsilon}_{t-s-1}(i)\right)^2}{2} \right). \tag{33}$$

To ensure the results are robust across the different time windows, we compute the variance of each shock in equations (32) and (33), using four alternative time windows: two quarters ($k=1$), four quarters ($k=2$), and eight quarters ($k=4$). 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).

Figure 2 shows the estimated series for the ratio of the standard deviation of sector-specific shocks to the standard deviation 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.[28]

Sensitivity of Inflation to Aggregate Demand. We use our proxy for the ratio τ_t/σ_t to study the empirical relevance of the increase (decrease) in the ratio for the reduced (increased) sensitivity of inflation to changes in aggregate demand.

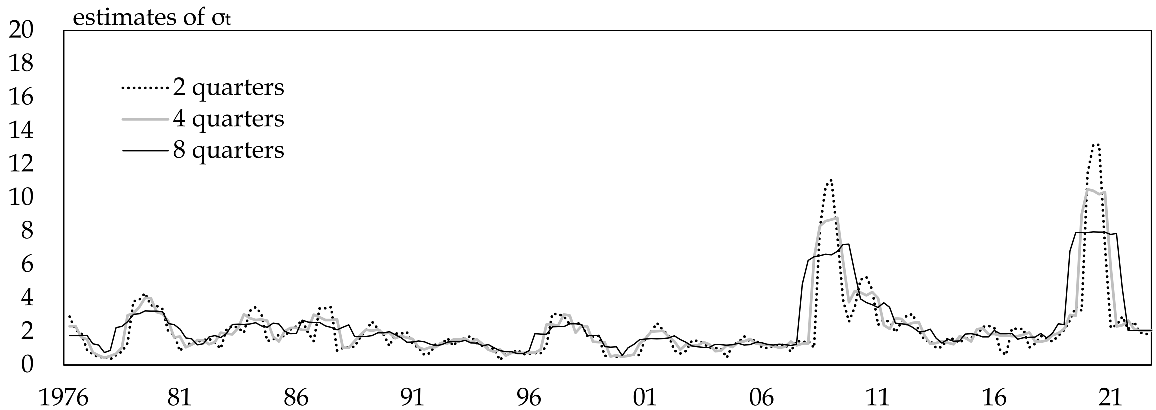
We set up the empirical model using the insights from the price equation (29) that accounts for the effect of information frictions in the relation between inflation and aggregate demand. We regress current inflation (π_t) on past inflation (π_{t-1}),[29] changes in current aggregate demand (u_t), an 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

[28]Movements in τ_t/σ_t are primarily driven by changes in the volatility of sector-specific demand shocks (τ_t) while the value for 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).

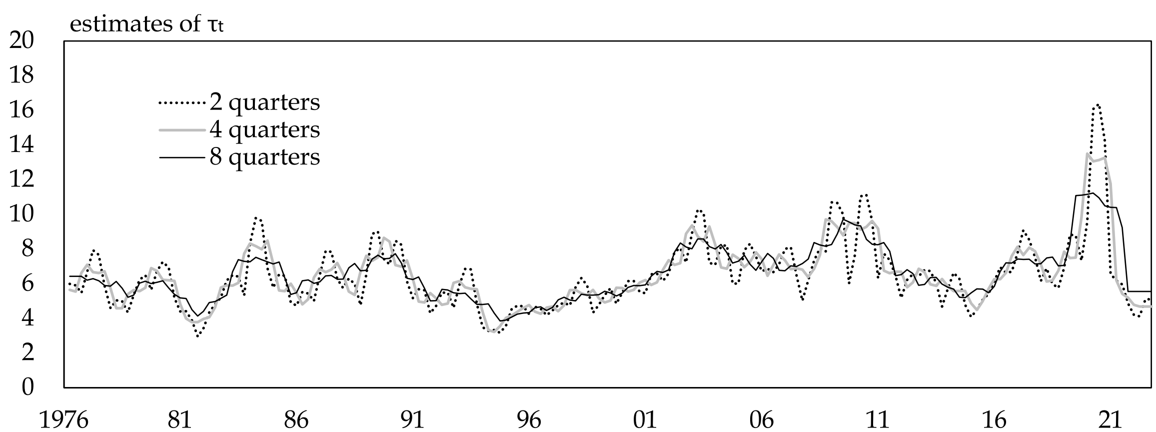
[29]We use quarterly changes in consumer price index as a proxy for aggregate inflation. The CPI is from the Japanese Statistics Bureau and available here https://www.stat.go.jp/english/data/cpi/index.html

Figure 2: Estimates of shock heterogeneity (τ_t/σ_t)

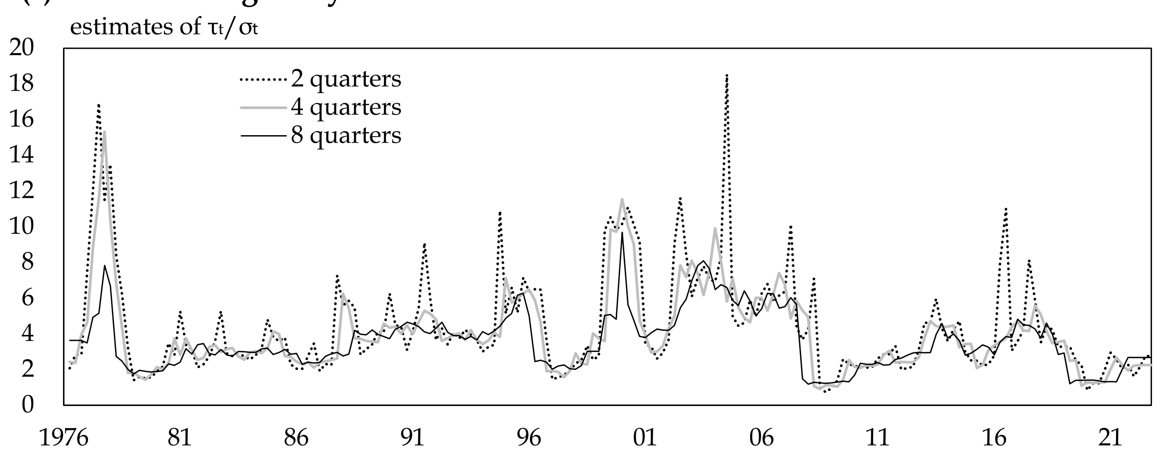
(a) Standard deviation of aggregate shocks



(b) Standard deviation of sector-specific shocks



(c) Shock heterogeneity



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

changes in current aggregate demand and the volatility ratio between sector-specific and aggregate shocks ($u_t \times \tau_t/\sigma_t$). 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 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 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:

$$\begin{aligned}\pi_t =& c_1 + \underbrace{\left(c_2 + c_3\mathbf{1}_{\{2000-2022\}} + c_4\left(\tau_t/\sigma_t\right)\right)}_{\alpha_1}\pi_{t-1} + \underbrace{\left(c_5 + c_6\mathbf{1}_{\{2000-2022\}} + c_7\left(\tau_t/\sigma_t\right)\right)}_{\alpha_2}u_t \\ &+ c_8 u_{t-1} + c_9 u_{t-2} + \varepsilon_t^c, \end{aligned} \tag{34}$$

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

Table 6 shows the estimates for equation (34), 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 the price equation (27). 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

Table 6: 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 ($u_t \times {}^{\tau_t}/_{\sigma_t}$)	(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	170	170	170
Adjusted-R^2	0.80	0.80	0.80

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.*

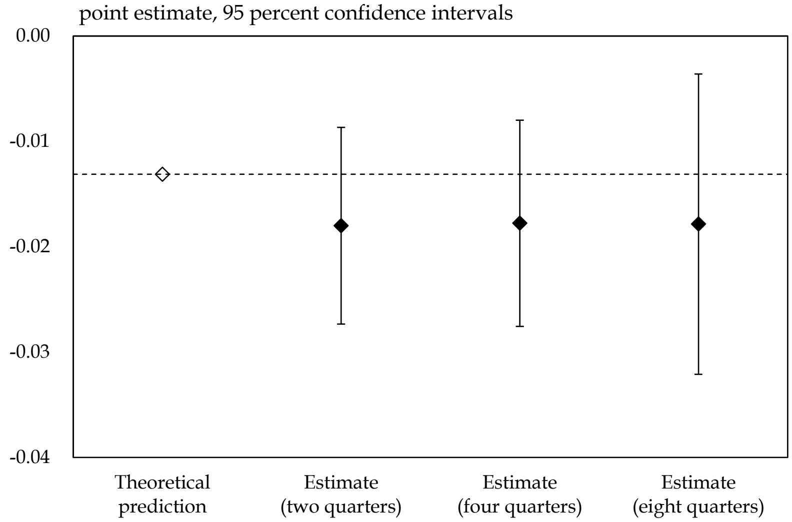
for our analysis, the interaction term between aggregate demand and the degree of shock heterogeneity ($u_t \times \tau_t/\sigma_t$) is negative and significant, implying that a rise in the τ_t/σ_t ratio reduces the positive correlation between inflation and aggregate demand, in accordance with the results of our analysis.

Figure 3 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 the coefficient α_2 on the interaction term $u_t \times \tau_t/\sigma_t$ in equation (29), which represents the theoretical interaction between shock heterogeneity and aggregate demand (white diamond).[30] 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. Therefore, our theoretical framework exhibits quantitative consistency with the estimates observed in the data.

Finally, to ensure that the significance of the negative relation between τ_t/σ_t and in-

[30]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.

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

flation is not driven by the inclusion of the 2000-2022 dummy variable, Table 7 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 ($u_t \times \mathbf{1}_{\{2000-2022\}}$) from equation (34). The regression coefficient on the term $u_t \times (\tau_t/\sigma_t)$ (bold entry) remains significant and negative, as in the benchmark regression.

Our results suggest that the imperfect information on sectoral demand, together with the changes in shock heterogeneity, has contributed to the time-variation in the sensitivity of inflation to the aggregate demand shock in Japan.[31][32]

4.3 Empirical Analysis on Sectoral Inflation Dynamics

This section estimates the ratio between the volatility of the sector-specific component and the aggregate component of demand for each sectors. It then tests 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.

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

[32] Appendix N.2 shows the estimated impulse response of inflation to aggregate demand.

Table 7: 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	0.01	0.02	0.04
×shock heterogeneity ($u_t \times {}^{\tau_t}/_{\sigma_t}$)	(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	**-0.02 *****	**-0.02 *****	**-0.02 ***
×shock heterogeneity ($\mathbf{u_t} \times {}^{\tau_t}/_{\sigma_t}$)	(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.*

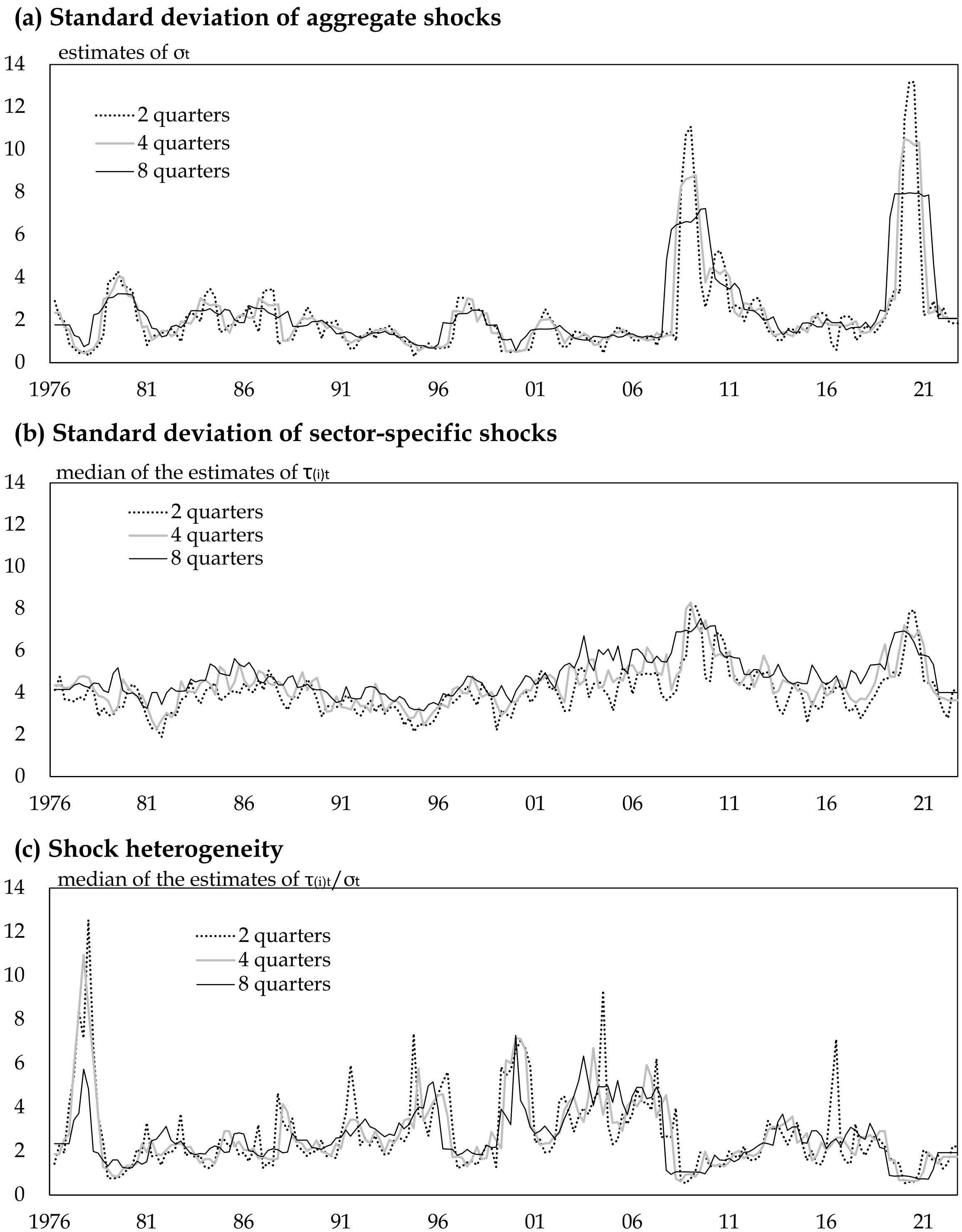
Estimation of $\tau_t(i)/\sigma_t$. To estimate the proxy for the shock heterogeneity in each sector, i.e. the ratio $\tau_t(i)/\sigma_t$, we follow the methodology in the previous section except that we do not take averages across sectors in equation (33) so that we can estimate heterogeneous $\tau_t(i)$. We also make the series in each sector standardized in that the average of the series is transformed to zero and the standard deviation is transformed to one. To match the data on shock heterogeneity with the sectoral inflation, we consider series for 23 industries.

Figure 4 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.

Sensitivity of Sectoral Inflation to Sector-specific Demand. Equation (30) 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 we know from our previous analysis in section 4.1 is negatively related to shock heterogeneity ($\tau_t(i)/\sigma_t$). In what follows, we investigates whether the model predictions are supported in the data.

To estimate the relation between the degree of shock heterogeneity and the sensitivity of

Figure 4: Estimates of shock heterogeneity in each sector ($\tau_t(i)/\sigma_t$)



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

the sectoral inflation to sector-specific demand, we follow the insights from the theoretical model, encapsulated by equation (30), 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.[33]

$$\pi_t(i) - \pi_t = d_1(i) + \underbrace{\left(d_2 + d_3 \mathbf{1}_{\{2000-2022\}} + d_4\left(\tau_t(i)/\sigma_t\right)\right)}_{\alpha_2} \widetilde{v}_t(i) + d_5 \widetilde{v}_{t-1}(i) + \varepsilon_t^d, \qquad (35)$$

where $d_1(i)$ is fixed effect indicator variable, parameters d_2-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 8: 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 ($\widehat{v}_t(i)$)	0.17 ***	0.18 ***	0.17 ***
	(0.05)	(0.05)	(0.05)
Changes in sector-specific demand ($\widehat{v}_t(i)$) ×time dummy (2000-2022)	-0.004	-0.01	-0.004
	(0.03)	(0.02)	(0.03)
Changes in sector-specific demand ($\widehat{v}_t(i)$) ×shock heterogeneity	**-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.*

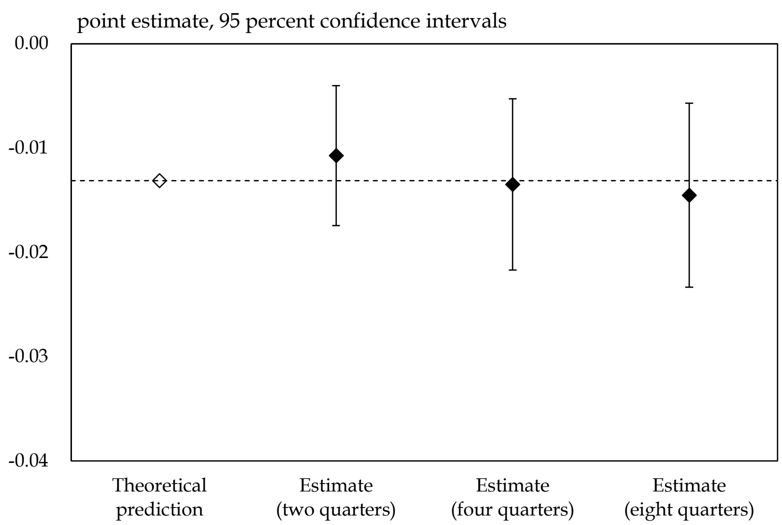
Table 8 shows the estimates for equation (35) for alternative measures of shock heterogeneity based on time windows of two quarters (column 1), four quarters (columns 2),

[33] 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 M.

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 supports a decrease in the sensitivity of the sectoral inflation in response to a raise in shock heterogeneity, consistent with the prediction in our theoretical model.

Figure 5 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 the coefficient α_2 on the interaction term $\tilde{v}_t(i) \times \tau_t/\sigma_t$ in equation (29), which represents the theoretical interaction between shock heterogeneity and sector-specific demand (white diamond).[34] 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.

Figure 5: 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 $\theta = 0.3,\ r = 0.7,\ \beta = 0.99, \rho_u = 0.33,\ \rho_v = -0.09$

Finally, to ensure that the significance of the negative relation between $\tau_t(i)/\sigma_t$ and sectoral inflation is not driven by the inclusion of the 2000-2022 dummy variable, Table 9 presents results for the benchmark regression that abstracts from the indicator variable

[34] 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.

$\mathbf{1}_{\{2000-2022\}}$ 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 ($\widetilde{v}_t(i) \times \mathbf{1}_{2000-2022}$) from equation (35). 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.[35]

Table 9: 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** ***
($\hat{v}_t(i)$) ×shock heterogeneity	(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.*

Appendix P shows that all results in this section remain broadly unchanged when we extend the sample to include the Covid-19 pandemic.

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. We use new sector-level survey data for the universe of Japanese firms to establish a positive co-movement in the expectations of aggregate and sector-specific components of demand. We then show that imperfect information allows a simple model with optimizing firms and demand driven by sector-specific and aggregate shocks to reproduce the observed positive co-movement in the 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 data for Japanese firms across 29 sectors.

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

Our study opens important avenues for future research. A fundamental question left unanswered is about the source of reduction in the volatility of sector-specific shocks. Is the decline in the volatility of sector-specific demand resulting from the improvement of production efficiency or, alternatively, is it a by-product of smoother input-output linkages among firms? Both sources lead to a decrease in the change of relative prices that is consistent with the reduction in the volatility of sector-specific demand, but with distinct impact on the propagation of shocks and different normative implications. Should the design and communication of monetary policy strategically account for the effect of the different components of demand on the firm's 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:

$$L = \left[\int_0^1 (C_t(i)\Theta_t(i))^{\frac{\eta-1}{\eta}} di\right]^{\frac{\eta}{\eta-1}} - \lambda_t \left(\int_0^1 P_t(i)C_t(i)di - Z_t\right), \tag{36}$$

and the first-order conditions are:

$$C_t(i)^{-\frac{1}{\eta}} C_t^{\frac{1}{\eta}} (\Theta_t(i))^{\frac{\eta-1}{\eta}} = \lambda_t P_t(i). \tag{37}$$

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

$$C_t(i) = C_t(j) \left(\frac{P_t(i)}{P_t(j)}\right)^{-\eta} \left(\frac{\Theta_t(i)}{\Theta_t(j)}\right)^{\eta-1}. \tag{38}$$

By substituting equations (37) and (38) into the definition of consumption expenditures ($Z_t \equiv \int_0^1 P_t(i)C_t(i)di$), it yields:

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

$$\Leftrightarrow \quad C_t(j) = P_t^{-\eta}(j)\Theta_t^{\eta-1}(j)Z_t \frac{1}{\int_0^1 P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)di}. \tag{39}$$

By substituting the equation:

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

into equation (39), it yields:

$$C_t(i) = \Theta_t^{\eta-1}(i) \left(\frac{P_t(i)}{P_t}\right)^{-\eta} C_t \frac{P_t^{1-\eta}}{\int_0^1 P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)di}. \tag{40}$$

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 (40) as:

$$C_t(i) = \Theta_t^{\eta-1}(i) \left(\frac{P_t(i)}{P_t}\right)^{-\eta} C_t. \tag{41}$$

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

$$C_t(i,j) = \left(\frac{P_t(i,j)}{P_t(i)}\right)^{-\widetilde{\eta}} C_t(i). \tag{42}$$

By combining equations (41) and (42), 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 (37) can be re-written as:

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

From the first-order condition (37) we derive the aggregate price index:

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

B Total Sectoral Demand and Aggregate and Sector-Specific Components

As shown in Appendix A, the demand for firm j in sector i in equation (12), can be expressed as:

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

where the demand for sector i, $C_t(i)$, can be re-written as:

$$C_t(i) = \Theta_t^{\eta-1}(i)\left(\frac{P_t(i)}{P_t}\right)^{-\eta} C_t, \tag{43}$$

where C_t is the aggregate demand and $\left(\frac{P_t(i)}{P_t}\right)^{-\eta}$ is the cross-price elasticity term. $\Theta_t^{\eta-1}(i)$ is the sector-specific demand shifter driven by the preference shocks. We can express the demand in equation (43) in nominal terms as:

$$P_tC_t(i) = (P_tC_t)\,\Theta_t^{\eta-1}(i)\left(\frac{P_t(i)}{P_t}\right)^{-\eta}, \tag{44}$$

where we name $P_tC_t(i)$ is the total sectoral demand and the demand is composed of two components: the aggregate demand P_tC_t and the sector-specific demand $\Theta_t^{\eta-1}(i)\left(\frac{P_t(i)}{P_t}\right)^{-\eta}$. By using $P_t \equiv \left[\int_0^1 P_t^{1-\eta}(i)\Theta_t^{\eta-1}(i)di\right]^{\frac{1}{1-\eta}}$ into equation (44), it yields the decomposition of the total sectoral demand $(P_t(i)C_t(i))$ into aggregate demand (P_tC_t) and sector-specific demand $(\left(\frac{P_t(i)}{P_t}\right)^{-\eta}\Theta_t^{\eta-1}(i)/\left[\int_0^1\left(\frac{P_t(i)}{P_t}\right)^{1-\eta}\Theta_t^{\eta-1}(i)di\right]^{\frac{-\eta}{1-\eta}})$, such that:

$$P_tC_t(i) = (P_tC_t)\left(\frac{\left(\frac{P_t(i)}{P_t}\right)^{-\eta}\Theta_t^{\eta-1}(i)}{\left[\int_0^1\left(\frac{P_t(i)}{P_t}\right)^{1-\eta}\Theta_t^{\eta-1}(i)di\right]^{\frac{-\eta}{1-\eta}}}\right). \tag{45}$$

In equation (45) the relative sectoral price $(P_t(i)/P_t)$ depends on the exogenous sector-specific demand shifter, $\Theta_t(i)$, and aggregate demand and sector-specific demand are independent of each other.

To link the demand function in equation (44) to the empirical framework in Section 2, we show that the growth rates of total sectoral demand in our model can be decomposed into that of aggregate and sector-specific demand, as in the survey data. The growth rate of these term is given by

$$\frac{P_tC_t(i)}{P_{t-1}C_{t-1}(i)} = \frac{P_tC_t}{P_{t-1}C_{t-1}}\frac{\Theta_t^{\eta-1}(i)}{\Theta_{t-1}^{\eta-1}(i)}\left(\frac{\frac{P_t(i)}{P_{t-1}(i)}}{\frac{P_t}{P_{t-1}}}\right)^{-\eta}.$$

The log-linearization around the symmetric equilibrium yields:

$$[\Delta p_t + \Delta c_t(i)] = [\Delta p_t + \Delta c_t] + [(\eta - 1)\,\Delta\theta_t(i) - \eta\,(\Delta p_t(i) - \Delta p_t)]\,, \tag{46}$$

where lower-case variables to indicate logarithms of the corresponding upper-case variables (i.e., $x_t \equiv \log X_t$) and Δ indicates the difference the variables between two periods ($\Delta x_t \equiv x_t - x_{t-1}$). Equation (46) shows that the growth of the total sectoral demand ($\Delta p_t + \Delta c_t(i)$) is composed of that of aggregate demand ($\Delta p_t + \Delta c_t$) and that of sector-specific demand ($(\eta - 1)\,\Delta\theta_t(i) - \eta\,(\Delta p_t(i) - \Delta p_t)$), as in the survey data.

C 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 $\int_0^1 \theta_t(i)di = 0$.

D Derivation of the Price Setting Rule

Using the following equations:

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

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

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:

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

E Proofs of Propositions

E.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, $\mathbb{E}_t[\tilde{v}_t]$ is given by,

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

E.2 Proof of Proposition 2

(i) $\mathbb{E}_t[q_t] - \mathbb{E}_{t-1}[q_t]$ and $\mathbb{E}_t[v_t(i)] - \mathbb{E}_{t-1}[v_t(i)]$ are expressed as follows.

$$\mathbb{E}_t[q_t] - \mathbb{E}_{t-1}[q_t] = q_{t-1} + \rho_u u_{t-1} + \mathbb{E}_t[e_t] - q_{t-1} - \rho_u u_{t-1} = \mathbb{E}_t[e_t],$$

$$\mathbb{E}_t[v_t(i)] - \mathbb{E}_{t-1}[v_t(i)] = \rho_v v_{t-1}(i) + \mathbb{E}_t[\epsilon_t(i)] - \rho_v v_{t-1}(i) = \mathbb{E}_t[\epsilon_t(i)].$$

Then, we show $\mathbb{C}(\mathbb{E}_t[e_t], \mathbb{E}_t[\epsilon_t(i)]) > 0$ as follows .$x_t(i)$ is composed of the following variables.

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

Therefore, firm i can generate signals on $(e_t, \epsilon_t(i))$ as follows.

$$x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i) = e_t + \epsilon_t(i).$$

Note that the variables in the left hand side are observables and those in the right hand side are unobservables. Hence, the left hand side is the signal for both $(e_t, \epsilon_t(i))$, and thus $\mathbb{E}_t[e_t]$ and $\mathbb{E}_t[\epsilon_t(i)]$ are expressed as,

$$\mathbb{E}_t[e_t] = \frac{\tau_t^2}{\sigma_t^2+\tau_t^2}(x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i)) = \frac{\tau_t^2}{\sigma_t^2+\tau_t^2}(e_t+\epsilon_t(i)),$$

$$\mathbb{E}_t[\epsilon_t(i)] = \frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}(x_t(i) - q_{t-1} - \rho_u u_{t-1} - \rho_v v_{t-1}(i)) = \frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}(e_t+\epsilon_t(i)).$$

Therefore, $\mathbb{C}(\mathbb{E}_t[q_t] - \mathbb{E}_{t-1}[q_t], \mathbb{E}_t[v_t(i)] - \mathbb{E}_{t-1}[v_t(i)]) > 0$ holds. Note that $\mathbb{C}(\mathbb{E}_t[q_{t+1}] - \mathbb{E}_{t-1}[q_{t+2}], \mathbb{E}_t[v_{t+1}(i)] - \mathbb{E}_{t-1}[v_{t+1}(i)]) > 0$ is obvious because the following equations hold.

$$\begin{aligned}\mathbb{E}_t[q_{t+1}] - \mathbb{E}_{t-1}[q_{t+2}] &= \rho_u(\mathbb{E}_t[q_t] - \mathbb{E}_{t-1}[q_t]), \\ \mathbb{E}_t[v_{t+1}(i)] - \mathbb{E}_{t-1}[v_{t+1}(i)] &= \rho_v(\mathbb{E}_t[v_t(i)] - \mathbb{E}_{t-1}[v_t(i)]).\end{aligned}$$

(ii) $\mathbb{E}_t\left[\sum_{h=1}^4 u_{t+h}\right]$ and $\mathbb{E}_t\left[\sum_{h=1}^4 \widetilde{v}_{t+h}(i)\right]$ are expressed as follows:

$$\begin{aligned}\mathbb{E}_t\left[\sum_{h=1}^4 u_{t+h}\right] &= \frac{1-{\rho_u}^5}{1-\rho_u}\mathbb{E}_t[u_t], \\ \mathbb{E}_t\left[\sum_{h=1}^4 \widetilde{v}_{t+h}(i)\right] &= \frac{1-{\rho_v}^5}{1-\rho_v}\mathbb{E}_t[\tilde{v}_t].\end{aligned}$$

Hence, we show $\mathbb{C}(\mathbb{E}_t[u_t], \mathbb{E}_t[\tilde{v}_t]) > 0$. $\mathbb{E}_t[u_t]$ and $\mathbb{E}_t[\tilde{v}_t]$ are, respectively given as,

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

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

(iii) $\mathbb{E}_t\left[\sum_{h=1}^4 u_{t+h}\right]$ is expressed as,

$$\mathbb{E}_t\left[\sum_{h=1}^4 u_{t+h}\right] = \frac{1-{\rho_u}^5}{1-\rho_u}\mathbb{E}_t[u_t] = \frac{1-{\rho_u}^5}{1-\rho_u}\rho_u u_{t-1} + \frac{\sigma_t^2}{\sigma_t^2+\tau_t^2}(e_t + \epsilon_t(i))$$

Next, $\mathbb{E}_t[v_t(i)] - \mathbb{E}_{t-1}[v_t(i)]$ is expressed as,

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

Hence, $\mathbb{C}\left(\mathbb{E}_t\left[\sum_{h=1}^5 u_{t+h}\right], \mathbb{E}_t[v_t(i)] - \mathbb{E}_{t-1}[v_t(i)]\right) > 0$ holds. □

E.3 Proof of Proposition 3

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:

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

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

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

$$\begin{aligned}
p_t^*(i) &= (1-\beta\theta)\left[(1-r)x_t(i) + r\mathbb{E}_t\left[p_t\right]\right] \;\; + \beta\theta\mathbb{E}_t[p_{t+1}^*(i)] \\
&= (1-\beta\theta)(1-r)x_t(i) + (1-\beta\theta)r\mathbb{E}_t\left[p_t\right] + \beta\theta\mathbb{E}_t[p_{t+1}^*(i)] \\
&= (1-\beta\theta)(1-r)x_t(i) + (1-\beta\theta)r\mathbb{E}_t\left[p_t\right] \\
&\quad +\beta\theta\mathbb{E}_t\left[a_1p_t + a_2x_{t+1}(i) + a_3q_t + a_4u_t + a_5v_t(i)\right] \\
&= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\mathbb{E}_t\left[p_t\right] \\
&\quad +\beta\theta a_2\mathbb{E}_t\left[x_{t+1}(i)\right] + \beta\theta a_3\mathbb{E}_t\left[q_t\right] + \beta\theta a_4\mathbb{E}_t\left[u_t\right] + \beta\theta a_5\mathbb{E}_t\left[v_t(i)\right] \\
&= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\mathbb{E}_t\left[p_t\right] \\
&\quad +\beta\theta a_2\mathbb{E}_t\left[q_t + u_{t+1} + v_{t+1}(i)\right] + \beta\theta a_3\mathbb{E}_t\left[q_t\right] + \beta\theta a_4\mathbb{E}_t\left[u_t\right] + \beta\theta a_5\mathbb{E}_t\left[v_t(i)\right] \\
&= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\mathbb{E}_t\left[p_t\right] \\
&\quad +\beta\theta\left(a_2 + a_3\right)\mathbb{E}_t\left[q_t\right] + \beta\theta\left(a_2\rho_u + a_4\right)\mathbb{E}_t\left[u_t\right] + \beta\theta\left(a_2\rho_v + a_5\right)\mathbb{E}_t\left[v_t(i)\right].
\end{aligned}$$

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

$$\mathbb{E}_t\left[p_t\right] = \left[\theta + (1-\theta)\,a_1\right]p_{t-1} + (1-\theta)\,a_2\mathbb{E}_t\left[q_t\right] + (1-\theta)\,a_3q_{t-1} + (1-\theta)\,a_4u_{t-1},$$

which yields:

$$\begin{aligned}
p_t^*(i) &= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\,a_1\right]p_{t-1} \\
&\quad + \left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_2 + \beta\theta\left(a_2 + a_3\right)\right]\mathbb{E}_t\left[q_t\right] \\
&\quad + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_3q_{t-1} \\
&\quad + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_4u_{t-1} \\
&\quad +\beta\theta\left(a_2\rho_u + a_4\right)\mathbb{E}_t\left[u_t\right] + \beta\theta\left(a_2\rho_v + a_5\right)\mathbb{E}_t\left[v_t(i)\right] \\
&= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\,a_1\right]p_{t-1} \\
&\quad + \left[\left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_2 + \beta\theta\left(a_2 + a_3\right)\right] + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_3\right]q_{t-1} \\
&\quad + \left[\left[\left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_2 + \beta\theta\left(a_2 + a_3\right)\right] + \beta\theta\left(a_2\rho_u + a_4\right)\right]\mathbb{E}_t\left[u_t\right] \\
&\quad +\beta\theta\left(a_2\rho_v + a_5\right)\mathbb{E}_t\left[v_t(i)\right] \\
&\quad + \left[(1-\beta\theta)r + \beta\theta a_1\right](1-\theta)\,a_4u_{t-1} \\
&= (1-\beta\theta)(1-r)x_t(i) + \left[(1-\beta\theta)r + \beta\theta a_1\right]\left[\theta + (1-\theta)\,a_1\right]p_{t-1} \\
&\quad +b_1q_{t-1} + b_2\mathbb{E}_t\left[u_t\right] + b_3\mathbb{E}_t\left[v_t(i)\right] + b_4u_{t-1}.
\end{aligned}$$

where

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

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:

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

By simplifying the conditions, we obtain:

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

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

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

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

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

E.4 Proof of Corollary 1

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

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

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

and

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

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

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

holds. Next, given $a_1 + a_2 + a_3 = 1$ and cash-in-advance constraint $q_t = p_t + y_t$, the equation (27) is expressed as follows.

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

F 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.[36] 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 10, 11, 12, 13, 14, 15, 16, 17, and 18 show the summary statistics of the sample sectors.

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

Table 10: 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 11: Summary statistics of Business Outlook Survey (Large firms, one period ahead)

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 12: Summary statistics of Business Outlook Survey (Large firms, two period ahead)

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	1.68	2.04	7.47	6.09	-0.26	0.15
Textiles	4.11	4.11	7.31	8.75	0.18	0.33
Wood Products	5.77	7.26	20.70	17.46	0.06	0.29
Pulp and Paper	3.35	2.21	7.04	5.95	0.07	0.23
Chemicals	6.66	4.32	5.24	5.55	0.19	0.42
Oil and Coal Products	1.58	1.54	6.72	6.29	0.01	0.16
Glass and Ceramics Products	6.72	3.67	10.13	7.44	0.26	0.38
Iron and Steel	6.46	4.82	8.83	7.07	0.20	0.24
Nonferrous Metals	5.76	4.66	8.31	7.43	0.00	0.18
Metal Product	6.05	4.37	11.34	7.36	0.05	0.26
General-Purpose Machinery	8.66	7.29	10.71	7.52	-0.08	0.16
Production Machinery	8.38	7.17	6.72	6.06	-0.01	0.26
Business Oriented Machinery	8.26	6.18	8.60	6.12	-0.43	-0.11
Electrical Machinery	8.74	5.96	8.00	7.25	0.04	0.35
Electric Device	10.91	7.25	6.70	5.39	0.09	0.20
Cars and Related Products	5.58	4.08	9.30	8.88	0.05	0.27
Other Transportation Equipment	-0.95	3.02	10.70	9.10	0.13	-0.02
Other Products	6.69	5.27	6.49	6.89	0.19	0.47
Agriculture, Forestry, and Fishing	0.81	5.03	29.65	18.78	-0.13	0.03
Mining and Quarrying of Stone and Gravel	-1.45	-0.28	7.24	4.68	0.07	0.06
Construction	2.66	3.39	11.98	8.58	-0.49	0.49
Electricity, Gas, Heat supply and Water	-0.03	3.58	6.03	7.23	-0.15	0.61
Information and Communications	7.25	4.19	6.35	7.67	-0.06	0.60
Transport and Postal Activities	3.50	3.94	4.93	6.84	0.30	0.61
Whole-sale	6.55	5.70	6.42	7.13	0.30	0.43
Retail	6.24	2.73	8.03	10.41	0.16	0.28
Real Estate	0.21	0.80	5.28	8.75	0.61	0.63
Lease	5.70	5.17	8.64	9.12	0.17	0.24
Goods Rental and Leasing	2.74	2.69	18.14	13.89	0.12	0.07
Accommodations, Eating and Drinking Services	7.25	5.96	12.80	12.74	0.23	0.63
Living-Related and Personal Services	12.87	7.40	12.54	12.97	0.03	0.26
Services for Amusement and Hobbies	7.78	3.56	13.06	11.18	0.18	0.37
Scientific Research, Professional and Technical Services	4.51	5.02	3.09	5.56	0.14	0.21
Healthcare and Education	13.46	7.34	12.15	13.06	0.39	0.55
Employment and Worker Dispatching Services	10.71	7.99	15.91	15.17	0.09	0.17
Other Service	5.61	5.19	4.85	5.72	0.22	0.27
Finance and Insurance	5.27	9.77	5.96	10.19	0.82	0.64

Table 13: 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 14: Summary statistics of Business Outlook Survey (Mid-sized firms, one period ahead)

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	-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 15: Summary statistics of Business Outlook Survey (Mid-sized firms, two period ahead)

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	1.71	0.68	11.33	11.41	-0.26	0.32
Textiles	-4.78	-4.03	11.72	14.64	0.27	0.52
Wood Products	1.99	2.41	18.83	19.23	-0.02	-0.01
Pulp and Paper	3.64	0.52	16.35	12.70	-0.10	0.21
Chemicals	7.10	5.02	7.79	9.01	0.09	0.36
Oil and Coal Products	2.35	2.87	18.72	16.83	0.04	-0.15
Glass and Ceramics Products	5.48	5.26	13.62	12.59	0.16	0.38
Iron and Steel	4.30	5.27	14.01	14.14	0.31	0.30
Nonferrous Metals	4.91	3.15	12.18	12.50	0.05	0.09
Metal Product	5.39	4.32	11.31	11.53	0.13	0.37
General-Purpose Machinery	8.17	7.13	13.64	12.59	-0.01	0.20
Production Machinery	6.28	4.61	9.39	9.77	0.06	0.31
Business Oriented Machinery	7.44	6.19	11.30	13.43	0.19	0.31
Electrical Machinery	7.43	3.56	12.40	11.43	0.26	0.41
Electric Device	10.81	7.65	9.43	8.66	0.21	0.30
Cars and Related Products	2.50	2.20	12.00	10.76	0.04	0.29
Other Transportation Equipment	2.89	0.71	19.13	15.98	0.07	0.13
Other Products	6.26	3.97	7.81	9.52	0.16	0.39
Agriculture, Forestry, and Fishing	-4.63	-3.10	14.14	13.20	0.17	0.08
Mining and Quarrying of Stone and Gravel	-5.26	-4.37	18.80	16.43	0.16	0.34
Construction	0.65	0.19	10.66	11.85	0.07	0.55
Electricity, Gas, Heat supply and Water	0.90	-0.27	10.16	9.98	0.18	0.40
Information and Communications	7.80	3.62	8.44	10.93	0.31	0.65
Transport and Postal Activities	0.31	0.51	8.37	10.22	0.21	0.43
Whole-sale	3.74	1.87	7.17	10.16	0.27	0.56
Retail	0.72	-0.73	11.18	14.71	0.16	0.41
Real Estate	-1.93	-2.14	5.56	10.87	0.63	0.70
Lease	-0.16	3.66	11.54	12.27	0.20	0.33
Goods Rental and Leasing	6.89	1.51	18.85	19.57	0.21	0.39
Accommodations, Eating and Drinking Services	2.72	2.23	12.61	14.37	0.45	0.56
Living-Related and Personal Services	5.72	1.69	14.13	16.62	0.40	0.43
Services for Amusement and Hobbies	-0.70	-0.30	12.02	11.86	-0.09	0.41
Scientific Research, Professional and Technical Services	5.82	3.15	7.41	9.95	0.22	0.43
Healthcare and Education	12.06	4.51	12.64	15.37	0.41	0.50
Employment and Worker Dispatching Services	12.30	6.78	17.88	18.56	0.50	0.41
Other Service	4.83	3.86	5.90	7.44	0.19	0.34
Finance and Insurance	4.92	6.66	7.51	11.31	0.48	0.57

Table 16: Summary statistics about Business Outlook Survey (Small 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	-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	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
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	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Table 17: Summary statistics of Business Outlook Survey (Mid-sized firms, one period ahead)

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	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
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	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Table 18: Summary statistics of Business Outlook Survey (Mid-sized firms, two period ahead)

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	-7.18	-9.36	10.75	12.45	0.22	0.50
Textiles	-9.93	-12.02	9.57	14.12	0.20	0.41
Wood Products	-10.73	-10.97	11.49	12.47	0.24	0.18
Pulp and Paper	-7.13	-7.68	12.26	14.24	-0.07	0.36
Chemicals	-2.25	-4.99	8.90	11.43	0.14	0.32
Oil and Coal Products	-7.98	-8.73	10.31	14.02	0.43	0.48
Glass and Ceramics Products	-10.26	-9.91	11.13	12.81	0.39	0.46
Iron and Steel	-1.54	-3.72	10.82	12.90	0.29	0.40
Nonferrous Metals	-2.86	-3.98	11.25	11.71	0.28	0.29
Metal Product	-3.11	-4.80	9.04	10.70	0.32	0.50
General-Purpose Machinery	-2.87	-4.48	8.82	11.88	0.09	0.08
Production Machinery	-2.31	-2.71	9.36	9.65	0.38	0.46
Business Oriented Machinery	1.53	-1.04	9.11	10.97	0.27	0.50
Electrical Machinery	-2.31	-2.92	12.09	12.46	0.44	0.44
Electric Device	-2.10	-3.04	10.99	10.70	0.27	0.35
Cars and Related Products	-3.95	-6.35	14.05	16.15	0.48	0.54
Other Transportation Equipment	-6.32	-6.39	12.17	13.61	0.41	0.40
Other Products	-6.27	-8.24	6.41	9.60	0.44	0.55
Agriculture, Forestry, and Fishing	-2.67	-9.53	10.62	14.76	0.02	0.25
Mining and Quarrying of Stone and Gravel	-9.50	-13.15	13.23	13.78	0.34	0.39
Construction	-8.58	-11.05	7.10	10.23	0.67	0.70
Electricity, Gas, Heat supply and Water	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Information and Communications	-0.59	-4.72	9.77	14.37	0.50	0.64
Transport and Postal Activities	-6.20	-7.77	7.73	10.86	0.51	0.63
Whole-sale	-8.59	-10.37	7.09	10.62	0.49	0.62
Retail	-11.57	-14.05	6.50	10.81	0.57	0.60
Real Estate	-5.29	-7.68	5.12	10.11	0.83	0.77
Lease	-6.83	-7.72	11.18	15.00	0.02	0.32
Goods Rental and Leasing	-5.79	-7.84	12.15	10.91	0.26	0.25
Accommodations, Eating and Drinking Services	-9.45	-11.76	10.58	13.58	0.41	0.47
Living-Related and Personal Services	-8.48	-12.59	11.15	13.06	0.15	0.30
Services for Amusement and Hobbies	-6.54	-6.94	11.16	13.79	0.26	0.47
Scientific Research, Professional and Technical Services	-4.61	-8.41	6.03	9.26	0.64	0.58
Healthcare and Education	-4.07	-8.49	10.57	13.73	0.24	0.35
Employment and Worker Dispatching Services	-1.95	-0.99	9.63	10.50	0.29	0.34
Other Service	-6.61	-7.98	5.98	8.21	0.68	0.60
Finance and Insurance	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

G 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.[37] 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 19, 20, 21, and 22 show the summary statistics of the sample sectors.

H 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.[38] The data cover the period 1975:Q3-2022:Q4 for 29 major sectors in the economy. Table 23 reports summary statistics.

I Tankan Survey

The Tankan (Short-Term Economic Survey of Enterprises in Japan) is a statistical survey conducted by the Bank of Japan. Its purpose is to provide an accurate depiction of business trends among enterprises in Japan. The survey started in 1974 and it is conducted quarterly, with rounds occurring in March, June, September, and December each year. The Tankan employs a sample survey framework where enterprises are selected from a population in accordance with statistical theory. The target population of the Tankan comprises private enterprises in Japan with a capital of 20 million yen or more. These enterprises are drawn from the Establishment Frame Database of the Ministry of Internal Affairs and Communications. Sample enterprises are chosen from the survey population using stratified sampling to meet established criteria for statistical accuracy. For example, the standard error ratio of sales must fall within the target range (3 percent for manufacturing and 5 percent for

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

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

Table 19: Summary statistics about survey data (nominal output growth expectations)

Dataset: Annual Survey of Corporate Behavior; 33 industries; 2003-2021

Sector	*(1) Historical averages*			*(2) Historical standard deviation*			*(3) First-order auto correlation*		
	One-year head	*Three-year ahead*	*Five-year ahead*	*One-year head*	*Three-year ahead*	*Five-year ahead*	*One-year head*	*Three-year ahead*	*Five-year ahead*
Foods	1.12	1.22	1.31	0.73	0.44	0.34	0.42	0.40	0.42
Textiles & Apparels	1.11	1.32	1.41	0.74	0.41	0.38	0.29	0.32	0.34
Pulp & Paper	1.08	1.31	1.41	0.97	0.49	0.43	0.38	0.55	0.56
Chemicals	1.20	1.36	1.44	0.90	0.48	0.35	0.30	0.33	0.39
Pharmaceutical	1.26	1.33	1.39	0.69	0.45	0.42	0.55	0.32	0.14
Oil & Coal Products	0.70	1.11	1.31	1.16	0.70	0.64	0.26	0.43	0.29
Rubber Products	1.01	1.24	1.37	0.97	0.54	0.39	0.02	0.20	0.10
Glass & Ceramics Products	1.04	1.19	1.28	0.97	0.58	0.39	0.30	0.29	0.28
Iron & Steel	1.06	1.19	1.24	0.94	0.53	0.43	0.37	0.64	0.66
Nonferrous Metals	1.10	1.27	1.36	0.87	0.52	0.44	0.35	0.37	0.45
Metal Products	1.05	1.20	1.26	0.80	0.46	0.35	0.50	0.62	0.59
Machinery	1.16	1.32	1.43	0.87	0.45	0.30	0.45	0.56	0.65
Electric Appliances	1.21	1.34	1.45	0.88	0.45	0.33	0.47	0.45	0.38
Transportation Equipment	1.11	1.24	1.33	0.88	0.54	0.41	0.31	0.20	0.32
Precision Instruments	1.26	1.42	1.56	0.87	0.54	0.43	0.60	0.58	0.39
Other Products	1.16	1.29	1.39	0.81	0.44	0.25	0.54	0.58	0.52
Fishery, Agriculture & Forestry	0.83	1.09	1.17	1.96	1.08	0.91	0.42	0.40	0.40
Mining	1.98	2.38	2.25	0.41	0.48	0.65	-0.40	-0.87	-0.98
Construction	1.20	1.35	1.44	0.82	0.51	0.35	0.54	0.50	0.53
Wholesale Trade	1.13	1.26	1.36	0.85	0.50	0.31	0.40	0.45	0.50
Retail Trade	1.00	1.11	1.20	0.80	0.49	0.35	0.50	0.39	0.42
Real Estate	1.12	1.28	1.40	0.76	0.43	0.29	0.38	0.17	0.06
Land Transportation	1.22	1.23	1.26	0.80	0.48	0.38	0.57	0.42	0.39
Marine Transportation	1.37	1.48	1.68	0.81	0.83	0.64	0.64	0.47	0.44
Air Transportation	0.67	1.07	1.44	1.54	1.25	0.69	0.72	-0.02	-0.44
Warehousing & Harbor Transportation Services	1.22	1.30	1.41	0.64	0.44	0.32	0.29	0.11	0.00
Information & Communication	1.03	1.22	1.33	0.83	0.47	0.28	0.17	0.03	0.21
Electric Power & Gas	1.43	1.41	1.47	1.08	0.50	0.39	0.31	0.29	0.38
Services	1.04	1.22	1.31	0.75	0.46	0.32	0.46	0.52	0.40
Banks	1.34	1.43	1.52	1.00	0.51	0.38	0.41	0.38	0.42
Securities & Commodity Futures	1.30	1.48	1.57	1.14	0.59	0.46	0.34	0.25	0.27
Insurance	1.33	1.34	1.44	1.31	0.62	0.45	0.47	0.19	0.34
Other Financing Businesses	1.37	1.40	1.50	0.83	0.57	0.46	0.36	0.32	0.20

Table 20: Summary statistics about survey data (real output growth expectations)

Dataset: Annual Survey of Corporate Behavior; 33 industries; 2003-2021

Sector	*(1) Historical averages*			*(2) Historical standard deviation*			*(3) First-order auto correlation*		
	One-year head	*Three-year ahead*	*Five-year ahead*	*One-year head*	*Three-year ahead*	*Five-year ahead*	*One-year head*	*Three-year ahead*	*Five-year ahead*
Foods	1.12	1.19	1.26	0.69	0.45	0.41	0.23	0.36	0.55
Textiles & Apparels	1.13	1.30	1.34	0.76	0.39	0.35	0.10	0.20	0.35
Pulp & Paper	1.19	1.36	1.43	0.91	0.45	0.42	0.11	0.21	0.34
Chemicals	1.21	1.33	1.40	0.87	0.43	0.35	0.10	0.23	0.55
Pharmaceutical	1.25	1.32	1.38	0.74	0.58	0.49	0.19	0.14	0.45
Oil & Coal Products	1.11	1.25	1.44	0.96	0.53	0.49	-0.07	0.08	0.12
Rubber Products	1.20	1.38	1.50	0.88	0.51	0.38	-0.10	0.14	0.26
Glass & Ceramics Products	1.03	1.16	1.26	1.03	0.63	0.47	0.15	0.17	0.51
Iron & Steel	1.11	1.21	1.25	0.91	0.41	0.37	0.13	0.49	0.66
Nonferrous Metals	1.13	1.25	1.30	0.91	0.47	0.43	0.23	0.40	0.60
Metal Products	1.16	1.24	1.28	0.68	0.40	0.36	0.23	0.46	0.52
Machinery	1.16	1.28	1.35	0.80	0.43	0.33	0.22	0.39	0.68
Electric Appliances	1.23	1.32	1.39	0.76	0.39	0.34	0.21	0.35	0.53
Transportation Equipment	1.09	1.18	1.26	0.86	0.49	0.36	0.03	0.07	0.35
Precision Instruments	1.17	1.30	1.42	0.80	0.47	0.45	0.35	0.45	0.54
Other Products	1.16	1.27	1.34	0.75	0.46	0.38	0.32	0.50	0.80
Fishery, Agriculture & Forestry	0.94	1.05	1.09	1.75	1.27	1.07	0.32	0.30	0.32
Mining	1.78	2.18	1.93	0.63	0.46	0.50	0.16	-0.27	-0.98
Construction	1.18	1.27	1.33	0.69	0.42	0.36	0.30	0.43	0.72
Wholesale Trade	1.13	1.22	1.30	0.75	0.46	0.38	0.15	0.30	0.60
Retail Trade	1.01	1.12	1.18	0.73	0.46	0.39	0.31	0.40	0.70
Real Estate	1.17	1.26	1.35	0.77	0.51	0.43	0.20	0.36	0.69
Land Transportation	1.27	1.23	1.27	0.68	0.43	0.34	0.13	0.09	0.37
Marine Transportation	1.39	1.64	1.75	0.67	0.59	0.53	0.34	0.37	0.46
Air Transportation	1.22	1.38	1.70	1.46	1.02	0.43	0.11	0.60	0.89
Warehousing & Harbor Transportation Services	1.25	1.29	1.38	0.64	0.48	0.41	0.09	0.30	0.57
Information & Communication	1.13	1.28	1.36	0.78	0.49	0.41	0.17	0.19	0.66
Electric Power & Gas	1.35	1.24	1.24	0.93	0.38	0.33	0.01	0.18	0.56
Services	1.10	1.25	1.32	0.69	0.44	0.37	0.33	0.45	0.58
Banks	1.29	1.31	1.34	0.91	0.41	0.37	0.04	0.22	0.58
Securities & Commodity Futures	1.39	1.43	1.47	0.99	0.51	0.44	0.10	0.22	0.45
Insurance	1.14	1.17	1.19	1.04	0.60	0.54	0.13	0.15	0.53
Other Financing Businesses	1.34	1.30	1.36	0.63	0.49	0.43	0.14	0.07	0.40

Table 21: Summary statistics about survey data (nominal sectoral demand growth expectations)

Dataset: Annual Survey of Corporate Behavior; 33 industries; 2003-2021

Sector	*(1) Historical averages*			*(2) Historical standard deviation*			*(3) First-order auto correlation*		
	One-year head	*Three-year ahead*	*Five-year ahead*	*One-year head*	*Three-year ahead*	*Five-year ahead*	*One-year head*	*Three-year ahead*	*Five-year ahead*
Foods	0.53	0.60	0.61	0.51	0.36	0.31	0.61	0.61	0.47
Textiles & Apparels	0.39	0.69	0.74	0.93	0.40	0.36	0.15	0.28	0.33
Pulp & Paper	-0.06	0.22	0.28	1.68	0.68	0.58	0.17	0.57	0.65
Chemicals	1.19	1.38	1.46	1.05	0.50	0.31	0.28	0.30	0.17
Pharmaceutical	1.40	1.63	1.60	0.57	0.44	0.52	-0.08	0.38	0.11
Oil & Coal Products	-1.02	-0.89	-0.86	1.60	1.52	1.46	0.31	0.56	0.59
Rubber Products	0.85	1.18	1.28	1.47	0.86	0.59	0.13	-0.01	0.13
Glass & Ceramics Products	0.37	0.47	0.53	1.14	0.95	0.76	0.34	0.38	0.27
Iron & Steel	0.49	0.67	0.74	2.39	0.96	0.53	0.05	0.15	0.32
Nonferrous Metals	1.04	0.96	0.93	2.09	1.44	1.39	0.25	0.41	0.46
Metal Products	0.36	0.54	0.52	1.32	0.65	0.52	0.48	0.49	0.44
Machinery	1.27	1.69	1.74	2.02	0.72	0.47	0.00	-0.28	-0.23
Electric Appliances	1.76	1.96	2.06	1.27	0.54	0.32	0.22	0.11	0.11
Transportation Equipment	1.08	1.06	1.05	2.00	0.82	0.59	0.16	-0.04	0.31
Precision Instruments	1.51	1.69	1.87	0.93	0.57	0.65	0.22	0.12	-0.01
Other Products	0.55	0.69	0.71	0.83	0.58	0.53	0.43	0.48	0.28
Fishery, Agriculture & Forestry	1.20	1.26	1.31	0.99	0.67	0.62	0.26	0.12	-0.12
Mining	1.81	2.15	2.03	0.44	0.48	0.59	0.20	-0.30	-0.63
Construction	-0.16	0.14	0.20	1.57	1.22	1.00	0.59	0.75	0.76
Wholesale Trade	0.77	1.01	1.11	1.02	0.51	0.34	0.43	0.25	0.34
Retail Trade	0.34	0.46	0.54	0.92	0.66	0.52	0.71	0.69	0.68
Real Estate	1.55	1.57	1.59	1.59	1.32	1.16	0.19	0.16	0.16
Land Transportation	0.42	0.50	0.53	0.69	0.55	0.47	0.79	0.76	0.70
Marine Transportation	2.14	2.51	2.67	1.59	1.30	1.10	0.01	-0.27	-0.32
Air Transportation	1.34	1.26	1.56	0.80	0.83	1.35	-0.91	-0.55	-0.67
Warehousing & Harbor Transportation Services	0.96	1.02	1.12	0.65	0.51	0.42	0.47	0.43	0.41
Information & Communication	1.75	1.98	2.12	1.29	0.91	0.82	0.36	0.34	0.59
Electric Power & Gas	1.42	1.61	1.59	0.92	0.69	0.70	0.10	0.36	0.60
Services	1.47	1.74	1.68	1.25	0.96	0.71	0.45	0.22	0.15
Banks	0.91	1.08	1.23	0.68	0.56	0.51	0.19	0.44	0.59
Securities & Commodity Futures	2.22	2.43	2.80	2.94	2.37	2.38	0.50	0.40	0.34
Insurance	1.00	1.19	1.29	1.36	0.94	0.74	0.64	0.59	0.56
Other Financing Businesses	0.58	1.11	1.33	2.62	1.89	1.79	0.50	0.51	0.31

Table 22: Summary statistics about survey data (real sectoral demand growth expectations)

Dataset: Annual Survey of Corporate Behavior; 33 industries; 2003-2021

Sector	*(1) Historical averages*			*(2) Historical standard deviation*			*(3) First-order auto correlation*		
	One-year head	*Three-year ahead*	*Five-year ahead*	*One-year head*	*Three-year ahead*	*Five-year ahead*	*One-year head*	*Three-year ahead*	*Five-year ahead*
Foods	0.46	0.54	0.55	0.36	0.26	0.23	0.44	0.35	0.22
Textiles & Apparels	0.42	0.67	0.70	0.83	0.33	0.32	-0.06	-0.14	-0.02
Pulp & Paper	-0.02	0.33	0.40	1.66	0.65	0.55	0.12	0.48	0.59
Chemicals	1.12	1.33	1.39	1.02	0.40	0.30	0.14	0.17	0.28
Pharmaceutical	1.73	1.90	1.93	0.63	0.67	0.72	0.31	0.36	0.30
Oil & Coal Products	-1.15	-1.02	-0.96	1.49	1.31	1.27	0.13	0.43	0.46
Rubber Products	0.85	1.22	1.33	1.48	0.91	0.61	0.13	-0.05	0.27
Glass & Ceramics Products	0.26	0.51	0.58	1.40	0.87	0.83	0.26	0.45	0.40
Iron & Steel	0.63	0.80	0.85	2.08	0.74	0.48	-0.04	-0.10	0.08
Nonferrous Metals	1.04	1.36	1.45	1.84	1.01	0.75	0.32	0.35	0.28
Metal Products	0.42	0.52	0.43	1.02	0.45	0.42	0.43	0.37	0.32
Machinery	1.29	1.65	1.68	1.96	0.75	0.48	-0.06	-0.26	-0.03
Electric Appliances	1.96	2.08	2.16	1.20	0.57	0.41	0.10	0.05	0.35
Transportation Equipment	1.06	1.02	1.01	1.99	0.78	0.48	0.09	-0.30	-0.16
Precision Instruments	1.70	1.88	1.88	0.93	0.97	0.81	0.24	0.28	0.36
Other Products	0.54	0.63	0.66	0.79	0.54	0.55	0.37	0.36	0.25
Fishery, Agriculture & Forestry	1.31	1.28	1.32	1.08	0.92	0.85	0.42	0.43	0.41
Mining	1.69	2.03	1.84	0.64	0.48	0.42	0.46	0.36	-0.91
Construction	-0.32	-0.01	0.04	1.40	1.04	0.85	0.49	0.68	0.71
Wholesale Trade	0.83	1.04	1.12	0.91	0.53	0.42	0.36	0.41	0.73
Retail Trade	0.31	0.45	0.51	0.76	0.50	0.40	0.54	0.57	0.59
Real Estate	1.46	1.51	1.51	1.76	1.51	1.28	0.28	0.40	0.49
Land Transportation	0.36	0.44	0.47	0.57	0.40	0.31	0.49	0.49	0.38
Marine Transportation	2.64	3.24	2.99	2.02	2.01	1.41	0.44	0.24	0.10
Air Transportation	1.08	1.13	1.40	0.74	0.68	1.22	-0.53	-0.68	-0.78
Warehousing & Harbor Transportation Services	0.98	1.02	1.12	0.65	0.55	0.47	0.30	0.48	0.59
Information & Communication	1.80	2.08	2.21	1.27	0.96	0.89	0.34	0.46	0.70
Electric Power & Gas	1.41	1.44	1.41	0.83	0.64	0.65	0.10	0.35	0.62
Services	1.47	1.70	1.63	1.06	0.77	0.56	0.36	0.11	0.04
Banks	0.95	1.02	1.08	0.66	0.50	0.51	0.06	0.61	0.74
Securities & Commodity Futures	2.09	2.35	2.71	2.96	2.34	2.23	0.43	0.33	0.27
Insurance	0.85	0.87	0.90	0.92	0.69	0.56	0.57	0.59	0.54
Other Financing Businesses	0.55	1.08	1.31	2.43	1.82	1.70	0.52	0.53	0.30

Table 23: 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

non-manufacturing). The Bank revises the Tankan sample enterprises once every two or three years, with surveys that supplement the Tankan also revised at the same time. Apart from these revisions, sample enterprises remain largely fixed. However, the Bank regularly assesses statistical accuracy (typically once a year) and, if necessary, adds new sample enterprises to prevent a decline in statistical accuracy due to factors such as bankruptcies, mergers, and other events. Table 24 and 25 show summary statistics of sectoral samples.

Table 24: Summary statistics of Tankan Survey (Demand DI)

Dataset: Tankan Survey; 24 industries; 2014/2Q-2023/1Q						
Sector	*(1) Historical averages*		*(2) Historical standard deviation*		*(3) First-order auto correlation*	
	Demand DI (current)	*Demand DI (future)*	*Demand DI (current)*	*Deman d DI (future)*	*Demand DI (current)*	*Demand DI (future)*
Textiles	-39.03	-38.81	8.96	7.86	0.86	0.89
Lumber & Wood products	-19.24	-22.49	13.46	11.29	0.65	0.73
Pulp & Paper	-29.16	-29.08	6.45	5.62	0.79	0.81
Chemicals	-12.30	-13.27	5.72	5.26	0.80	0.84
Petroleum & Coal products	-21.65	-21.43	6.66	6.44	0.76	0.73
Ceramics, Stone & Clay	-19.86	-19.89	6.19	5.84	0.81	0.84
Iron & Steel	-19.76	-19.43	18.87	17.03	0.89	0.89
Nonferrous metals	-11.24	-12.38	15.27	12.11	0.84	0.85
Food & Beverages	-18.14	-18.00	3.37	3.21	0.82	0.82
Processed metals	-15.49	-15.97	10.20	8.72	0.82	0.80
General-purpose, Production & Business oriented machinery	-8.89	-11.22	9.99	9.36	0.88	0.88
Electrical machinery	-6.89	-8.62	11.33	10.27	0.88	0.88
Transportation machinery	-10.24	-11.76	9.46	8.45	0.73	0.81
Other manufacturing	-28.19	-29.16	5.62	5.32	0.73	0.76
Construction	-3.89	-8.05	5.29	5.62	0.85	0.86
Real estate, Goods rental & Leasing	-20.70	-23.95	4.50	3.51	0.81	0.76
Wholesaling & Retailing	-15.59	-16.70	7.88	7.11	0.91	0.91
Transport & Postal activities	-16.00	-15.68	9.44	7.75	0.86	0.87
Information communication	-6.57	-8.14	4.36	4.04	0.78	0.83
Electric & Gas utilities	-2.38	-2.35	2.45	2.10	0.66	0.61
Services for businesses	-5.51	-7.11	6.22	5.94	0.82	0.86
Services for individuals	-25.95	-25.89	7.34	5.35	0.86	0.86
Accommodations, Eating & Drinking services	-40.95	-42.14	16.90	14.25	0.86	0.89
Mining & Quarrying of stone and gravel	-7.51	-5.65	9.28	7.67	0.63	0.57

J Firms' Expectations on Aggregate and Sectoral Demands: Inflation Expectations

Section 2 in the main text examines the correlation between firms' expectations on aggregate and sectoral demands by using firms' expectations on one-year ahead output growth and sectoral demand growth, respectively, as proxies. It then finds the positive correlation

Table 25: Summary statistics of Tankan Survey (Inflation expectations)

Dataset: Tankan Survey; 24 industries; 2014/2Q-2023/1Q									
Sector	*(1) Historical averages*			*(2) Historical standard deviation*			*(3) First-order auto correlation*		
	One-year head	*Three-year ahead*	*Five-year ahead*	*One-year head*	*Three-year ahead*	*Five-year ahead*	*One-year head*	*Three-year ahead*	*Five-year ahead*
Textiles	1.09	1.41	1.29	0.73	0.41	0.49	0.95	0.93	0.93
Lumber & Wood products	1.26	1.54	1.50	0.74	0.31	0.40	0.93	0.79	0.88
Pulp & Paper	1.11	1.14	1.15	0.75	0.39	0.45	0.93	0.87	0.92
Chemicals	1.05	1.12	1.12	0.64	0.33	0.38	0.95	0.92	0.92
Petroleum & Coal products	1.22	1.46	1.39	0.70	0.36	0.42	0.94	0.73	0.84
Ceramics, Stone & Clay	1.22	1.44	1.34	0.77	0.38	0.50	0.95	0.90	0.94
Iron & Steel	1.24	1.24	1.27	0.74	0.44	0.49	0.93	0.90	0.91
Nonferrous metals	1.15	1.30	1.21	0.74	0.44	0.47	0.94	0.91	0.90
Food & Beverages	1.09	1.32	1.24	0.75	0.43	0.50	0.95	0.93	0.94
Processed metals	1.20	1.34	1.33	0.73	0.40	0.48	0.95	0.93	0.94
General-purpose, Production & Business oriented machinery	1.07	1.32	1.23	0.73	0.37	0.47	0.96	0.95	0.95
Electrical machinery	0.99	1.25	1.20	0.63	0.35	0.44	0.96	0.94	0.95
Transportation machinery	1.01	1.25	1.19	0.64	0.31	0.43	0.96	0.91	0.94
Other manufacturing	1.11	1.28	1.25	0.69	0.38	0.43	0.95	0.95	0.94
Construction	1.28	1.46	1.44	0.67	0.41	0.47	0.95	0.95	0.95
Real estate, Goods rental & Leasing	0.93	1.16	1.13	0.58	0.36	0.41	0.94	0.95	0.94
Wholesaling & Retailing	1.09	1.30	1.24	0.66	0.37	0.45	0.95	0.94	0.95
Transport & Postal activities	1.04	1.31	1.23	0.57	0.27	0.33	0.94	0.92	0.92
Information communication	0.90	1.14	1.06	0.51	0.29	0.33	0.94	0.92	0.94
Electric & Gas utilities	0.99	1.11	1.12	0.50	0.33	0.36	0.92	0.86	0.90
Services for businesses	1.00	1.35	1.24	0.52	0.30	0.37	0.93	0.90	0.92
Services for individuals	0.98	1.21	1.16	0.64	0.36	0.42	0.95	0.91	0.93
Accommodations, Eating & Drinking services	1.28	1.55	1.46	0.73	0.37	0.49	0.95	0.93	0.93
Mining & Quarrying of stone and gravel	1.34	1.66	1.45	0.77	0.39	0.44	0.91	0.78	0.87

between them, This Appendix re-examines the correlation by using one-year ahead inflation expectations as a proxy for firms' expectations about changes in aggregate demand. Table 26 shows the estimation results and it indicates that all of the estimates for the sensitivity of inflation expectations to changes in firms' expectations about aggregate demand are positive and significant while those for the placebo industries are almost zero and insignificant.

Table 26: Firms' Expectations on Aggregate and Sectoral Demands: Inflation Expectations

Dataset: Tankan Survey; 2004/2Q-2023/1Q						
Dependent Variable: Inflation expectations$_t$ (one-year ahead)						
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Demand DI$_t$ (current) -Demand DI$_{t-1}$(one-period ahead)	0.004***	0.002***	0.003***	0.005***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Placebo Demand DI$_t$ (current) -Placebo Demand DI$_{t-1}$(one-period ahead)				0.001	0.001	0.001
				(0.001)	(0.001)	(0.001)
Inflation expectations$_t$ (three-year ahead)		0.697***			0.696***	
		(0.055)			(0.056)	
Inflation expectations$_t$ (five-year ahead			0.431***			0.429***
			(0.068)			(0.068)
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Period effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	864	864	864	864	864	864
Cross Section	24	24	24	24	24	24
Adjusted-R^2	0.96	0.98	0.94	0.96	0.98	0.97

*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.*

K 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 (2), (3) and (5). More concretely, we use equation (2) 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 $\sigma_t^2 = \mathbb{V}(e_t) = \mathbb{E}[e_t^2]$ is approximated by $\frac{1}{2k+1}\sum_{s=-k}^{k}\widehat{e}_t^2$.

Similarly, we use equation (3) 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 $(\rho_v, \epsilon_t(i) - \epsilon_{t-1}(i))$:

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

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

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

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
$\tau_t^2 = \mathbb{V}(\epsilon_t(i)) = \mathbb{E}[\epsilon_t^2(i)]$ by $\frac{1}{2k+1}\sum_{s=-k}^{k}\left(\frac{1}{29}\sum_{i=1}^{29}\frac{(\widehat{\epsilon}_t(i)-\widehat{\epsilon}_{t-1}(i))^2}{2}\right)$.[39]

Table 27 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.

L 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

[39] Note that the following equation holds,

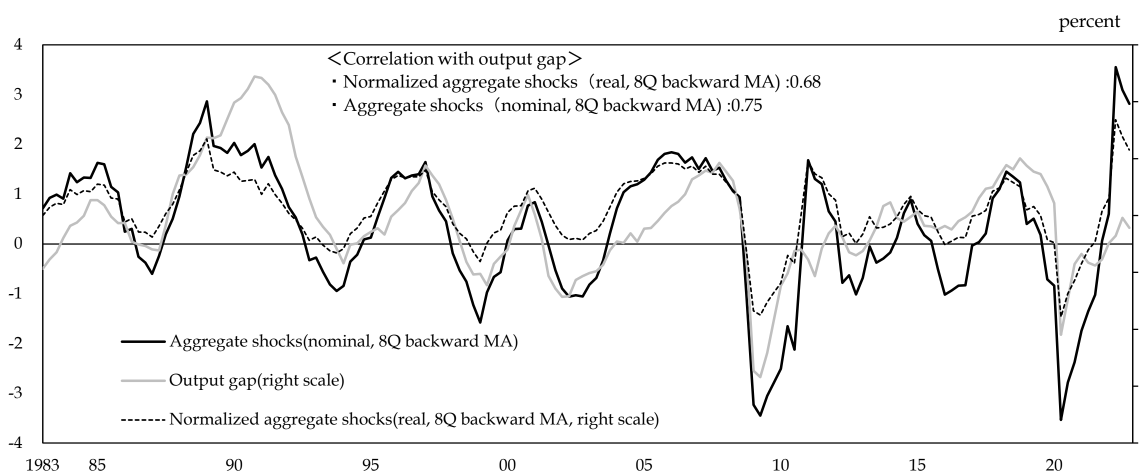
$$\begin{aligned}\mathbb{V}\left(\widehat{\epsilon}_t(i) - \widehat{\epsilon}_{t-1}(i)\right) &= \mathbb{E}\left[\left(\widehat{\epsilon}_t(i) - \widehat{\epsilon}_{t-1}(i)\right)^2\right] = 2\mathbb{V}\left(\epsilon_t(i)\right) \\ \Leftrightarrow \;& \mathbb{V}\left(\epsilon_t(i)\right) = \frac{1}{2}\mathbb{V}\left(\epsilon_t(i)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

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

Table 27: 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		-0.11		4.31		-0.02		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	0.69	-0.47	3.12	9.38	0.33	-0.22	2.93	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

Figure 6: 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, $\frac{1}{8}\sum_{s=0}^{7} u_{t-s}$,[40] with the averages of changes in total sectoral demand

[40]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

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.[41]

Figure 6 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.

M 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 1981:M1-2022:M12 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). Table 28 shows summary statistics of the sectoral inflation.

N IRF of Aggregate Inflation to Aggregate Demand Shocks

N.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 7 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

(i.e. stock data), we ensure that our measure is consistent with conventional measures.

[41] 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/.

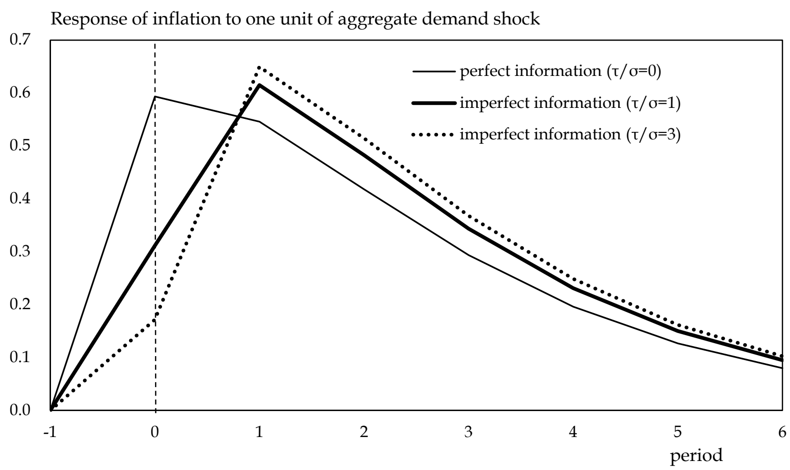
Table 28: Descriptive statistics about PPI data

Dataset: producer price index (seasonally adjusted, QoQ), 23sectors; 1985/2Q-2022/4Q			
Sector	*(1) Historical averages*	*(2) Historical standard deviation*	*(3) First-order auto correlation*
Foods	0.56	1.30	0.67
Textiles & Apparels	0.30	1.86	0.62
Wood Products	0.70	4.22	0.45
Pulp and Paper	0.53	2.81	0.61
Chemicals	0.35	2.35	0.59
Oil and Coal Products	1.17	6.98	0.34
Glass and Ceramics Products	0.57	1.83	0.57
Iron and Steel	0.65	2.59	0.66
Nonferrous Metals	0.45	4.77	0.56
Metal Product	0.55	1.77	0.59
Machinery	0.39	1.60	0.55
Electric Device	0.06	1.26	0.63
Transportation Equipment	0.09	1.03	0.51
Mining and Quarrying of Stone and Gravel	0.75	2.25	0.69
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 23.

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 7: Impulse response functions of aggregate inflation to aggregate shocks



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

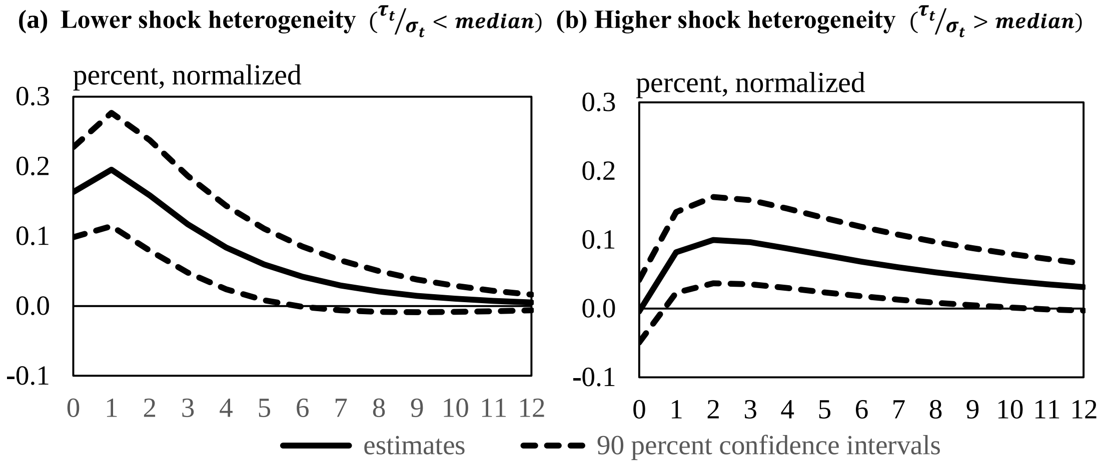
N.2 Empirical Assessment

As shown in Figure 7, 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.

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

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 8: Responses of inflation to aggregate shocks



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 8 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.

O 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 (30) 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 4.3 is negatively related to shock heterogeneity ($\tau_t(i)/\sigma_t$). In what follows, we investigates 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 (30), 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.[42] The empirical specification of sectoral inflation equation is:

$$\begin{aligned}\pi_t(i) =& d_1(i) + \underbrace{\left(d_2 + d_3\mathbf{1}_{\{2000-2022\}} + d_4\left(\tau_t(i)/\sigma_t\right)\right)}_{\alpha_1}\pi_{t-1} + \underbrace{\left(d_5 + d_6\mathbf{1}_{\{2000-2022\}} + d_7\left(\tau_t(i)/\sigma_t\right)\right)}_{\alpha_2}x_t(i) \\ &+ d_8u_{t-1} + d_9u_{t-2} + d_{10}\widetilde{v}_{t-1}(i) + \varepsilon_t^d, \qquad (47)\end{aligned}$$

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 29 shows the estimates for equation (47) 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 30 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 (47). The regression coefficient on the term $x_t(i) \times (\tau_t(i)/\sigma_t)$ (bold entry)

[42] 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 M.

Table 29: 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	0.05	0.07	0.06
×time dummy (2000-2022)	(0.15)	(0.16)	(0.16)
Lag of inflation	-0.003	0.01	0.01
×shock heterogeneity	(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	0.02	0.01	0.02
×time dummy (2000-2022)	(0.02)	(0.02)	(0.02)
Changes in total demand	**-0.01 *****	**-0.01 *****	**-0.01 ****
×shock heterogeneity	(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.*

remains significant and negative, as in the benchmark regression. The estimation results confirm the theoretical prediction.

P Robustness of the Regression Results

The estimation results in the main text and Appendix O 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 aggregate inflation dynamics, Table 31 is the counterpart of Table 6 and 32 corresponds with Table 7. Moreover, in terms of sectoral inflation dynamics, Table 33 is the counterpart of Table 8 and 34 corresponds with Table 9. Finally, Table 35 is the counterpart of Table 29 and 36 corresponds with Table 30. Importantly, the estimation results of these Tables remain broadly unchanged if samples during the Covid-19 pandemic are excluded.

Table 30: 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	(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	(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.*

Table 31: 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)	-0.25 *	-0.25 *	-0.24
($\pi_{t-1} \times 1_{\{2000-2019\}}$)	(0.13)	(0.14)	(0.15)
Lag of inflation	0.01	0.02	0.02
×shock heterogeneity ($u_t \times {}^{\tau_t}/_{\sigma_t}$)	(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	-0.01	-0.01	-0.02
dummy (2000-2019) ($u_t \times 1_{\{2000-2019\}}$)	(0.03)	(0.03)	(0.03)
Changes in aggregate demand	**-0.02** ***	**-0.02** ***	**-0.02** ***
×shock heterogeneity ($u_t \times {}^{\tau_t}/_{\sigma_t}$)	(0.005)	(0.005)	(0.01)
Observations	176	176	176
Adjusted-R^2	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 32: 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	0.01	0.02	0.02
$\times$*shock heterogeneity* ($u_t \times {}^{\tau_t}/_{\sigma_t}$)	(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	**-0.02** ***	**-0.02** ***	**-0.02** ***
$\times$***shock heterogeneity*** ($u_t \times {}^{\tau_t}/_{\sigma_t}$)	(0.01)	(0.01)	(0.01)
Observations	188	188	188
Adjusted-R^2	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 33: 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 ($\hat{v}_t(i)$)	-0.01	-0.02	-0.02
$\times$*time dummy (2000-2019)*	(0.02)	(0.02)	(0.02)
Changes in sector-specific demand	**-0.01** ***	**-0.01** ***	**-0.01** ***
($\hat{v}_t(i)$) $\times$***shock heterogeneity***	(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 34: 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	**-0.01 *****	**-0.01 *****	**-0.01 *****
($\hat{v}_t(i)$) ×shock heterogeneity	(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 35: 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	0.07	0.08	0.08
×time dummy (2000-2022)	(0.11)	(0.11)	(0.11)
Lag of inflation	-0.01	-0.002	-0.01
×shock heterogeneity	(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	0.01	0.002	0.002
×time dummy (2000-2022)	(0.02)	(0.02)	(0.02)
Changes in total demand	**-0.01 ****	**-0.01 *****	**-0.01 ****
×shock heterogeneity	(0.003)	(0.003)	(0.003)
Observations	3,598	3,598	3,598
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.*

Table 36: 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	(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	(0.003)	(0.003)	(0.003)
Observations	3,598	3,598	3,598
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.*